FINAL REPORT

"Morphological Study of Tapi River using Remote Sensing Technique"

(Volume-I)



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CERTIFICATE

Sub: "Morphological Study of Tapi River using Remote Sensing Technique"

This is to certify that present Technical report on "**Morphological Study of Tapi River using Remote Sensing Technique**" contains the morphological study carried out by the team of S. V. National Institute of Technology-Surat (SVNIT-Surat) for Tapi River using Remote Sensing Technique. Present study has been carried out as per the scope outlined in the Memorandum of Understanding (MoU) between SVNIT Surat and Central Water Commission (CWC), signed on March 18, 2015. The present technical report contains detailed scope of work, literature review, study reach, river basin, input data, hydrological data processing and analysis, basin geology, land use changes, reconnaissance, river morphology, stream bank erosion analysis, impaired stream analysis, details of typical river training work proposed at critical locations and flood affected areas along the Tapi River. The study results are based on the topographic sheet collected from the Survey of India and satellite imagery of years 1981, 1990, 2000, and 2010; and hydrological data collected from CWC and State Government agencies. The results of the study are also supported by the field reconnaissance for the critically erosion prone areas along the Tapi River. The sedimentation issues that prevail in the Hatnur Reservoir and in Lower Tapi River, downstream of Ukai Dam are addressed in detail. The typical river training works are also proposed for the restoration of the critical and important river reaches. The present work has been carried out as per the order No: 4/19/2012/SVNIT/Morpho/110-122 dated 17/03/2015.

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EXECUTIVE SUMMARY

The report titled "**Morphological Study of Tapi River using Remote Sensing Technique**" gives the details of the study carried out to quantify the morphological changes in the Tapi River at decadal basis with respect to bank line of year 1971-79 digitized using the Survey of India toposheets. The decadal erosion and deposition areas along the river have been computed. Also, the migration of the bank lines is computed for the entire reach of the river. The report contains total 15 Chapters which provides the details of the literature on morphological study, characteristic of the reach and basin, input data used, hydrological data processing and their analyses, basin geology, land use changes, field reconnaissance, morphology of the river, stream bank erosion analysis, impaired stream analysis, details of the river training work proposed for restoration of the critical and important river reaches and flood affected areas along the river. The key findings of present study as well as the studies which require to be investigated further, are highlighted in following paragraphs: -

(1) UPPER TAPI RIVER

a) The lengths of right bank line (RBL) and left bank line (LBL) of the Upper Tapi River for period under consideration varies between 352 to 355 km and 351 to 354 km respectively. The RBL predominantly shows positive migration towards northern direction (+ve shift: widening), while LBL shows negative shift (migration to right side, narrowing) with respect to the base year under consideration (1971-1979). The shifts of RBL and LBL are opposite in nature, i.e., erosion on the right bank is compensated by corresponding deposition on left bank. The RBL of Reach 1 (Ch. 0 to 50 km) and Reach 6 (CH. 300 to 350 km) shows maximum area loss during base year up to 2010 in the Upper Tapi river. In Reach 1, the river passes through its youthful stage, where the velocity of flow is very high. The Reach 6 falls just upstream of Hatnur dam. Field investigations revealed that migrations of right bank line and left bank line are due to infilling of Hatnur reservoir, and creation of afflux in the upstream of the reservoir (Figs 10.3 and 10.4)

b) The banks of Tapi River have been observed to be erosion resistant, and no major long-term threats along the upper river reaches are noticed. At Chainage 308.0 km (Burhanpur Fort), the significant erosion was observed during the field visit near the fort. To protect the Burhanpur Fort (Ch. 308 km) from erosion, the gabion wall may be constructed. Moreover, repelling groynes or spurs can also be planned in upstream of the structure to minimize the erosion effects as per the guidelines laid in IS 8408:1994 (Photos 9.85-9.87).

c) In Upper Tapi river, the sinuosity values are within the limit of threshold meandering (Sinuosity < 1.5) except in reach 2, which extends between Tipnapur Village (CH: 50 km) and Dokya Village (CH: 100 km) in Madhya Pradesh. The moderately high value of sinuosity in this reach can be attributed to the meandering path being followed by the river through confined bed rock reaches of Upper Tapi Gorge between Tipnapur Village and Teska. Also, the minor increase in sinuosity index values are reported with time in reaches 2 (CH: 50 to 100 km), 5 (CH: 200 to 250 km) and 7 (CH: 300 to 350 km). This is an indication that the river trying to dissipate its excess energy by following curved paths, which may not accelerate the bank erosion rate as the banks are consisting of resistant rocks. The river flows in single channel in most of its course in Upper Tapi River; however, multiple channel formation is found in certain reaches, but of shorter lengths, not sufficient to form significant braids.

d) Total number of the rainy days in the Upper Tapi basin is showing a decreasing trend. Out of 24 rain gauge stations, 12 depicts the increasing trend of total annual rainfall, and the rest are showing decreasing trend. Mean annual maximum flow discharge at stations Dedtalai and Burhanpur stream gauging stations are 4191.3 $m^3 s^{-1}$ and 7598.5 $m^3 s^{-1}$ respectively. The 2.5-year return period flood at Dedtalai and Burhanpur are 4443 $m^3 s^{-1}$ and 8079.1 $m^3 s^{-1}$ respectively. The average runoff coefficient (runoff/ rainfall) at Hatnur dam is 0.21. At Burhanpur station, the decreasing trends in sediment transport rate are observed during the monsoon months. The construction of new minor hydraulic structures in the Upper Tapi Basin may be the possible reason for the decreasing trends in suspended sediment transport rates at the outlet of the Upper Tapi River (Table 6.7).

e) In the Upper Tapi basin, the forest cover has been found to reduce from 59.40% to 49.56% during 1990-2010. In contrast to it, the agricultural land has been found to increase by 13.64% from 15.79% in 1990 to 29.43% year 2010. This increase in agricultural land is at the expense of the forest cover and fallow land in the sub-basin. The increase in built-up area (1.28%) is

not observed to be significant when compared with the rest of the classes. The water bodies are observed to be expanding, and the scrub lands are observed to be declining during 1990-2010 by 0.35% and 0.80% respectively (Table 8.3).

f) The analysis of cross-sections before and after the occurrence of floods in years 1994 and 2006 reveals that the cross-sections of the Upper Tapi River were not altered significantly, except at Dedtalai stream gauging station in 1994, wherein the right bank was observed to get eroded (Fig 10.27).

g) The observed rate of sedimentation in Hatnur Reservoir was 2.374 ha-m/100 sq.km/year, which is five times the rate adopted in planning of the reservoir, i.e., 0.451 ha-m/100 sq.km/year (Annual Research Report, MERI, 2007-2008). Also, the average annual sediment erosion rates from Burhanpur and Yerli sub-catchments were observed to be 5.839 t/ha and 3.98 t/ha respectively (Fig 10.20). Excessive deposited sediments into the Hatnur Reservoir can be planned for dredging in association with State Govt. agencies. The same can be used for construction of flood protection measures along the river or other construction purposes near the structure.

h) The water quality in the said reach fall in the 'C' grade as per CPCB criteria (TOI Report, 2017).

(2) MIDDLE TAPI RIVER

a) The lengths of RBL and LBL of the Middle Tapi River for period under consideration varies between 234 to 256 km and 236 to 257 km respectively from the analyses of satellite imagery and SoI toposheets undertaken for different periods (Table 10.1). The RBL shows positive migration (erosion) in most of the chainages. The maximum positive shifts in LBL and RBL are observed just the downstream of Hatnur Dam at CH: 350 km. The LBL, invariably shows negative shift (deposition) along Middle Tapi river reaches (Table 10.3). The larger width of the channel just downstream of Hatnur Reservoir could be due to erosion of either banks due to release of relatively clear water from the reservoir during the monsoon (Fig 10.10). The Middle Tapi River also shows prominent erosion in its right bank compared to left bank. Similarly, the left bank undergoes deposition in all the reaches. Reaches 8 (CH: 350-CH: 400), 9 (CH: 400-CH: 450) and 12 (CH: 550-CH: 581) undergoes maximum loss of area due to bankline migration due erosion (Table 11.11). Reach 8 falls just downstream of Hatnur Dam. Reach 12 falls just upstream of Ukai Reservoir. The probable cause of high migration of LBL

and RBL in Reach 12 may be due to formation of new banklines due to afflux in the Ukai reservoir. It can be observed that the deposition areas are also nearing highest values in Reaches 8, 9 and 12 (Table 11.12).

b) At Ch. 589 km (Kavithe-Kukurmunda Bridge), Ch. 468 km (Mudawad), Ch. 454 (Gangapuri, Jalod) are found highly active and significant erosion were observed. At Gangapuri, Jalod, Maharashtra (CH: 454.0 km), repelling gryone may be constructed to arrest the erosion of the left bank (Photo 12.11). At, Mudawad, Maharashtra (CH: 478.0 km) (Photo 12.11), the bank stabilization structure such as guide bund may be constructed at the confluence to reduce/arrest the erosion. At Sarangkheda Bridge, Maharashtra (CH: 537.9 km) (Photos 12.8-12.9), to safe guard the bridge abutment, the guide bund is required to be provided on left bank between barrage and bridge as per the IS: 10751:1994. At Kavithe-Kukarmunda Bridge, Gujarat (CH: 589.0 km) (Photo 12.6), to protect the left bank and safe guard the bridge abutment, the guide bunds are to be provided.

c) The values of sinuosity of Middle Tapi river show that the river follows sinuous course throughout its translational path. Although occasional bends are present in the Middle Tapi River, no prominent meander reaches are found in the said reach, and the values of sinuosity varies from 1.10 to 1.30 (Table 11.3). The PFI values for reaches 8-12 (CH: 350 to 581 km) of Middle Tapi River is not showing significant braiding (Table 11.7). While examining the course of Middle Tapi River from Hatnur Dam to Ukai Reservoir, no major braiding pattern is seen anywhere. However, in Reach 8, between Vagdud (CH: 368.65 km) and Bhusawal (CH: 376.39 km), there is a stretch of Tapi river where the river flows in multiple channels. This can be attributed to the considerable change in stream slope between these two locations, i.e., a stream slope of approximately 1 in 317.

d) In the Middle Tapi basin, out of total 28 rainguage stations, 14 raingauge stations reflect increasing trend in the number of rainy days. Total annual rainfall is decreasing at 14 raingauge stations in the basin. Mean annual maximum flow discharge at Savkheda, Gidhade and Sarangkheda stations were observed to be 8720.9 $m^3 s^{-1}$, 8733.1 $m^3 s^{-1}$ and 8886.4 $m^3 s^{-1}$ respectively. The 2.5-year return period floods at Savkheda, Gidhade and Sarangkheda are 9159.4 $m^3 s^{-1}$, 9159.4 $m^3 s^{-1}$ and 9352 $m^3 s^{-1}$ respectively during the study period. The average runoff coefficient at Ukai dam (at the outlet of Middle Tapi River) is 0.18. It can be observed that, in the recent decade, i.e., 2000-2010, there has been an increase in the sediment transport

rate in all months except in September month (Table 6.17). The Tapi River flows through alluvial plains as it enters its Middle reaches. The increase in sediment transport rates may be attributed to the enhanced agricultural activities in the basin. The increase in sediment transport rates in Middle Tapi river in recent years, may accelerate the sediment deposition in Ukai reservoir (reservoir at the tail end of Middle Tapi river). The watershed areas of Middle Tapi river are required to be managed to reduce the excessive silt entry into the river.

e) It can be observed that agricultural land and fallow land together occupy more than 60% of the total area of the sub-basin. This can be attributed to the abundancy of alluvial soil in the sub-basin, which makes it perfect for cultivation and human occupancy. The second predominant land-use class is the forest cover, which can be seen on the northern as well as north-western part of the sub-basin. The land-use classes like built-up area, water and scrub land occupy comparatively less percentage area in the sub-basin. As reported in case of Upper Tapi river, there is continuous increase in agricultural area reported in the Middle Tapi river. On the other hand, there is a decrease in forest, fallow and scrub lands in the sub-basin (Fig 8.4a-8.4f)

f) Series of barrages/minor storage structures are coming up along the reaches of Middle Tapi River which may store the entire flow during the lean period. Under such circumstances, the riparian rights of water sharing States is required to be clearly identified to avoid further complication regarding water availability in future.

g) Compared to Upper Tapi River, the villages/ urban areas and State Highways in Middle Tapi River reaches are relatively more vulnerable to erosion vis-à-vis river reaches in Upper Tapi river. The locations of Middle Tapi River fall under the category of highly vulnerable to not vulnerable, as per the classification proposed in present study.

h) The water quality in the said reach fall in the ‘C’ grade as per CPCB criteria (TOI Report, 2017).

(3) LOWER TAPI RIVER

a) The length of RBL and LBL of the Lower Tapi River for period under consideration varies between 131 km to 136 km and 122 km to 226 km respectively, as observed while analyzing SoI toposheets and Satellite imagery for different periods. There is no significant migration observed in both banks except at last chainage, i.e., CH: 792 km (located near Hazira, Gujarat where Tapi River joins Arabian Sea). The larger shifting/migration of RBL and LBL at this

location have occurred due to combined effects of tidal currents in the Arabian Sea and main flow from Tapi river.

b) At CH: 787 km (Tapi Estuary Suvali gam), CH: 750 km (Utran-Kapodara Bridge), CH. 735 km (near old magistrate office) the river is found to be found active and significant erosions are observed. At Tapi Estuary System, Suvali Gam, Hazira (CH: 787.0 km), to protect the banks, the provision of gabions is recommended. The series of permeable spurs in the right bank are required to be constructed just upstream of existing spurs to protect the adjacent road (NH-8) (Section 12.2.1 of report). At Kamrej and Kholvad Villages, Surat (CH: 736 km and 739 km), the groynes or spurs at suitable locations are required to be constructed to arrest further erosion at inner bend (Section 12.2.2 of report). The physical model study is recommended before implementation and planning the layouts of aforesaid corrective measures.

c) The Lower Tapi River, generally, falls in the category of sinuous river as sinuosity is in the range of 1.10 to 1.50. In the reach (CH: 697-747 km), the value of sinuosity has been found to reach threshold value of meandering river. While observing the computed values of plan form index (PFI), it is seen that the last reach (CH: 747-792km) of the river, falls under the category of braided river (Tables 11.4 and 11.8).

d) Most of the rain gauge stations in the Lower Tapi River show increasing trend in total annual rainfall. Out of 11 rain gauge stations, total 9 stations, depict increasing trend in number of rainy days. Lower Tapi Basin falls within the zone of severe rainstorms, and heavy rainfall spells have been observed in the recent past. As per historical records, Tapi river has experienced large floods in the years 1727, 1776, 1782,1829, 1837, 1872, 1944, 1959, 1968, 1970, 1994, 1998 and 2006. The lower reaches of the Tapi River, especially the Surat City has faced maximum destruction due to the havoc caused by severe floods. The Surat city on the bank of the lower Tapi River was highly affected by recent floods, in the years 1994, 1998 and 2006. The Surat flood of year 2006, alone had caused direct damages to the time of Rs. 21,000 crores. The carrying capacity of the Tapi River in the Surat city has been found to get reduced drastically which is the prime reason for flooding in the Lower Tapi River. Provisioning of 'Early warning system' for flood forecasting in the Surat city is essentially required while accounting the inflow prediction model for Ukai reservoir, reservoir simulation and hydrodynamic modelling downstream of the Ukai reservoir.

e) The agricultural land in Lower Tapi River has been increased by 8.74% during 1990-2010. The forest areas are observed to be declining while agricultural and built-up land are increasing in the duration. There has been a decrease of 6.09% in forest area in the sub-basin during 1990-2010. There has been a transition of fallow land into cultivable land in the basin. The waterbodies are observed to be expanding while the scrub lands are observed to be declining (Table 8.5).

f) Excessive siltation upstream and downstream of Singanpore weir and extensive development in coastal floodplain could be the possible causes, for reduction in the carrying capacity of the river in the city (Section 10.9.4). The planning for desilting of sediments in the upstream and downstream of Singanpore weir can be undertaken by the State Govt. agencies, and desilted sediments can be used for construction of river training works in the lower Tapi river and coastal protection works, possibly using the geo-bags and geo-tubes. The systematic study on possible morphological changes due to desilting of the river bed is required to be undertaken before planning such major desilting exercises.

g) While analyzing the variation in the cross-sectional geometry of Ghala stream gauging station that falls in Lower Tapi River, it was observed that the river bed adjacent to the right bank has undergone local scouring, during 1989-2004, over a length of 130 m. Such erosion in the stream gauging site could be due to ongoing sand mining activity in the vicinity of the site. The possible changes in the water rating curves are required to be assessed time to time to account aforesaid morphological changes.

h) The vulnerability of Lower Tapi River ranges from highly vulnerable to not vulnerable. The villages like Ushked Khurd, Puna, Un, Kosadi, Umarsadi and Kamlapor, which falls in Surat District of Gujarat, fall under highly vulnerable category due to their proximity with the eroded bank lines.

i) As per the analysis reported, using cluster analysis methodology, the water quality in the river in the Surat city (stations Varachha, Rander, Weir Cum Causeway) is relatively impaired compared to other upstream stations. Although, the Tapi River water was categorized as ‘C’ grade, the water quality of the river has been reported to ‘D’ and ‘E’ grades within the city limits (TOI Report, 2017). Also, on the upstream of the Singapore weir lake, thick layer of water hyacinth was noticed which might substantially deplete the dissolved oxygen (DO), and may cause odour in the water.

The following further investigations/actions need to be undertaken in due course: -

a) The morphological study reported for Lower Tapi river indicated that, carrying capacity of the river in Surat city has drastically been reduced due to extensive development in the coastal urban floodplain and siltation in the bed of Tapi river. The following actions are suggested with reference to morphology/flooding of Lower Tapi river: -
    i) The Surat city is highly susceptible to flooding as and when severe storms come in the catchment of Ukai reservoir, particularly in the end of the monsoon, when the reservoir is at FRL (full reservoir level). Under such condition, entire inflow into the reservoir must be passed in the downstream of the reservoir, and massive loss to the life and property is expected in the Surat city. Keeping in view, the susceptibility of Surat city to flooding, it is the need of the hour to develop 'Early warning System' for the Surat city while accounting real time information of inflow into the Ukai reservoir, reservoir simulation, controlled releases from the reservoir in the downstream channel and providing advance information to the people in the city to prepare themselves against the flooding.
    ii) Two-dimensional hydrodynamic model for inundation of Urban Surat centre is required to be developed while considering releases from Ukai reservoir and sea tidal levels as upstream and downstream boundary conditions respectively. Such model may be useful in identifying various risk zones in the city, which, in turn, may be useful in controlling the development in the urban flood plain.
    iii) The possibility of using the desilted sediments, particularly in the river bed in Surat city, for the construction of flood protection measures along the river/coastal protection works, and other construction purposes, be explored by the Surat Municipal Corporation in consultation with Narmada, water resources, water supply and Kalpsar department and Road and building departments. The sediments silted in the downstream of Singanpore weir may not be suitable for construction purposes due to the presence of excessive salt content.
b) The quality of water in the Tapi river, particularly in the Surat city, need to be addressed at the earliest while identifying the possible causes for the degraded water quality in the urban areas, and implement possible measures to restore the healthy condition of the river.

c) The critical erosion prone areas identified along the Tapi river, are required to be noted by the concerned State Govt. agencies. The identified critical areas need to be studied individually, and possible curative measures are to be adopted to avoid aggravating the situations further. The contents presented in Chapter 9- Chapter 12 need to be referred.

d) The alarming siltation rate has been reported in the Hatnur reservoir. The previous studies have indicated that Burhanpur catchment is more fragile to erosion vis-à-vis Purna sub-catchment. The specific study for identifying critical erosion prone areas of Burhanpur and Purna sub-catchments need to be undertaken for providing possible soil conservation measures, and reducing the silting into the Hatnur reservoir. The Hatnur reservoir, being a minor storage structure, the possibility of desilting of the deposited sediments and its usage be explored by the State Govt. agencies.

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ACKNOWLEDGEMENT

We thankfully acknowledge the support provided by the SVNIT authority for permitting the team to take up the project and help toward carrying out the relevant procurements and computation of present work. We are thankful to the Directorate of Morphology and Climate Change, Central Water Commission (CWC), Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD&GR), Government of India for showing their faith by awarding the work to SVNIT-Surat.

We are also thankful to Survey of India (SoI), Dehradun, Gandhinagar, Jabalpur and Pune; National Remote Sensing Center (NRSC), Hyderabad; National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur; Geological Survey of India (GSI), Nagpur; Water Resources Information System-India (WRIS); India Meteorological Department (IMD), Pune; Central Pollution Control Board (CPCB) and Gujarat Pollution Control Board (GPCB) for providing the required data for the present study.

We express special thanks to Surat Irrigation Circle (SIC), Ukai Civil Circle, Government of Gujarat; Sub-division offices of CWC at Dhule, Nashik, Bhusaval Sub-divisions and Surat; Tapi Irrigation Development Corporation (TIDC) Jalgaon, Government of Maharashtra; Public Works Division, Nashik, Government of Maharashtra; Public Works Department, Bhopal, Government of Madhya Pradesh; Surat Municipal Corporation; National Water Academy (NWA), Pune and ESSAR STEEL LIMITED, Surat, for providing the necessary data and fruitful inputs during the visits to their offices and support in organizing workshop successfully.

We express deep sense of gratitude to all members of Consultancy Evaluation-Cum-Monitoring Committee for giving their valuable suggestions during the discussions of inception and interim reports of foregoing project.

We are thankful to the local people with whom the team interacted during the site visit for providing the information related to Tapi river.

The assistance rendered by Ms. Resmi S. R., Research scholar in the project; Mr. Akshay Rajak and Ms. Kavya Rajendran, Post Graduate students in the project; in preparing technical report is duly acknowledged. Also, the help provided by research scholars, Shri Viraj D. Loliyana, Shri Priyank J. Sharma and Shri Nishant Sourabh; and Ms. Meenal Dave, Technician working in Centre of Excellence (CoE) on "Water Resources and Flood Management", SVNIT-Surat in drafting the report, is highly appreciated.

At last, the team is thankful to all those who helped us directly or indirectly in the completion of this project.

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CONTENTS

		Certificate	**ii**
		Executive Summary	**iii-xi**
		Acknowledgment	**xii-xiii**
		Contents	**xiv-xx**
		List of Figures	**xxi-xxvi**
		List of Tables	**xxvii-xxix**
		List of Photos	**xxx-xxxiv**

VOLUME-I

S. No.		**Description**	**Page No.**
1		**INTRODUCTION**	**1-5**
	1.1	GENERAL	1
	1.2	NEED FOR MORPHOLOGICAL STUDIES	2
	1.3	OBJECTIVES OF THE PRESENT STUDY	3
	1.4	DETAILED SCOPE OF THE STUDY (TERMS OF REFERENCE)	4
2		**LITERATURE REVIEW**	**6-19**
	2.1	SHIFTING AND EROSION OF BANKLINES	6
	2.2	PLANFORM CHANGES IN RIVERS	8
	2.3	HYDRAULIC GEOMETRY OF RIVERS	11
	2.4	RIVER MORPHOLOGY IN CONTEXT WITH BASIN TOPOGRAPHY AND LAND USE CHANGES	13
	2.5	FLOOD FREQUENCY ANALYSIS AND TREND ANALYSIS OF HYDROLOGIC AND CLIMATIC DATA	16
3		**STUDY REACH**	**20-24**
	3.1	TAPI RIVER	20
	3.2	MAJOR TRIBUTARIES OF TAPI RIVER	20
	3.3	WATER RESOURCES PROJECTS ALONG THE TAPI RIVER	22
4		**RIVER BASIN**	**25-34**
	4.1	TAPI RIVER BASIN	25
	4.2	FLOOD PROTECTION MEASURES	26
	4.3	DAMS, BARRAGES/WEIRS AND WATER RESOURCES PROJECTS	26
	4.4	IMPORTANT CITIES/TOWNS, CWC HO STATIONS AND AIRPORTS	30
	4.5	TOPOGRAPHY OF TAPI BASIN	31
	4.6	SOIL AND GEOLOGY OF TAPI BASIN	32
5		**INPUT DATA**	**35-42**
	5.1	PHYSIOGRAPHIC DATA PROCESSING AND ANALYSIS	35
	5.2	SATELLITE DATA	36

	5.3	HYDROLOGIC AND HYDRAULIC DATA	38
	5.4	CROSS-SECTION DATA	38
	5.5	METEOROLOGICAL DATA	40
	5.6	WATER QUALITY DATA	40
	5.7	SOIL AND GEOLOGY DATA	41
	5.8	SEDIMENT DATA	41
6		**HYDROLOGICAL DATA PROCESSING AND ANALYSIS**	**43-76**
	6.1	GENERAL	43
	6.2	CLIMATIC CONDITIONS THAT PREVAIL IN TAPI BASIN	43
	6.3	TREND ANALYSIS	44
		6.3.1 Mann-Kendall Test	44
		6.3.2 Sen's Slope Estimation Test	45
		6.3.3 Innovative Trend Analysis	45
		6.3.4 Rainfall Indices	46
		6.3.5 Results of Trend Analysis in Upper Tapi Basin	46
		6.3.6 Results of Trend Analysis in Middle Tapi Basin	52
		6.3.7 Results of Trend Analysis in Lower Tapi Basin	52
	6.4	AT-SITE FLOOD FREQUENCY ANALYSIS AND RESULTS	59
		6.4.1 Test for Independency (Lag-one Autocorrelation Test)	60
		6.4.2 Test for Homogeneity (Cumulative Deviations Test)	62
		6.4.3 Estimation of Flood Discharges using Gumbel's Distribution	63
	6.5	DEVELOPMENT OF HYDRAULIC GEOMETRY EQUATIONS	67
		6.5.1 Hydraulic Geometry Equations	67
		6.5.2 Stream Power and Sediment Transport Competence	68
		6.5.3 Hydraulic Geometry Equations at Dedtalai, Burhanpur, Gidhade and Sarangkheda Stream-gauging Stations	68
	6.6	RAINFALL RUNOFF ANALYSIS	71
	6.7	ANALYSIS OF SUSPENDED SEDIMENT	73
7		**BASIN GEOLOGY**	**77-90**
	7.1	GENERAL	77
	7.2	GEOLOGY IN TAPI BASIN	77
		7.2.1 Upper Tapi River	77
		7.2.1.1 Betul district (Madhya Pradesh)	77
		7.2.1.2 Amravati district (Maharashtra)	81
		7.2.1.3 Burhanpur district (Madhya Pradesh)	82
		7.2.2 Middle Tapi basin	83
		7.2.2.1 Jalgaon district	83
		7.2.2.2 Dhule district	85
		7.2.2.3 Nandurbar district	86
		7.2.3 Lower Tapi basin	87
		7.2.3.1 Tapi district	87
		7.2.3.2 Surat district	88

8		**LAND-USE CHANGES**	**91-108**
	8.1	GENERAL	91
	8.2	DATA AVAILABILITY AND ANALYSIS	91
	8.3	METHODOLOGY	92
	8.4	LAND-USE CHANGES, RESULTS AND DISCUSSIONS	93
		8.4.1 Burhanpur Sub-basin	93
		8.4.2 Middle Tapi River Sub-basin excluding Girna Sub-basin	97
		8.4.3 Lower Tapi Basin	102
	8.5	IMPACT OF LAND-USE CHANGES ON RIVER MORPHOLOGY	106
9		**RECONNAISSANCE**	**109-184**
	9.1	GENERAL	109
	9.2	VISIT TO LOWER TAPI RIVER REACHES	109
		9.2.1 Tapi Estuary System, Suvali Gam, Hazira	109
		9.2.2 Bhatpor Village, Surat	112
		9.2.3 Nehru Bridge Site, Surat	113
		9.2.4 Variav and Amroli Villages, Surat	115
		9.2.5 Utran-Kapodra Bridge Site	117
		9.2.6 Savjibhai-Korat Bridge Site	119
		9.2.7 Bodhan Village, Mandvi	120
		9.2.8 Umarsadi Haripura Bridge Site, Mandvi	122
		9.2.9 Mandvi Bridge Site	124
	9.3	VISIT TO MIDDLE TAPI RIVER REACHES	126
		9.3.1 Kavithe-Kukarmunda Bridge Site	126
		9.3.2 Prakasha Barrage, Nandurbar, Maharashtra	130
		9.3.3 Sasde Village, Maharashtra	133
		9.3.4 Biladi-Bamkheda Village, Maharashtra	134
		9.3.5 Sarangkheda Stream Gauging Site/ Sarangkheda Barrage, Maharashtra	137
		9.3.6 Gidhade Stream Gauging Site, Maharashtra	142
		9.3.7 Babulde Village, Maharashtra	145
		9.3.8 Mudawad Village, Maharashtra	147
		9.3.9 Padalsare Dam, Maharashtra	150
		9.3.10 Gangapuri, Jalod, Maharashtra	154
		9.3.11 Awar, Maharashtra	157
		9.3.12 Rameshwaram Temple, Palsod Village, Maharashtra	159
		9.3.13 Road Bridge (MH SH 186) near Nhavi P Adawad, Maharashtra	162
		9.3.14 Bhusaval CWC Gauging Site, Maharashtra	164
	9.4	VISIT TO UPPER TAPI RIVER REACHES	166
		9.4.1 Hathnur Dam	166
		9.4.2 Changdev Village, Maharashtra	168
		9.4.3 Rajghat and Najirighat, Burhanpur, Madhya Pradesh	169
		9.4.4 Mohana Nadi Sangam, Burhanpur, Madhya Pradesh	173

		9.4.5 Dabalikhurd Villlage, Nepanagar	175
		9.4.6 Melchuka Village, Madhya Pradesh	177
		9.4.7 Dedtalai CWC Stream Gauging Site	179
		9.4.8 Rama Kheda Village	180
		9.4.9 Chandora Dam	182
		9.4.10 Tapti Kund, Multai	183
10		**RIVER MORPHOLOGY**	**185-232**
	10.1	NATURAL RIVER CHANNEL MECHANICS	185
	10.2	CHARACTERISTICS OF THE TAPI RIVER AND ITS BANKS	187
	10.3	QUANTIFICATION OF RIVER BANK MIGRATION	188
		10.3.1 Quantification of Bank Migration in Upper Tapi River	189
		10.3.2 Quantification of Bank Migration in Middle Tapi River	193
		10.3.3 Quantification of Bank Migration in Lower Tapi River	195
	10.4	QUANTIFICATION OF CHANGE IN RIVER WIDTH	197
	10.5	EFFECT OF PEAK FLOWS ON RIVER MORPHOLOGY	200
	10.6	EFFECT OF CHANGES IN ANNUAL RAINFALL IN THE BASIN ON RIVER MORPHOLOGY	202
		10.6.1 Floods in Lower Tapi River	202
		10.6.2 Failure of Chandora Dam in Upper Tapi River	203
	10.7	IDENTIFICATION OF MAJOR MORPHOLOGICAL PROBLEMS IN TAPI RIVER	203
		10.7.1 Lower Tapi River (Ukai Dam-CH: 647 km to Arabian Sea-CH: 792 km)	204
		10.7.1.1 Tapi Estuary System, Suvali Gam, Hazira (CH: 787 km)	204
		10.7.1.2 Utran-Kapodara Bridge (CH: 750 km)	205
		10.7.2 Middle Tapi River (Hathnur Dam-CH: 350 km to Ukai Reservoir-CH: 581 km)	205
		10.7.2.1 Kavithe-Kukarmunda Bridge, Gujarat (CH: 589 km)	205
		10.7.2.2 Mudawad, Maharashtra (CH: 478 km)	206
		10.7.2.3 Gangapuri, Jalod, Maharashtra (CH: 454 km)	207
		10.7.3 Upper Tapi River (Tapi Kund-CH: 0 to Hathnur Reservoir-CH: 350 km)	207
		10.7.3.1 Hathnur Dam Site, Madhya Pradesh (CH: 350 km)	208
		10.7.3.2 Burhanpur Fort, Sanjaynagar, Madhya Pradesh (CH: 308 km)	208
	10.8	IMPACTS OF MAJOR HYDRAULIC STRUCTURES ON RIVER MORPHOLOGY	209
		10.8.1 Ukai Dam (CH: 647 km)	209
		10.8.2 Hatnur Dam (CH: 350 km)	210
	10.9	CHANNEL EVOLUTION ANALYSIS	212
		10.9.1 Upper Tapi River	213
		10.9.2 Middle Tapi River	218
		10.9.3 Lower Tapi River	221

		10.9.4 Variation of Bed Level in Lower Tapi River from Ghala stream gauging station to Arabian Sea	224
	10.10	WATER QUALITY AND IMPAIRED STREAM ANALYSIS	226
		10.10.1 Water Quality	226
		10.10.2 Trend in Water Quality Parameter	226
		10.10.3 Impaired Stream Analysis	228
		10.10.4 Data Used	228
		10.10.5 Methodology	229
		10.10.6 Results and Discussions	229
11		**STREAM BANK EROSION ANALYSIS**	**233-257**
	11.1	GENERAL	233
	11.2	METHODOLOGY	233
	11.3	DELINEATION OF RIVER BANK LINE	235
	11.4	PLAN FORM OF THE RIVER	235
		11.4.1 Sinuosity Index	236
		11.4.2 Meandering parameters	240
		11.4.3 Plan Form Index (PFI)	241
	11.5	RIVER BANK EROSION/ MIGRATION	246
	11.6	ASSESSMENT OF VULNERABILITY IN TAPI BASIN IN CONTEXT TO RIVER BANK EROSION	250
	11.7	PRIORITISATION OF LAND AREA LOST	253
12		**DETAIL OF TYPICAL RIVER TRAINING WORKS PROPOSED FOR RESTORATION OF CRITICAL AND IMPORTANT REACHES**	**258-283**
	12.1	GENERAL	258
	12.2	RESTORATION WORKS FOR IMPORTANT REACHES	258
		12.2.1 Tapi Estuary System, Suvali Gam, Hazira (CH: 787.0 km)	258
		12.2.2 Kamrej and Kholvad Villages, Surat (CH: 736 km and 739 km)	262
		12.2.3 Kavithe-Kukarmunda Bridge, Gujarat (CH: 589 km)	264
		12.2.4 Sarangkheda Bridge, Maharashtra (CH: 537.9 km)	267
		12.2.5 Mudawad, Maharashtra (CH: 478 km)	270
		12.2.6 Gangapuri, Jalod, Maharashtra (CH: 454 km)	271
		12.2.7 Burhanpur Fort, Sanjaynagar, Madhya Pradesh (CH: 308 km)	273
	12.3	DETAILS OF LOCATIONS WITH EXCESSIVE SEDIMENT DEPOSITION	276
	12.4	DETAILS OF EXISTING BRIDGES IN TAPI RIVER	278
13		**FLOOD AFFECTED AREA**	**284-295**
	13.1	INTRODUCTION	284
	13.2	DATA ANALYSIS AND INTERPRETATION	288
		13.2.1 The flood of year 2006	288
		13.2.2 Tidal levels during flood of year 2006	288

	13.3	RESULTS AND DISCUSSIONS	289
		13.3.1 Hydraulic Properties of the flood in the River and Floodplain	289
		13.3.2 Prediction of Rating Curves in the Lower Tapi River	292
		13.3.3 Rating Curves using 1D-2D Coupled Approach	292
	13.4	CONCLUDING REMARKS	294
14		**RESULTS AND DISCUSSIONS**	**296-304**
	14.1	INTRODUCTION	296
	14.2	UPPER TAPI RIVER	296
	14.3	MIDDLE TAPI RIVER	298
	14.4	LOWER TAPI RIVER	301
	14.5	FURTHER STUDY / INVESTIGATIONS RECOMMENDED	303
15		**WORKSHOP REPORT**	**305-324**
		Annexure-I	309
		Annexure-II	310-312
		Annexure-III	313
		Annexure-IV	314-316
		Annexure-V	319-321
		Annexure-VI	322-323
		Annexure-VII	324
		REFERENCES	**325-331**

VOLUME-II (APPENDIX)*

	CH: 0 km – CH: 50 km, Reach 1; Year 1981	Morpho/11/01/2017
	CH: 50 km – CH: 100 km, Reach 2; Year 1981	Morpho/11/02/2017
	CH: 100 km – CH: 150 km, Reach 3; Year 1981	Morpho/11/03/2017
APPENDIX A1	CH: 150 km – CH: 200 km, Reach 4; Year 1981	Morpho/11/04/2017
	CH: 200 km – CH: 250 km, Reach 5; Year 1981	Morpho/11/05/2017
	CH: 250 km – CH: 300 km, Reach 6; Year 1981	Morpho/11/06/2017
	CH: 300 km – CH: 350 km, Reach 7; Year 1981	Morpho/11/07/2017
	CH: 0 km – CH: 50 km, Reach 1; Year 1990	Morpho/11/08/2017
	CH: 50 km – CH: 100 km, Reach 2; Year 1990	Morpho/11/09/2017
	CH: 100 km – CH: 150 km, Reach 3; Year 1990	Morpho/11/10/2017
APPENDIX A2	CH: 150 km – CH: 200 km, Reach 4; Year 1990	Morpho/11/11/2017
	CH: 200 km – CH: 250 km, Reach 5; Year 1990	Morpho/11/12/2017
	CH: 250 km – CH: 300 km, Reach 6; Year 1990	Morpho/11/13/2017
	CH: 300 km – CH: 350 km, Reach 7; Year 1990	Morpho/11/14/2017
	CH: 0 km – CH: 50 km, Reach 1; Year 2000	Morpho/11/15/2017
	CH: 50 km – CH: 100 km, Reach 2; Year 2000	Morpho/11/16/2017
APPENDIX A3	CH: 100 km – CH: 150 km, Reach 3; Year 2000	Morpho/11/17/2017
	CH: 150 km – CH: 200 km, Reach 4; Year 2000	Morpho/11/18/2017
	CH: 200 km – CH: 250 km, Reach 5; Year 2000	Morpho/11/19/2017
	CH: 250 km – CH: 300 km, Reach 6; Year 2000	Morpho/11/20/2017

	CH: 300 km – CH: 350 km, Reach 7; Year 2000	Morpho/11/21/2017
	CH: 0 km – CH: 50 km, Reach 1; Year 2010	Morpho/11/22/2017
	CH: 50 km – CH: 100 km, Reach 2; Year 2010	Morpho/11/23/2017
	CH: 100 km – CH: 150 km, Reach 3; Year 2010	Morpho/11/24/2017
APPENDIX A4	CH: 150 km – CH: 200 km, Reach 4; Year 2010	Morpho/11/25/2017
	CH: 200 km – CH: 250 km, Reach 5; Year 2010	Morpho/11/26/2017
	CH: 250 km – CH: 300 km, Reach 6; Year 2010	Morpho/11/27/2017
	CH: 300 km – CH: 350 km, Reach 7; Year 2010	Morpho/11/28/2017
	CH: 350 km – CH: 400 km, Reach 8; Year 1981	Morpho/11/29/2017
	CH: 400 km – CH: 450 km, Reach 9; Year 1981	Morpho/11/30/2017
APPENDIX B1	CH: 450 km – CH: 500 km, Reach 10; Year 1981	Morpho/11/31/2017
	CH: 500 km – CH: 550 km, Reach 11; Year 1981	Morpho/11/32/2017
	CH: 550 km – CH: 581 km, Reach 12; Year 1981	Morpho/11/33/2017
	CH: 350 km – CH: 400 km, Reach 8; Year 1990	Morpho/11/34/2017
	CH: 400 km – CH: 450 km, Reach 9; Year 1990	Morpho/11/35/2017
APPENDIX B2	CH: 450 km – CH: 500 km, Reach 10; Year 1990	Morpho/11/36/2017
	CH: 500 km – CH: 550 km, Reach 11; Year 1990	Morpho/11/37/2017
	CH: 550 km – CH: 581 km, Reach 12; Year 1990	Morpho/11/38/2017
	CH: 350 km – CH: 400 km, Reach 8; Year 2000	Morpho/11/39/2017
	CH: 400 km – CH: 450 km, Reach 9; Year 2000	Morpho/11/40/2017
APPENDIX B3	CH: 450 km – CH: 500 km, Reach 10; Year 2000	Morpho/11/41/2017
	CH: 500 km – CH: 550 km, Reach 11; Year 2000	Morpho/11/42/2017
	CH: 550 km – CH: 581 km, Reach 12; Year 2000	Morpho/11/43/2017
	CH: 350 km – CH: 400 km, Reach 8; Year 2010	Morpho/11/44/2017
	CH: 400 km – CH: 450 km, Reach 9; Year 2010	Morpho/11/45/2017
APPENDIX B4	CH: 450 km – CH: 500 km, Reach 10; Year 2010	Morpho/11/46/2017
	CH: 500 km – CH: 550 km, Reach 11; Year 2010	Morpho/11/47/2017
	CH: 550 km – CH: 581 km, Reach 12; Year 2010	Morpho/11/48/2017
	CH: 647 km – CH: 697 km, Reach 13; Year 1981	Morpho/11/49/2017
APPENDIX C1	CH: 697 km – CH: 747 km, Reach 14; Year 1981	Morpho/11/50/2017
	CH: 747 km – CH: 792 km, Reach 15; Year 1981	Morpho/11/51/2017
	CH: 647 km – CH: 697 km, Reach 13; Year 1990	Morpho/11/52/2017
APPENDIX C2	CH: 697 km – CH: 747 km, Reach 14; Year 1990	Morpho/11/53/2017
	CH: 747 km – CH: 792 km, Reach 15; Year 1990	Morpho/11/54/2017
	CH: 647 km – CH: 697 km, Reach 13; Year 2000	Morpho/11/55/2017
APPENDIX C3	CH: 697 km – CH: 747 km, Reach 14; Year 2000	Morpho/11/56/2017
	CH: 747 km – CH: 792 km, Reach 15; Year 2000	Morpho/11/57/2017
	CH: 647 km – CH: 697 km, Reach 13; Year 2010	Morpho/11/58/2017
APPENDIX C4	CH: 697 km – CH: 747 km, Reach 14; Year 2010	Morpho/11/59/2017
	CH: 747 km – CH: 792 km, Reach 15; Year 2010	Morpho/11/60/2017

*The graphical plots on A0 size (scale: 1:50,000) are also submitted separately with current report for Appendices A1-A4, B1-B4 and C1-C4.

LIST OF FIGURES

Fig No.	Title	Page No.
2.1	Calculation of braiding indices	10
3.1	Tapi river, tributaries and major dams	21
4.1	Index map of Tapi river basin	25
4.2	River drainage map	27
4.3	Levee constructed in Lower Tapi river reach	28
4.4	Dams, weirs/barrages and water resources projects in the 10 km × 10 km buffer zone of Tapi basin	29
4.5	Cities/towns, CWC Hydrological Observation (HO) stations and airports in the buffer zone of Tapi basin	31
4.6	Elevation zones in Tapi basin	33
5.1	CWC cross-sections along Tapi river	39
6.1	Illustration of decreasing, increasing and trendless regions (Şen 2012)	46
6.2	Innovative trend analysis results of total annual rainfall for Akola rain gauge station	49
6.3	Innovative trend analysis results of total annual rainfall for Bhainsdehi rain gauge station	49
6.4	Innovative trend analysis results of total annual rainfall for Dharni rain gauge station	50
6.5	Innovative trend analysis results of number of rainy days for Dharni rain gauge station	50
6.6	Innovative trend analysis results of number of rainy days for Atner rain gauge station	51
6.7	Innovative trend analysis results of number of rainy days for Chikhalda rain gauge station	51
6.8	Innovative trend analysis results of total annual rainfall for Jalgaon rain gauge station	54
6.9	Innovative trend analysis results of total annual rainfall for Nandurbar rain gauge station	54
6.10	Innovative trend analysis results of no. of rainy days for Kalvan rain gauge station	55
6.11	Innovative trend analysis results of total annual rainfall at Kathor rain gauge station	57
6.12	Innovative trend analysis results of total annual rainfall at Kamrej rain gauge station	57
6.13	Innovative trend analysis results of number of rainy days at Olpad rain gauge station	58
6.14	Innovative trend analysis results of number of rainy days at Puna rain gauge station	58

Fig No.	Title	Page No.
6.15	Autocorrelation function (correlogram) with 5% significance tolerance band for the observed discharge time series	61-62
6.16	Exceedance probability curves at various stations	65-66
6.17	Variation of Rainfall-Runoff coefficients at Hathnur Dam during 1990-2013	72
6.18	Variation of Rainfall-Runoff coefficients at Ukai Dam during 1990-2013	73
6.19	Sediment rating curve during 1980-1990 for the month June at Burhanpur station	75
6.20	Sediment rating curve during 1990-2000 for the month June at Burhanpur station	75
6.21	Sediment rating curve during 2000-2010 for the month June at Burhanpur station	75
6.22	Sediment rating curve during 1980-1990 for the month June at Sarangkheda station	76
6.23	Sediment rating curve during 1990-2000 for the month June at Sarangkheda station	76
6.24	Sediment rating curve during 2000-2010 for the month June at Sarangkheda station	76
7.1	Geological distribution along Tapi river buffer zone	78
7.2	Details of aquifer in Middle Tapi river (a) Tapi alluvium region (b) Panel diagram of alluvium aquifer	79
7.3	Hydrogeology of Betul district	80
7.4	Hydrogeology of Amravati district	81
7.5	Hydrogeology of Burhanpur district	83
7.6	Hydrogeology of Jalgaon district	84
7.7	Hydrogeology of Dhule district	85
7.8	Hydrogeology of Nandurbar district	87
7.9	Hydrogeology of Tapi district	88
7.10	Hydrogeology of Surat district	89
8.1(a)	Land-use land-cover classification for the year 1990 for Burhanpur sub-basin	94
8.1(b)	Land-use land-cover classification for the year 2000 for Burhanpur sub-basin	94
8.1(c)	Land-use land-cover classification for the year 2010 for Burhanpur sub-basin	95
8.2(a)	Decadal variations in area (agriculture) for Burhanpur sub-basin	95
8.2(b)	Decadal variations in area (built-up) for Burhanpur sub-basin	96
8.2(c)	Decadal variations in area (water) for Burhanpur sub-basin	96
8.2(d)	Decadal variations in area (forest) for Burhanpur sub-basin	96
8.2(e)	Decadal variations in area (fallow) for Burhanpur sub-basin	97

Fig No.	Title	Page No.
8.2(f)	Decadal variations in area (scrub land) for Burhanpur sub-basin	97
8.3(a)	Land-use land-cover classification for the year 1990 for Middle Tapi sub-basin	98
8.3(b)	Land-use land-cover classification for the year 2000 for Middle Tapi sub-basin	99
8.3(c)	Land-use land-cover classification for the year 2010 for Middle Tapi sub-basin	99
8.4(a)	Decadal variations in area (agriculture) for Middle Tapi sub-basin	100
8.4(b)	Decadal variations in area (built-up) for Middle Tapi sub-basin	100
8.4(c)	Decadal variations in area (water) for Middle Tapi sub-basin	101
8.4(d)	Decadal variations in area (forest) for Middle Tapi sub-basin	101
8.4(e)	Decadal variations in area (fallow) for Middle Tapi sub-basin	101
8.4(f)	Decadal variations in area (scrub land) for Middle Tapi sub-basin	102
8.5(a)	Land-use land-cover classification for the year 1990 for Lower Tapi sub-basin	103
8.5(b)	Land-use land-cover classification for the year 2000 for Lower Tapi sub-basin	103
8.5(c)	Land-use land-cover classification for the year 2010 for Lower Tapi sub-basin	104
8.6(a)	Decadal variations in area (agriculture) for Lower Tapi sub-basin	104
8.6(b)	Decadal variations in area (built-up) for Lower Tapi sub-basin	105
8.6(c)	Decadal variations in area (water) for Lower Tapi sub-basin	105
8.6(d)	Decadal variations in area (forest) for Lower Tapi sub-basin	105
8.6(e)	Decadal variations in area (fallow) for Lower Tapi sub-basin	106
8.6(f)	Decadal variations in area (scrub land) for Lower Tapi sub-basin	106
9.1	Location map of Tapi estuary system, Suvali Gam, Hazira	110
9.2	Location map of Bhatpor village, Surat	112
9.3	Location map of Nehru Bridge site in Surat city	114
9.4	Location map of Variav Village and Amroli Village in Surat	116
9.5	Location map of Utran-Kapodara Bridge Site	118
9.6	Location map of Savjibhai-Korat Bridge Site	119
9.7	Location map of Bodhan village near Mandvi taluka, Surat	121
9.8	Location map of Umarsadi Haripura Bridge Site, Mandvi	123
9.9	Location map of Mandvi Bridge Site	125
9.10	Location map of Kavithe-Kukarmunda Bridge site	127
9.11	Location map of Prakasha barrage site	130
9.12	Location map of Sasde Village, Nandurbar, Maharashtra	133

Fig No.	Title	Page No.
9.13	Location map of Bamkheda Village, Nandurbar, Maharashtra	135
9.14	Location map of Sarangkheda CWC Site, Nandurbar, Maharashtra	138
9.15	Location map of Gidhade CWC Site, Maharashtra	143
9.16	Location map of Babulde site, Maharashtra	145
9.17	Location map of Mudawad Site, Maharashtra	147
9.18	Location Map of Padalsare Dam	151
9.19	Location map of Gangapuri, Jalod, Maharashtra	154
9.20	Location map of Awar, Maharashtra	158
9.21	Location map of Rameshwaram Temple at confluence of Girna and Tapi rivers	160
9.22	Location map of road bridge site (MH SH 186) near Nhavi P Adawad	163
9.23	Location map of Bhusawal CWC stream gauging site	164
9.24	Location map of Hathnur dam	167
9.25	Location map of Changdev village	169
9.26	Location map of Rajghat and Najirighat in Burhanpur	170
9.27	Location map of Mohona Nadi Sangam in Burhanpur	173
9.28	Location map of Dabalikhurd site in Nepanagar	175
9.29	Location map of Melchuka village, Madhya Pradesh	177
9.30	Location map of Dedtalai CWC stream gauging site	179
9.31	Location map of Rama Kheda village	180
9.32	Location map of Chandora dam	182
9.33	Location map of Tapti Kund, Multai	183
10.1	Layout map of Tapi basin showing the toposheets that lie along the main river	188
10.2	Sign convention adopted for river bank migration	190
10.3	Migration of RBL in Upper Tapi river	190
10.4	Migration of LBL in Upper Tapi river	192
10.5	Migration of RBL in Middle Tapi river	194
10.6	Migration of LBL in Middle Tapi river	195
10.7	Migration of RBL in Lower Tapi river	196
10.8	Migration of LBL in Lower Tapi river	196
10.9	Changes in bank width in Upper Tapi river	198
10.10	Changes in bank width in Middle Tapi river	198
10.11	Changes in bank width in Lower Tapi river	199
10.12	Location Map of Tapi Estuary System, Suvali Gam, Hazira	204

Fig No.	Title	Page No.
10.13	Location Map of Utran-Kapodara Bridge	205
10.14	Location Map of Kavithe-Kukarmunda Bridge	206
10.15	Location Map of Mudawad, Maharashtra	206
10.16	Location Map of Jalod, Maharashtra	207
10.17	Location Map of Hatnur Dam site, Maharashtra	208
10.18	Location Map of Burhanpur Fort, Maharashtra	208
10.19	Location Map of Ukai Dam, Gujarat	210
10.20	Trend of sediment yield rate (t/ha) from Burhanpur vis-à-vis Yerli sub catchments (The data for the period 1973-1979 were not available for Burhanpur)	211
10.21	Upper Tapi river from Tapi Kund to Dhanori	213
10.22	Longitudinal bed profile of Upper Tapi river	214
10.23	Upper Tapi Gorge (Dhanori to Ratamati)	214
10.24	Alluvial reach in Upper Tapi river (Ratamati-Hatnur Reservoir)	215
10.25	Cross sections of Upper Tapi river at various locations; a) Taikheda; b) Mendha; c) Burhanpur and d) Changdev (based on surveyed data of year 2015)	216
10.26	Variation in cross-sections at stream gauging stations of Upper Tapi river	217
10.27	Longitudinal bed profile of Middle Tapi river	219
10.28	Braided reach between Vagdud and Bhusawal in Middle Tapi river	220
10.29	Cross-section of Middle Tapi river at Gidhade and Bhusawal (based on surveyed data of year 2015)	220
10.30	Variation in cross-sections at stream gauging stations of Middle Tapi river	221
10.31	Longitudinal bed profile of Lower Tapi river	221
10.32	Cross-section of Lower Tapi river at Bodhan and Kapodara (Based on surveyed data of year 2015)	222
10.33	Lower Tapi river meander belt in Katargam, Gujarat	222
10.34	Variation in cross-sections at stream gauging stations of Lower Tapi river (Here zero chainage is taken at Singanpore weir and measuring upstream to Ghala stream gauging station)	223
10.35	Variation of Thalweg line of Lower Tapi river from Singanpur weir to Ghala (Here zero chainage is taken at Singanpore weir and measuring downstream to the Arabian Sea)	225
10.36	Variation of Thalweg line in Lower Tapi river from Singanpur Weir to Arabian Sea	225
10.37	Dendogram of Cluster Analysis	231
11.1	Methodology adopted in morphological study	234

Fig No.	Title	Page No.
11.2	Diagram representing the calculation of the sinuosity for Single-channel and Multi-channel rivers (Friend and Sinha, 1993)	237
11.3	Meandering course between Tipnapur and Teska in CH: 50 km to CH: 100 km river reach	238
11.4	Straight reach between Ukai Dam (CH: 647 km) and Kadod (CH: 697 km)	239
11.5	Meandering reach between Kadod (CH: 697 km) and Surat (CH: 747 km)	240
11.6	Diagram representing the calculation of the meandering parameters	240
11.7	Definition sketch for Plan Form Index (*PFI*)	242
11.8	Braided reach in Middle Tapi river between Vagdud and Bhusawal	244
11.9	Braided reach in Lower Tapi river between Khedpur and Puna	245
11.10	Braided reach in Lower Tapi river between Umarsadi and Kudashi	245
11.11	Braided reach in Lower Tapi river between Rundh Magdalla and Arabian Sea	246
12.1	Location map of Tapi estuary system, Suvali Gam, Hazira	259
12.2	Location map of Kholvad and Kamrej villages	263
12.3	Location map of Kavithe-Kukarmunda bridge site	265
12.4	Typical sketch of a parallel guide bund (IRC-89:1997)	267
12.5	Location map of Sarangkheda barrage and road bridge MH SH-1	268
12.6	Location map of Mudawad Village	270
12.7	Location map of Gangapuri, Jalod, Maharashtra	272
12.8	Typical sketch of repelling gryone (IS 8408:1994)	273
12.9	Location map of Rajghat and Najirighat in Burhanpur	274
13.1	Zone wise distribution of Surat city excluding outskirt rural area (Timbadiya et al. 2015)	285
13.2	Flow hydrograph of Ukai during flood of year 2006 (Timbadiya et al. 2015)	288
13.3	Tidal level (downstream boundary condition) during flood of year 2006	289
13.4	Temporal changes in areal extent of the flood	291
13.5	Rating curve (Q-h relationship) along the lower Tapi river using 1D-2D coupled model (Timbadiya et al. 2015)	293
13.6	Cross sections of lower Tapi river at (A) Ukai dam (B) Kakrapar weir (C) Mandvi bridge (D) Ghala Village (E) Singapore weir (F) Nehru bridge (Surat city) (Timbadiya et al. 2015)	294

LIST OF TABLES

Table No	Title	Page No.
4.1	Details of dams that fall within the buffer zone of Tapi Basin	30
4.2	Details of barrages/weirs that fall within the buffer zone of Tapi Basin	31
4.3	Details of HO Stations that fall within the buffer zone of Tapi Basin	32
4.4	Details of towns that fall within the buffer zone of Tapi Basin	32
4.5	Elevation zones in Tapi Basin	33
4.6	Area covered by various soils in Tapi Basin	34
5.1	SOI toposheets along Tapi River, procured from MADC, SOI, Dehradun	35
5.2	Projection parameters for LCC Projection System	36
5.3	Satellite imagery downloaded for the year 1981	36
5.4	Satellite imagery collected for year 1990	37
5.5	Satellite imagery collected for year 2000	37
5.6	Satellite imagery collected for year 2010	37
5.7	Hydraulic data collected in present investigation	38
5.8	Meteorological data collected in present investigation	40
5.9	Data regarding water quality	41
5.10	Data regarding suspended sediment (g/L)	41
6.1	Results of trend analysis carried out in rain gauge stations of Upper Tapi Basin	47
6.2	Results of trend analysis carried out in rain gauge stations of Middle Tapi Basin	53
6.3	Results of trend analysis carried out in rain gauge stations of Lower Tapi Basin	56
6.4	Statistical details computed for various stations	60
6.5	Autocorrelation coefficients for first 10 lags	61
6.6	Test statistics computed for Cumulative Deviations test	63
6.7	At-site flood quantiles for various return periods	64
6.8	Hydraulic geometry equations at Dedtalai stream gauging station	69
6.9	Hydraulic geometry equations at Burhanpur stream gauging station	69
6.10	Hydraulic geometry equations at Gidhade stream gauging station	69
6.11	Hydraulic geometry equations at Sarangkheda stream gauging station	69
6.12	Exponents of at-station hydraulic geometry during 1980-1990	70
6.13	Exponents of at-station hydraulic geometry during 1990-2000	70
6.14	Exponents of at-station hydraulic geometry during 2000-2010	70

Table No	Title	Page No.
6.15	Stream power computed at various stations	70
6.16	Rainfall-Runoff coefficients at Hatnur Dam and Ukai Dam	72
6.17	Decadal variation in sediment rating curve equation exponents	74
8.1	Dataset used in the present study	92
8.2	Description of the land-use/ land-cover classes	92
8.3	Percentage areas falling under different land-use classes	93
8.4	Percentage areas falling under different land-use classes	100
8.5	Percentage areas falling under different land-use classes	104
10.1	The lengths of LBL, RBL and CL for Upper, Middle and Lower Tapi River	189
10.2	Shifting of right bank and left bank at 20 km chainages (Upper Tapi River)	191
10.3	Shifting of right bank and left bank at 20 km chainages (Middle Tapi River)	193
10.4	Shifting of right bank and left bank at 20 km chainages (Lower Tapi River)	195
10.5	Variation in channel width along river length (Upper Tapi River)	197
10.6	Variation in channel width along river length (Middle Tapi River)	198
10.7	Variation in channel width along river length (Lower Tapi River)	199
10.8	Variation in hydraulic geometry parameters with different flow categories (1980-1990)	200
10.9	Variation in hydraulic geometry parameters with different flow categories (1991-2000)	201
10.10	Variation in hydraulic geometry parameters with different flow categories (2001-2010)	201
10.11	Historical record of floods in Surat City	209
10.12	Silt accumulated in Hatnur Reservoir	211
10.13	Reduction in volume of water during 2007-09 in Lower Tapi River reaches	226
10.14	Water quality parameters analyzed at different station	226-227
10.15	Water quality parameters with mean value at the different sites	230-231
10.16	Details of the intake wells of the SMC	232
11.1	The lengths of RBL and LBL for Upper, Middle and Lower Tapi River	235
11.2	Sinuosity Index (P) for different years in Upper Tapi River	237
11.3	Sinuosity Index (P) for different years in Middle Tapi River	238
11.4	Sinuosity Index (P) for different years in Lower Tapi River	239
11.5	Meandering parameters for different years in Tapi River	241
11.6	Average PFI values for different years in Upper Tapi River	242

Table No	Title	Page No.
11.7	Average PFI values for different years in Middle Tapi River	243
11.8	Average PFI values for different years in Lower Tapi River	243
11.9	Erosion and deposition areas due to migration of RBL in Upper Tapi River	247
11.10	Erosion and deposition areas due to migration of LBL in Upper Tapi River	247
11.11	Erosion and deposition areas due to migration of RBL in Middle Tapi River	248
11.12	Erosion and deposition areas due to migration of LBL in Middle Tapi River	248
11.13	Erosion and deposition areas due to migration of RBL in Lower Tapi River	249
11.14	Erosion and deposition areas due to migration of LBL in Lower Tapi River	249
11.15	Grades assigned for different criteria considered in vulnerability assessment	251
11.16	Levels of vulnerability	251
11.17	Vulnerability Index for Upper Tapi River	254
11.18	Vulnerability Index for Middle Tapi River	255-256
11.19	Vulnerability Index for Lower Tapi River	256-257
12.1	Details of the river training works proposed for restoration of critical river reaches	275-276
12.2	Details of locations with excessive sediment deposition in Upper Tapi River	277
12.3	Details of locations with excessive sediment deposition in Middle Tapi River	277
12.4	Details of locations with excessive sediment deposition in Lower Tapi River	278
12.5	Details of existing bridges in Lower Tapi River	279-280
12.6	Details of existing bridges in Middle Tapi River	281-282
12.7	Details of existing bridges in Upper Tapi River	283
13.1	Major floods in the Lower Tapi River in last five decades	284
13.2	Zone-wise Urban Area in Surat City	285
13.3	Hydraulic properties of flood in lower Tapi River (Source: Timbadiya et al. 2015)	290
13.4	Wave hydraulic for flood of year 2006 on floodplain (Surat City) (Source: Timbadiya et al. 2015)	290

LIST OF PHOTOS

Photo No.	Description	Page No.
9.1	The alarming proximity of right bank to the NH 6 road	110
9.2	The right bank getting eroded at Suvali Gam, Hazira	111
9.3	Protection provided at the right bank getting degraded	111
9.4	Dry channel observed in Bhatpor, Surat (view from right bank)	113
9.5	Retaining wall constructed along the periphery of right bank	113
9.6	Rip-rap stones provided at the right bank in view to protect the retaining wall	114
9.7	View of Nehru bridge and Makkai Pool bridge from right bank of Tapi river	115
9.8	Levee constructed in order to protect left bank near Nehru bridge, Surat	115
9.9	Flood gate constructed across the river in Variav village	116
9.10	Embankment constructed to protect the right bank of Tapi river	117
9.11	Newly constructed flood gate across Tapi river in Amroli village	117
9.12	Erosion on the right bank of the river at Utran-Kapodra bridge site	118
9.13	Flood plain getting encroached on the left bank of Tapi river	119
9.14	Construction of intake well in progress on left bank of Tapi river	120
9.15	Intake wells already constructed on the left bank of Tapi river	120
9.16	Excessive floral growth observed in Tapi river at Savjibhai-Korat bridge site	121
9.17	Sand mining activities taking place near the left bank	122
9.18	Rocky particles transported from upstream lying on the river bed	122
9.19	Bund constructed using sand bags on left bank to protect the agricultural lands	123
9.20	Sand mining activities taking place in the river, view from the right bank (the eroded right bank and sand bars formed in the river can also be seen)	124
9.21	View of Umarsadi Haripura bridge towards the left bank of the Tapi river	124
9.22	Rocky bed stratum and growth of vegetation upstream of Mandvi bridge site	125
9.23	View of the eroded right bank downstream of Mandvi bridge site	126
9.24	Kavithe-Kukarmunda bridge, Nizar Taluka, Gujarat	127
9.25	Details of the Velda 3 lift irrigation scheme	128
9.26	Velda 3 lift irrigation scheme on the left bank of Tapi river	128
9.27	Protection at left bank for the lift irrigation scheme and cutting of the left bank	129
9.28	Unprotected left bank downstream of the lift irrigation scheme under the threat of erosion	129

Photo No.	Description	Page No.
9.29	Location of road bridge (MH SH-17) and Prakasha barrage	131
9.30	View of Gomai river, right bank tributary of the Tapi river	131
9.31	Rocky bed strata downstream of Prakasha barrage	132
9.32	Silty bank material found at the Prakasha barrage site	132
9.33	Erosion on right bank; banks are observed to get cut	133
9.34	Deposition observed on the left bank at Sasde, Maharashtra	134
9.35	Pumping of water carried out at the right bank	135
9.36	Right banks which have got cut due to flowing water	136
9.37	Deposition on the left bank of the river	136
9.38	Excessive sand mining observed at the upstream of the site	137
9.39	View of Sarangkheda barrage	138
9.40	The crest level of Sarangkheda barrage	139
9.41	Boulders seen on the banks of the river	139
9.42	Parent material of the river bed downstream of Sarangkheda barrage	140
9.43	Erosion observed underneath the abutment of road bridge (MH SH1) on left bank	141
9.44	Rip-rap protection provided on left bank downstream of Sarangkheda barrage	141
9.45	Cutting of left bank in the immediate downstream of Sarangkheda barrage	142
9.46	Sulwada barrage; located 1 km downstream of Gidhade stream gauging site	143
9.47	Details of Gidhade stream gauging site	144
9.48	Suspension cable for current meter measurements at Gidhade	144
9.49	Alluvial right bank of the Tapi river at Gidhade	145
9.50	bridges running parallel across the Tapi river near Babulde	146
9.51	Cutting of right bank near Babulde	146
9.52	Confluence of Tapi and Panjara rivers	148
9.53	Eroded structure at the confluence of Tapi and Panjara rivers	148
9.54	Erosion at the outer (concave-left) bank	149
9.55	Deposition at the inner (convex-right) bank	149
9.56	Clayey material at the bank of the river	150
9.57	View of construction work in progress at Padalsare Dam	151
9.58	View of downstream guide wall at Padalsare Dam	152
9.59	View upstream of Padalsare Dam showing confluence of Aner and Tapi rivers	152
9.60	View upstream of Padalsare Dam	153

Photo No.	Description	Page No.
9.61	Hydrologic measurements carried out by HDUG at Padalse stream gauging site, upstream of Padalsare dam	153
9.62	Erosion on left bank of the river	155
9.63	Deposition on right bank of the river	155
9.64	Intake well and eroded structure on the left bank at upstream of the bridge	156
9.65	bridge constructed across the Tapi river at Jalod, Maharashtra	156
9.66	Sand mining activities taking place at the left bank	157
9.67	Erosion on right bank of the river	158
9.68	Scour protection works to safeguard bridge piers	159
9.69	Confluence of Girna and Tapi rivers	160
9.70	Minor bank cutting on right bank opposite to the confluence point of Tapi river	161
9.71	river bed material observed at the confluence site	161
9.72	Bank erosion observed on the left bank of Tapi river upstream of the confluence site	162
9.73	Significant deposition on the right bank of Tapi river upstream of the confluence site near Palsod village	162
9.74	Deposition on the left bank of Tapi river, upstream of the road bridge MH SH 186	163
9.75	Stage measurements on bridge piers at Bhusawal CWC gauging site	165
9.76	View of Tapi river downstream of Bhusawal CWC stream gauging site	165
9.77	View of Tapi river upstream of Bhusawal CWC stream gauging site	166
9.78	View of Hathnur dam from downstream	167
9.79	View of road bridge downstream of Hathnur dam	168
9.80	View of Hathnur dam and reservoir	168
9.81	Confluence of Tapi and Purna rivers at Changdev village	169
9.82	Rajghat on right bank of Tapi river in Burhanpur	170
9.83	Considerable deposition on the left bank just upstream of Rajghat in Burhanpur	171
9.84	Damaged portion of Fort wall near Rajghat in Burhanpur	171-172
9.85	High flood level during 2006 floods at Rajghat in Burhanpur	172
9.86	View of Tapi river from Nagjirighat in Burhanpur	173
9.87	View of road bridge as a part of Burhanpur-Jalgaon highway (MP SH 50), 1.6 km downstream of the Mohona river confluence	174
9.88	Confluence of Tapi and Mohona rivers in Burhanpur	174
9.89	View of parent bed material in stream bed near Dabalikhurd, Nepanagar	175
9.90	View of road bridge under construction near Dabalikhurd, Nepanagar	176

Photo No.	Description	Page No.
9.91	View of abandoned weir near Dabalikhurd, Nepanagar	176
9.92	Minor cutting observed in the right bank near the bridge	177
9.93	View of Tapi river downstream of Melchuka village	178
9.94	View of meander bend showing excessive deposition in the inner bend	178
9.95	View of Dedtalai CWC stream gauging site	179
9.96	View of Tapi river upstream of Dedtalai CWC stream gauging site	180
9.97	View of rocky strata of river bed upstream of Rama Kheda village	181
9.98	View of river bed downstream of Rama Kheda village	181
9.99	Nominal erosion on the right bank near Rama Kheda village	182
9.100	View of Chandora dam on Tapi river, 12 km downstream of Multai	183
9.101	View of Tapti Kund, Multai	184
9.102	View of Gomukh near ancient temple from where Tapi river flows outside	184
12.1	The alarming proximity of right bank to the road NH-6 near Essar, Hazira	260
12.2	Protection of right bank with permeable spurs	261
12.3	Gabions provided for protection of electric transmission towers	262
12.4	Step gabions provided for bank protection near Kholvad village	263
12.5	Vertical bank cutting on left bank near Kamrej village	264
12.6	Erosion on left bank, upstream of Kavithe-Kukarmunda bridge	265
12.7	Erosion on left bank, downstream of Kavithe-Kukarmunda bridge	266
12.8	Erosion observed underneath the abutment of road bridge (MH SH 1) on left bank	269
12.9	Cutting of left bank in the immediate downstream of Sarangkheda barrage	269
12.10	Erosion on the left bank of Tapi river and right bank of Panjara river at the point of confluence	271
12.11	Erosion on left bank of the river	272
12.12	Damaged portion of Fort wall near Rajghat in Burhanpur	274
13.1	Maximum water level during flood of 2006 at Pragna vidhyalaya in North zone	286
13.2	Maximum water level during flood of 2006 at Pandol in North zone	286
13.3	Maximum water level during flood of 2006 at Variavi Bazar in Central zone	287
13.4	Maximum water level during flood of 2006 at Athwagate in West zone	287
15.1	Inaugural Session (Left to Right): Dr. P L Patel (Professor, CED and PI), Dr. S R Gandhi (Director, SVNIT Surat), Shri. Ajay K Sinha (Director, Morphology, CWC), Dr. J E M Macwan (Head, CED, SVNIT Surat) and Dr. P V Timbadiya (Asst. Professor, CED and Co-PI)	306

Photo No.	Description	Page No.
15.2	Group Photo of Workshop – 2017	307
15.3	Certificate and workshop group photo distribution to the participants by Shri. M.P Singh and Dr. G.L Asawa (Retd. Professor, IIT Roorkee)	308
15.4	Presentations by Dr. P L Patel, Dr. P V Timbadiya, Ms. Resmi S R and Mr. Priyank J Sharma	317
15.5	Interactive session with field experts	318

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Morphology of a river is a field of science which deals with variation in its planform and cross section due to the processes of erosion and sedimentation. The dynamics of flow and sediments play major role in shaping the river in due course. Further, hydrologic systems like river evolve as result of both natural and anthropogenic influences such as changes in land and water uses caused by urbanization, agriculture, climate change, modifications to water infrastructure and water usage etc. The morphological study of a river is required in planning, design and efficient maintenance of hydraulic structures falling along its alignment. The Tapi River, particularly its lower reach, is of great importance with reference to frequent flooding and its influence on urban infrastructures of the coastal urban flood plains like Surat city. The significance of major and minor structures like Ukai, Hatnur and Girna reservoirs play major roles in shaping the morphology of the Tapi River.

The Central Water Commission, Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR,RD&GR), Government of India, approached SVNIT, Surat to carry out Morphological study of Tapi River using Remote Sensing Technique and identify the critical erosion prone areas along the flow of the rivers. (Proposal to SVNIT made vide letter No.4/19/2012-Morpho/402-406, dated 30-10-2012). The objectives and detailed scope of work were discussed and finalised in the first meeting of Consultancy Evaluation cum Monitoring Committee (CEMC) with IIT's and NIT's and they were requested to submit the consultancy proposals on aforesaid theme. In response to the proposal submitted by Sardar Vallabhbhai National Institute of Technology- Surat (SVNIT-Surat) for Morphological Study of Tapi River using Remote Sensing Technique (letter no. CED/PLP/3282/2012-13, dated March 28, 2013), a meeting was held on 18th March 2015 at Central Water Commission (CWC), Government of India, represented by the Director, Morphology Directorate and Dr. P.L. Patel, Professor, Civil Engineering Department, SVNIT-Surat. As an outcome, a Memorandum of Understanding was signed between CWC and SVNIT-Surat, for Consultancy services for "Morphological Study of Tapi River using Remote Sensing Technique" and the same was forwarded to SVNIT-Surat vide letter No.4/19/2012/SVNIT/Morpho/287-288, dated May 11, 2015.

1.2 NEED FOR MORPHOLOGICAL STUDIES

All around the globe, the rivers are posed to threats due to excessive erosion and deposition owing to the lateral migration of their banks. One of the major reasons for such phenomena is the imbalance between the sediment transport capacity and sediment inflow. If the sediment inflow is less than the carrying capacity, erosion takes place and, similarly, if the inflow is greater than carrying capacity, the river tries to maintain its stability by depositing the excess sediments, both in the bed as well as its banks. In either case, it is difficult for engineers and planners to effectively arrest such phenomena and maintain the stability of the river reaches and its adjoining areas where agricultural fields, towns, monuments etc. are likely to be located. During the lean season, the shoals in the low water channels cause problems in navigation, whereas, during flood season, the deep channels migrate laterally and erode the banks posing threat of serious damages to valuable property, lines of communication, towns and villages etc.

The study of river morphology and implementation of suitable river training works as appropriate have become imperative for our Nation as large areas of our country are affected by floods every year causing severe damages to the life and property in spite of existing flood control measure taken both by Central and State Governments. Problems are aggravating mainly due to large quantity of silt/sediment being carried and deposited in its downstream reaches of river. The special behaviour of the river needs to be thoroughly understood for evolving effective strategies to overcome the problem posed by it. The morphological studies play an important role in knowing the nature of rivers which helps in planning, design and maintenance of flood protection/ river training works and water resources projects. The morphological studies help in finding the vulnerable spots for bank erosion/deposition.

The Tapi River has three major reservoirs; in its upper reach (Hatnur reservoir), middle reach (Girna reservoir) and lower reach (Ukai reservoir). The lower reach of Tapi River, downstream of Ukai reservoir, has been subject to the frequent flooding. The major past floods in the lower Tapi River reach are the floods of the years 1727, 1776, 1782,1829, 1837, 1872, 1944, 1959, 1968, 1970, 1994, 1998 and 2006. The flood during 1968 with the peak discharge of 42500 m^3/s was largest in the last century. The average annual flood with return period of 2.33 years at Ukai dam is 14323 m^3/s. The floods of year 2006 alone had caused damage to the Surat city to the tune of Rs. 21000 crores. Also, 150 human lives were lost in 2006 flood, and 80% of Surat city is flooded for several days. The warning level and danger level at Surat city are 8.5 m and 9.5 m respectively. In recent past, the Tapi River at Surat City had gone major reduction

in its carrying capacity, may be due to encroachment in the flood plain and siltation in the river. The several initiatives has been undertaken for controlling the floods in Lower Tapi River including construction of levees on both banks of rivers. In view of above, the morphological study of Tapi River using Remote Sensing technique is essentially required to identify the critical reaches of the channel, and suggest suitable measures to maintain the stability of the river reaches under consideration.

1.3 OBJECTIVES OF THE PRESENT STUDY

The specific objectives of the study are:

- To compile complete river drainage map in GIS by integrating available secondary maps in Water Resources Information System (WRIS) of CWC.
- To collect additional required information on major flood protection structures, existing water resources projects, important cities/ towns, CWC H.O sites, airport, island etc., and to integrate the same with final river drainage maps.
- To study shifting of river course and also changes in its plan form from the base year till 2010, by collecting 4 sets of satellite imagery at 10 years interval in addition to one set of Survey of India toposheets for the base year on a scale of 1: 50,000.
- Carry out the Channel Evolution Analysis to describe the status of the river channel, i.e., analysis of the channel dimension, pattern, and longitudinal profile identifying distinct river reaches, i.e., channel in upper reaches, channel in flood plain with bank erosion etc.
- To compile changes in Land Use/Land cover, and study of its impact on river Morphology.
- Work out the rate of bank erosion/deposition in terms of erosion area w.r.t. base year at every 50 km river reach.
- To assess the present condition of critical reaches of the main channel of river by conducting ground reconnaissance and field reconnaissance trips.
- To evaluate the impacts of major hydraulic structures on morphological behaviour of river course and its impacts on river morphology.
- To plot probability curve (Exceedance Probability vs Flow rate) and show flow rates corresponding to return periods of 1.5 and 2 years for different CWC H.O. locations.
- To relate the morphological changes in river on the basis of available peak discharges of different years in the time domain considered in this study.

- To study impact of changes in annual rainfall in the basin on river morphology.
- To identify critical and other vulnerable reaches / locations. Analysis of respective rate of river course shifting and based on it, future prediction of river course behaviours.
- To suggest suitable river training works for restoration of critical reaches depending on site conditions.

1.4 DETAILED SCOPE OF THE STUDY (TERMS OF REFERENCE)

- To procure the required inventory of one set of Survey of India (SOl) toposheets in respect of reference time datum on a scale of 1:50,000 from SOl.
- To acquire satellite imagery corresponding to IRS LISS-I, LISS-II, LISS-III which covers the study area, from NRSC.
- Analysis using SOI toposheets (say year 1970) and digital satellite imagery of IRS LISS-I, LISS-II and LISS-III sensors, comprising scenes for the years 1980, 1990, 2000 and 2010. Due non-availability of above data during 1980, the foreign satellite data (LANDSAT-IV) are used. The maps and imagery are registered and geo-referenced with respect to Survey of India (1:50,000 scale) toposheets w.r.t. to base year by using standard technique & GIS tool.
- Delineation of River Bank Line, River Centre Line along with generation of important GIS layers of river banks, major hydraulic structures, embankments/levees, railway bridge line, island, airport, cities/towns/villages, and important monuments etc. located in the vicinity of river banks.
- Estimation of left and right bank shifting amount(s) w.r.t. base year and appropriate graphical plotting of these shifting.
- Evaluation of braiding of different river course reaches by using Plan Form Index (PFI) criteria along with its threshold classification, wherever required.
- Estimation and comparison of each bank erosion for different reaches in term of erosion area of the river w.r.t. base year by using appropriate GIS tool.
- Comparison of delineated different river courses on the same graphical plot on A0 size.
- Demonstrating the most critical reaches separately with appropriate suitable stream reaches) restoration with a recommendation of suitable bank stabilisation technique(s) depending upon the channel planform and condition.

- Using the available cross section data for identifying riffle locations, and measure topography changes, extract necessary information to analyse the channel, which ultimately led to identifying the channel stage or condition.
- Ascertaining the river Channel Dimension; river channel width and the representative cross section with the help of the channel hydrograph, suspended sediments etc.
- To develop the Maximum Flow Probability curves at CWC H.O. sites located on Tapi river, to predict the channel discharge corresponding to 1.5 year and 2 year Return Interval (RI). These values, i.e., 2-year Return Interval is widely accepted as the "Channel Forming Discharge" or "Bankfull". These are the flows that contribute most to the channel dimensions.
- To develop the channel profile; channel profile is commonly referred to channel slope or gradient.
- To carry out impaired stream analysis; as part of the scope of work, part of impaired streams to be identified along with the causes and sources by the consultant and to recommend stream restoration mechanism/methods.
- To compile changes in Land Use/Land cover, and study of its impact on river Morphology.

CHAPTER 2
LITERATURE REVIEW

2.1 SHIFTING AND EROSION OF BANKLINES

Sarma et al. (2007) studied the Burhi Dihing River which follows a meandering pattern for about 220 km throughout the alluvial plains of Assam including a short rocky and hill tract in between. Topographical maps of 1974 and 1972; satellite data of years 2001 and 2004 were analysed using GIS to study the sequential changes in the position of bank lines of the river due to consistent erosion of banklines. Two broad kinds of changes were observed, e.g., alteration of direction of flow due to neck cut-off and progressive gradual change of the meander bends that accounts for translational, lateral, rotational, extensional and other types of movement of the meander bends. Study of bankline shift due to the bank erosion was carried out for the periods 1934-1972, 1972-2001, 2001-2004 and 1934-2004 at every 15 km intervals. The hard rocks of the hilly tract situated in between alluvial plains resulted in development of entrenched meandering and this tract had suffered minimum bank erosion. During the entire period (1934-2004) of study, the overall erosion on the both banks was 31.169 km^2 and overall sediment deposition was 30.101 km^2.

Kummu et al. (2008) analysed the bank erosion problem in the Vierntiane-Nong Khai section of the Mekong River, where the Mekong borders the Thailand and Lao PDR. The bank movement rates were quantified using two Hydrographic Atlases dated 1961 and 1992, derived originally from aerial photos and a field survey, and SPOT5 satellite images acquired on 4 December 2004 and 28 April 2005 with a resolution of 2.5 m in natural colours. Bank erosion and accretion rates on the left (Lao PDR) and right (Thailand) banks of the Mekong were analysed for two time periods: 1961–1992 and 1992–2005, respectively. The quantified average bank erosion rates were found to be slow, ranging from 0.8 to 1.0 m/ac for the first and second analysis period, respectively. These average annual erosion rates are only 0.1% of the channel width, which is very low on a global scale. However, erosion rates were much higher for the islands in the river, 2.4 and 4.8 m/ac for the two time periods. The quantified accretion for the main banks was 0.4 m/ac during 1961–1992 and 0.7 m/ac during 1992–2005, which for the islands increased from 0.6 to 6.4 m/ac from the first to the second period.

Florsheim et al. (2008) recognized that bank erosion is one component of the natural disturbance regime of river systems and is integral to long-term geomorphic evolution of fluvial

systems and to ecological sustainability; hence identifying bank erosion as a desirable attribute of rivers. They identified four shortcomings in current river management, i.e., (1) failure to understand and accommodate bank erosion processes and functions, (2) failure to consider bank erosion management at the appropriate scale, (3) failure to consider secondary effects of bank erosion-control infrastructure, and (4) failure to consider long-term and cumulative effects of bank erosion-control infrastructure. They explained that spatial extent and temporal frequency of bank erosion processes should be well documented to allow for long-term watershed analyses that could illuminate the cumulative effects of channel bank infrastructure. To address current and past management failures, they have come up with broad alternatives to accommodate geomorphic processes that promote riparian functions, i.e., (a) dynamic-process conservation areas, (b) erosion easements, (c) elimination of direct stressors, and (d) non-structural approaches, such as those that include live vegetation that may moderate bank erosion processes without limiting long-term geomorphic evolution.

Panda and Bandyopadhyay (2011) analyzed the Bhagirathi River in Murshidabad district using satellite images of 1970, 1977, 1990, 2000 and 2006, and found that major changes had occurred in Southern part of the river compared to the Middle part. The topographic maps of year 1970 was also compared with the satellite images to observe the changes over time. The formations like point bars, oxbow lakes, meanders etc. were found to get influenced by discharge, soil types and sediment transport. Maximum erosion was found to take place at Dear Balagachi after Baidyanathpur. It was observed that traditional bank protection works like concrete walls, cemented stones and bricks, play significant roles in the interference in water dynamics of erosive and depositional phenomenon.

Das et al. (2012) studied the Subansiri-Ranganadi Doab, located in Lakhimpur district, Assam, which is one of the worst flood-affected areas in Brahmaputra valley. Using IRS LISS imagery of 1997 and 2009 as input in GIS, the shifting of the bank lines in the flood plains of the Subansiri-Ranganadi Daob were studied. During the study period, the river Subansiri migrated westward and widened substantially with erosion of an area of 19.137 km^2. Similarly, the erosion area of Ranganadi, river was 0.897 km^2. The channel changes were mainly due to concave bank erosion associated with high flow stages.

Sarkar et al. (2012) aimed to quantify the actual bank erosion/deposition along the Brahmaputra River within India for a period of eighteen years (1990-2008). The entire course

of Brahmaputra River in Assam from upstream of Dibrugarh to the town Dhubri near Bangladesh border, for a stretch of around 620 km was studied using an integrated approach of Remote Sensing and GIS. Mapping for the channel configuration of the Brahmaputra River for years 1990 and 2008 was done using IRS 1A LISS-I, and IRS-P6 LISS-III satellite images respectively. The analysis of satellite data provided, not only the information on the channel configuration of the river system on repetitive basis, but also have brought out several significant facts about the changes in river morphology, stable and unstable reaches of the river banks and changes in the main channel.

Thakur et al. (2012) studied the river bank erosion hazard due to morphometric changes in the Ganga River in the upstream of Farakka Barrage up to Rajmahal. Morphometric parameters, such as, Sinuosity, Braiding Index, and percentage of the island area to the total river reach area were measured for the years of 1955, 1977, 1990, 2001, 2003, and 2005 from topographical maps, LANDSAT and IRS satellite images. The analysis revealed that there were drastic increase in aforesaid parameters over the period of time. Sinuosity being large, the river was engulfing the large areas of left bank every year. The victims were mostly of Manikchak and Kaliachak-II blocks of Malda district, with a loss of around 1,670 ha agricultural land since 1977. The study revealed that bank failure were due to certain factors like soil stratification of the river bank, presence of hard rocky area (Rajmahal), high load of sediment and difficulty of dredging and construction of Farakka Barrage as an obstruction to the natural river flow.

2.2 PLANFORM CHANGES IN RIVERS

Brice (1964) defined the braiding index (*BI*) as follows:

$$BI = \frac{2\Sigma L_i}{L_R} \qquad \mathbf{2.1}$$

where ΣL_i is the length of all the islands and/or bear in the reach, and L_R is the length of the reach measured between the banks of the channel belt (Fig 2.1).

Chitale (1970) observed that a particular stream can have single or multiple channel in one reach. The multiple channel was classified into anabranching, deltaic, reticulate and braided. The meanders were classified into regular and flat, regular and acute, irregular and flat, irregular and acute, simple and compound meanders.

Hooke (1977) identified two types of movement in channel planform in meandering rivers in Devon, England. The first type, where the channel moves downstream by maintaining its planform dimensions. It can be considered as a natural process, which occurs within the state of dynamic equilibrium and hence doesn't constitute a channel change. The second type of movement is where there is variations in channel form and parameters such as braiding index, sinuosity, hydraulic geometry and pattern over the years.

Kellerhals et al. (1977) classified the river channels basically on the interpretation of air photos and detailed survey of Canadian rivers.
The data required to classify the channels were as follows:

- Whether the stream passes through aggradation, degradation, partly entrenched or entrenched with no flood plains.
- Description of plan-form of the channel, viz., straight, sinuous, irregular or regular meanders, or tortuous.
- Presence of bars and islands.
- Lateral activity viz., meanders moving downstream, avulsion, downstream progression, entrenched loop development and cut-offs.

Murray-Rust et al. (1978) introduced two modifications in defining the braiding ratio. They stated that apparent bar length might be caused by variations in water level, and 'braid length' would be defined from upstream divergence to downstream convergence around the bars lying on the thalweg line of the channel. They also proposed that meander length should be measured for each channel belt (in a braided reaching apparently taking the major channel) and this should be used to define the channel belt. Rust (1978) define the braiding ratio as follows:

$$B_p = \frac{2\Sigma L_b}{L_m} \qquad 2.2$$

where ΣL_b is the sum in a reach, of the braid lengths, between channel thalweg divergences and confluences and L_m is the mean of the meander wavelength in a reach of the channel belt (Fig 2.1).

Friend and Sinha (1993) modified the definition of braiding index by using the idea of total sinuosity developed by Richards (1982) and measured as follows:

$$B = \frac{Lc_{tot}}{Lc_{max}} \qquad 2.3$$

where, Lc_{tot} is the sum of the mid-channel lengths of all the segments of primary channels in a reach, and Lc_{max} is the mid-channel length of the widest channel through the reach (Fig 2.1).

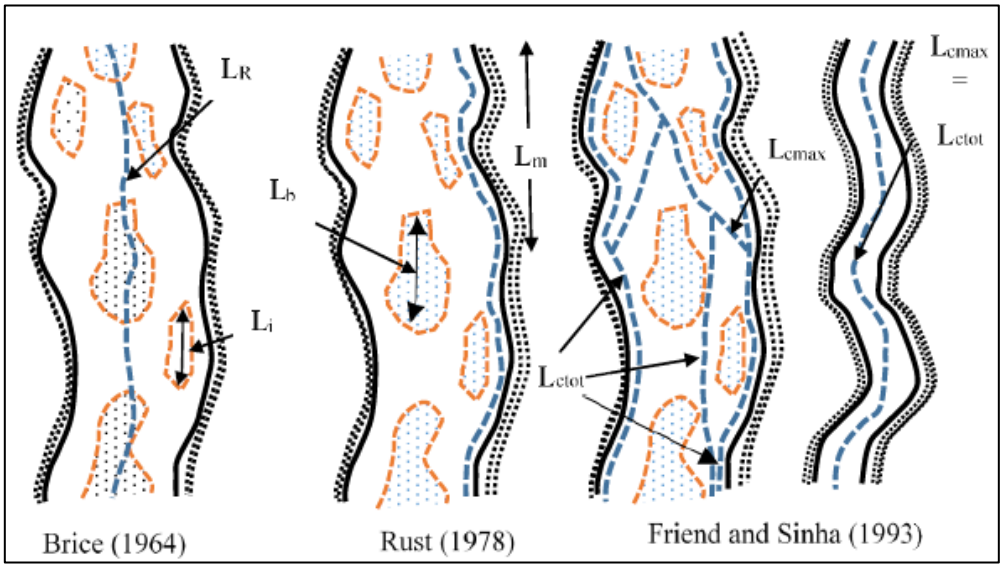


Fig 2.1 Calculation of braiding indices

Winterbottom (2000) analysed the planform of the channel on a reach of the Rivers Tay and Tummel, Scotland by using variety of data-sources for medium (> 25 years and < 250 years) and short-term periods (< 25 years). Analyses of planform characteristics and changes in width, braiding index and sinuosity were conducted on the reach between years 1755 and 1976 using map data as an input to GIS. Aerial photographs of the years 1971 and 1994 were utilised to determine the more recent changes. In the medium term, analysis showed that significant changes have occurred with a mean reduction in the channel width of 34% during the period. In the short period also comparable rate of changes were observed. Incision and subsequent stabilisation of lateral and mid-channel gravel bars by vegetation had resulted in overall increase in the stability of the study reach.

Hooke (2007) studied and examined the evidence of autogenic, self-organized and non-linear behaviour of the rivers around the world. Some examples exhibited trends of increasing sinuosity over time and a few show limits from which large decreases had occurred. Several case studies revealed non-linear behavior and increasing complexity of form. The example of

a reach in which multiple cut-offs occurred was analyzed for mechanisms of self-organization of the planform and in the pool-riffle pattern. Riffles were found more closely spaced and more transient in rapidly changing and higher sinuosity parts of the channel. Hypothetical trajectories of different meander behavior, including bedrock meanders, were plotted and the behavior of different meandering systems were studied.

Aswathy et al. (2008) carried out study to obtain the factors influencing the sinuosity of the Pannagon River, Kottayam, Kerala using IRS P6 LISS III satellite data and GIS. The river was found to follow meandering course and exhibit a narrow, highly sinuous and cut channel. The satellite and topographic data, geological maps, field investigations, generated themes on lithology, structure, geomorphology, slope etc. were analyzed to obtain the channel morphology of the Pannagon River. The average sinuosity index of the selected reaches in the river was 1.6 in 1967 and 1.8 in 2004. The sinuosity of the Pannagon River was found to depend on a number of geological factors including river tectonics and riparian vegetation.

Nicoll and Hickin (2010) examined the planform geometry and migration behavior of confined meandering rivers at 23 locations in Alberta and, British Columbia in Canada. The relationships developed for geomorphologic parameters were found to fall within the standard range specified for freely meandering rivers, but small discrepancies were found due to unique meandering pattern of confined meanders.

2.3 HYDRAULIC GEOMETRY OF RIVERS

Yang et al. (1981) studied and observed that, by application of theory of minimum rate of energy dissipation along with Manning-Strickler equation and dimensionless unit stream power equation for the sediment transport, the exponents of hydraulic geometry relations can be obtained. The theoretical limitation of the analyses was that channels should be approximately rectangular in shape.

Kale et al. (1994), in their work on geomorphic and hydrologic aspects of monsoon floods, reported that Narmada and Tapi Rivers in central India are characterized by one of the most intense flood regimes in the seasonal tropics. They studied the catastrophic flood on Tapi River Basin in July 1991 that occurred from heavy rains and a dam break. Flood competence studies indicated that flood power of the two rivers is comparable with some of the largest historic and prehistoric floods reported from other parts of the world. The rivers were found to preserve

geomorphic and sedimentological records of palaeofloods for the last two millennium. Examination of the synoptic conditions associated with the flood generating low-pressure systems revealed that, all but a few of them, are the result of Bay of Bengal depressions. They concluded their work with the necessity of including geomorphic, sedimentological and botanic information in the planning and design of water resource development projects.

Singh (2003) stated at-a-site hydraulic geometry involves mean values over a certain period, such as a week, a month, a season or a year. He stressed on the fact that hydraulic geometry is of fundamental importance in planning, design, and management of river engineering and training works. He explained that all the theories that have been developed on hydraulic geometry of channels assumes that the flow is steady and uniform, and the river tends to attain a state of equilibrium or quasi-equilibrium.

Kale (2007) explained that efficacy of extreme events is directly linked to the flood power and total energy expended. The geomorphic effectiveness of floods was evaluated in terms of distribution of stream power per unit boundary area (ω) over time, for three very large floods of the 20th Century in the Indian Peninsula. These floods stood out as outliers when compared with the peak floods per unit drainage area recorded elsewhere in the world. They used flood hydrographs and at-a-station hydraulic geometry equations, computed for the same gauging site or a nearby site, to construct approximately stream-power curves and to estimate the total energy expended by each flood. The estimates indicated that the minimum power per unit area values for all three floods were sufficiently high, and stream energy was above the threshold of boulder movement (90 W m^{-2}) for several tens of hours. The peak unit stream power values and the total energy expended during each flood were in the range of 290–325 W m^{-2} and 65–160 × 10^6 J respectively. The average and peak flood powers were found to be higher or comparable to those estimated for extreme palaeo or modern floods on low-gradient, alluvial rivers.

Kale and Hire (2007) made an attempt to evaluate the temporal variations in specific stream power and total energy expenditure for geomorphic work during the monsoon season for the Tapi River, in central India. Continuous daily discharge data (1978–1990), hydraulic geometry equations and the relationship between discharge and water surface slope were used to compute the daily specific stream power (ω) for the Savkheda stream gauging site in the Middle Tapi Basin. The total amount of energy generated by all the monsoon flows was estimated by

integrating the area under the ω-graph derived for the monsoon season. They observed that the large floods have one-third share in the total monsoon energy expenditure. In the absence of appropriate data on the year wise geomorphic effects, the geomorphic work was evaluated in terms of the total transported suspended sediment load. The total monsoon sediment load is strongly related to the total monsoon energy. The results of the study indicated that the average flow competence and capacity were remarkably higher during wetter monsoon seasons and flood years than during the shorter and drier monsoon seasons.

Kale and Hire (2004) said that geomorphic effects of floods are function of several controlling factors, such as magnitude, frequency, rate of sediment movement, flood power, duration of effective flows, sequence of events and the channel geometry. In their study, these measures of effectiveness were evaluated for the monsoon-dominated, flood-controlled and incised Tapi River, India by defining four flow categories: low flows, moderate flows, floods and large floods. Ratios between effectiveness parameters of moderate flows on one hand and the floods, large floods and maximum floods on the other, were computed to understand the relative importance of moderate and large flows. In addition to this, stream-power graphs for large floods were constructed, and the changes in channel form were analysed by using multi-date cross-sections. The results of the study indicated that morphological characteristics of the bedrock as well as the alluvial channels of the monsoonal and incised Tapi River are maintained by large-magnitude, but low frequency floods that occur at long intervals.

Stewardson (2005) conducted 54 surveys on 17 river reaches, mostly in south east Australia and showed that the five reach hydraulic variables are sufficient to characterise the gross hydraulic conditions along a river reach. Reach hydraulic geometry relations have a considerable potential to improve the analyses of fluvial processes and physical habitats across catchments. Comparison between the hydraulic geometry variables at a station along the reaches were also undertaken.

2.4 RIVER MORPHOLOGY IN CONTEXT WITH BASIN TOPOGRAPHY AND LAND USE CHANGES

Hazarika et al. (2015) assessed the land-use changes driven by river dynamics in the flood affected areas of Upper Brahmaputra plains using Remote Sensing and GIS techniques. The effect of two major tributaries of Brahmaputra, i.e., Gai and Simen, were documented. The planform changes were analyzed using the topographic maps and Landsat data. The bankline

migration was quantified and the rate of erosion and deposition were calculated. The land use land cover mapping was done using ERDAS IMAGINE and the changes over the period of consideration were assessed. These changes showed an increase in the settlement and decrease in grass lands. Also, agricultural lands were found to get affected by the erosion-deposition processes of the river.

Kumar et al. (2015) delineated the catchment and carried out the morphometric analysis using GIS technique. The study dealt with the integrated watershed management of Baliya micro watersheds, located in the Udaipur district of Rajasthan, India. The low value of the bifurcation ratio of 4.19 revealed that the drainage pattern had not been distorted by structural disturbance. The high value of the elongation ratio (0.68) compared to the circulatory ratio (0.27) indicated an elongated shape of the watershed. The high value of drainage density (5.39 km/km^2) and stream frequency (12.32) showed that the region had impermeable subsoil material under poor vegetative cover with a low relief factor. The relief ratio and relative relief were found to be 0.041 and 0.99% respectively.

Biswas et al. (2014) carried out the analysis to understand the drainage basin dynamics and their usefulness in watershed prioritisation and management in terms of soil erosion studies and groundwater potential assessment and flood hazard risk reduction in mountainous rivers. Morphometric analysis of a Himalayan River (Supin River) basin has been taken as a case study. The entire Supin River basin has been subdivided into 27 sub-watersheds and 36 morphometric parameters have been calculated under four broad categories, i.e., drainage network, basin geometry, drainage texture, and relief characteristics. The various morphometric parameters have been correlated with each other to understand their underlying relationship and control over the basin hydro-geomorphology.

Bali et al. (2012) performed geomorphologic analysis on the Himalayan Glacio-fluvial basin, India. The geomorphologic parameters including the stream frequency, drainage density, drainage texture etc. indicated the presence of unconsolidated, unstratified and highly pervious glacial overburden material which aids the infiltration of rainwater and snowmelt into the soil. The form factor values calculated for various sub-basins indicated that the sub-basins with high value of form factors are more prone to flash floods. Also, the irregularities in the geomorphologic parameters explained the presence of tectonically active regions in the study area.

Ozdemir and Bird (2009) have evaluated two drainage networks derived from two different sources to determine the influence of sub-basins to flooding on the main channel in the Havran River basin. Drainage networks for the sub-basins were derived from both topographic maps scaled 1:25.000 and a 10-m resolution digital elevation model (DEM) using geographic information systems (GIS). Morphometric parameters were applied to the two types of drainage networks at sub-basin levels. These parameters were used to assess the influence of the sub-basins on the main channel with respect to flooding.

Boix-Fayos et al. (2007) in their study explained that catchment-scale land-use changes and erosion-control works have geomorphic consequences as can be seen in the morphological evolution of river channels. An analysis of the consequences of check dams and reforestation works that took place in the 1970s was conducted on the channel morphology in the Rogativa catchment (53 km^2) in SE Spain. A land-use change detection analysis of the catchment between 1956, 1981, and 1997 was performed. River channel changes were mapped between 1956 and 1997. Furthermore, morphological field mapping of river reaches, location of all check dams, and characterization of the areas upstream and downstream of them were carried out. Sediment sampling along 10.5 km of the channel and analysis of time series precipitation data were performed.

Chopra et al. (2005) studied the two sub-watershed in Gurdaspur district using Remote Sensing and GIS techniques. They observed that both the sub-watersheds are showing dendritic to sub-dendritic drainage pattern with moderate drainage texture. A strong control on the drainage was observed by high bifurcation ratio. The deviation from straight line indicating regional upliftment, was observed by plotting graphs between logarithms of number of stream vs. stream order. The area was underlined by impermeable sub-surface material which was due to low drainage density value. The sub-watersheds having elongated shape were observed by determining circulatory and elongation ratio.

Clark and Wilcock (2000) examined river channel response to pervasive land-use changes in three watersheds in northeastern Puerto Rico. They observed that, in the past 50 years, land use had shifted to forest, suburban, and industrial use, sharply reducing sediment supply and producing a smaller decrease in water supply. These changes in water and sediment supply are likely to have had a significant impact on river channels in the region, although little historical information is available to directly evaluate the channel response. They explained that

downstream trends in channel geometry and channel sedimentation may be due to an incomplete removal of excess coarse sediment supplied to the river during the period of intensive agriculture.

Strahler (1952) named the headwater streams as the first order streams. Two first order streams joins to give a second order stream. It revolves around the assumption that two streams of the same order that falls in one basin carry approximately equal amount of discharge. This theory is most commonly used while assigning order to streams.

Horton (1945) initially started with the quantitative analysis of stream network which facilitates the comparison between drainage basins to various aspects of the drainage patterns and define the properties of the drainage basin. He explained that main stream denoted by the same order, all the way from its mouth to headwaters is assigned with highest order and order changes at every junction, whereas, lowest order is assigned to the fingertip tributaries. This convention however, possessed certain amount of subjectivity.

2.5 FLOOD FREQUENCY ANALYSIS AND TREND ANALYSIS OF HYDROLOGIC AND CLIMATIC DATA

Goyal (2014) presented his work on statistical analysis of long term trends in rainfall during 1901-2002 in the state of Assam, India. For analysing the trends, Sen's slope estimator test and Mann-Kendall test were used. Precipitation data for 21 stations were collected and analysed for both annual and seasonal variations.

Timbadiya et al. (2013) presented the trend analysis of observed annual peak flow time series data at four stream gauging stations in the Tapi Basin. Innovative trend analysis, recently proposed by Şen (2012), and Mann Kendall test were used to ascertain the trend in extreme annual flow (flood) at aforesaid gauging stations in the Tapi Basin. Also, the time series of extreme flow data were checked for their serial correlation and, subsequently, flood frequency analysis was undertaken to obtain floods of different return periods. The fitted probability distributions were also used to predict extreme flow into the Ukai Reservoir on the basis of information from upstream gauging stations. The methodology has also been used to predict runoff into the reservoir from the ungauged catchments.

Hussain and Pasha (2009) carried out an *L*-moment based regional frequency analysis on seven sites of Punjab, Pakistan. Discordancy measure was calculated to screen the data, heterogeneity measure was obtained by conducting simulation experiments using the 4-parameter Kappa distribution and the best distribution was chosen using the *L*-moment ratio diagram and the Z^{DIST} statistics. Based on these, three distributions; GNO, GPA and GEV were identified as the suitable candidates for regional distribution. Accuracy measures for the estimated regional growth curves and quantiles were calculated for the three candidate distributions, using Monte Carlo simulations. Simulations study showed that GNO distribution is the robust distribution with GPA as suitable alternative but GEV is not an appropriate distribution for the study area.

Castellarin et al. (2008) studied the effect of cross correlation among sites in regional flood frequency analysis and assessed the impact of the same on statistical tests. They observed that even though generally ignored, cross correlation among flood sequences can reduce the power of statistical homogeneity tests significantly. The effectiveness of the well-known Hosking and Wallis' H-measure when intersite dependence is taken into account was analysed through Monte Carlo experiments. A theoretical correction was also proposed for the test that can account for the impact of inter-site cross correlation of floods.

Viglione et al. (2007) made a comparison of various homogeneity tests for regional frequency analysis. The classical homogeneity tests based on L-moments were compared with two rank based tests, the k-sample Anderson Darling Test and Durbin and Knott test. The performance of these tests were assessed by a series of Monte Carlo experiments and it was concluded that the homogeneity tests based on L-moments are more reliable when the sample data are slightly skewed whereas when the data is heavily skewed, rank based tests comes in handy.

Jingyi and Hall (2004) performed regional flood frequency analysis on 86 sites in the Gan River Basin, China and developed regionalised relationship to estimate flood magnitudes for ungauged and poorly gauged catchments. Several clustering techniques like Wards method, fuzzy c-means method, residuals method etc. were done and finally the Kohonen Neural network based clustering technique which could both delineate the regions as well as assign the sites to the regions was found to be best suited for their study. Regional at-site growth curves were derived using the L-moment algorithm as well as the fuzzy c-mean algorithm and it was found that the latter performed well when there is considerable contrast between the

growth curves of different sites in the region. Regional flood relationships were developed for ungauged catchments using the index-flood method as well as ANN technique. ANN technique gave superior results compared to the index-flood method.

Kumar et al. (2003) developed regional flood frequency relationship for Middle Ganga Plains Subzone 1(f) of India using a GEV index-flood procedure incorporating the method of L-moments. Screening of the data was carried out using Discordancy measure and a homogenous region containing 8 sites were defined. The L-moment ratio diagram and Z^{DIST} statistic showed that GEV was the best fit distribution of the region. Based on these results they developed regional frequency relationship for gauged as well as ungauged catchments. Also a relationship between the mean annual peak flood and the catchment area was developed. The estimation model was finally verified by developing test catchments and model catchments and was found to perform well for small, medium and large catchments in the basin.

Castellarin et al. (2001) evaluated the relative performance of four hydrological similarity measures which are used to form homogenous regions for regional frequency analysis in Northern-Central Italy. These measures constitute the seasonality indexes that reflect the timing of extreme events and the catchment characteristics which includes the frequency distribution of the rainfall extremes and the extent of impervious portion of the catchment. A hierarchical clustering scheme is adopted in order to delineate homogenous regions. The performance of the similarity measures is quantified using Monte Carlo experiment. The results showed that for the study area, similarity measures based on seasonality indices was the most effective whereas for ungauged catchments, a similarity measure incorporating both rainfall statistics and soil permeability was the best.

Kjeldsen et al. (2001) performed regional flood frequency analysis on the annual maximum series of flood flows in the KwaZulu-Natal province, South Africa, using the index-flood method. The series was developed from relatively unregulated rivers. The study area was divided into two homogenous sub-regions by cluster analysis taking into consideration the monthly rainfall concentration. The goodness of fit test carried out showed that the Generalized Normal Distribution (GNO), Pearson Type-III distribution and the Generalized Pareto Distribution were suitable for Region 2. Region 1, due to the presence of few flood events of extreme magnitude, was found to ill-fit all the distributions. Probability plots were made using

suitable plotting position formulae for revealing the tendencies such as regional bias in the estimation of extreme events.

Adamowski (2000) performed regional frequency analysis on the annual maximum and partial duration flood data in the Provinces of Ontario and Quebec, Canada. Based on the density function shapes (unimodal and bimodal) the region was subdivided into nine homogenous regions. The analyses revealed the presence of unimodality and bimodality in the flood data which pointed to the limitations in the parametric method involved in flood estimation for the method assumes that all the flood events comes from a unimodal distribution. L-moment analysis revealed that even though the series is not unimodal, separate rainfall and snowmelt PD series extracted from the same data set could each be described by unimodal distributions. L-moment tests confirmed that separate rainfall and snowmelt PD series statistics are homogeneous but the overall series is heterogeneous. A regional relationship is developed using nonparametric analysis on the AM and PD flood series.

Vogel et al. (1998) constructed L-moment diagrams for annual minimum, average and maximum flows for more than 1400 river basins in USA. The goodness-of-fit studies revealed that three distributions, LN3, GEV and LP3 were providing good approximations for annual maximum flows. They also observed that the two parameter distributions like Gumbel distribution gave not so good results in the basins. The study also revealed that for annual minimum and average flows in US can be best represented using P3 distribution. Also, they suggest that LP3 distribution is a very flexible one and can fit almost all the river basins considered in the study. The paper winds up pointing out that it is high time that frequency analysis is conducted on annual minimum as well as average flows.

Burn (1989) presented a statistical technique for delineating groups of stations for regional flood frequency analysis. A heuristic approach which involves k-means clustering was adopted to divide a large area into homogenous sub-regions. The selection of appropriate number of clusters was done with the help of measures of the reduction in within group variability associated with increasing the number of groups. A basin similarity measure coupled with regional homogeneity measure was used to evaluate the station partitioning obtained from the clustering algorithm. The methodology was adopted for flood frequency analysis of rivers in southern Manitoba, Canada, and the results showed that the identified group of stations can be considered sufficiently homogenous to effect an efficient spatial data transfer.

CHAPTER 3
STUDY REACH

3.1 TAPI RIVER

The Tapi River originates near Multai in Betul district at an elevation of 752m above mean sea Level (MSL). The Tapi River joins Arabian Sea in the Gulf of Cambay after flowing past the Surat city. The river receives tidal influence for a length of about 25 km upstream from the river mouth in the sea. The total length of this west flowing river from its origin to its out fall into the sea is 724 km. For the first 282 km the river flows in Madhya Pradesh, out of which 54 km forms the common boundary with Maharashtra State. It flows for 228 km in Maharashtra before entering the Gujarat State. Traversing a length of 214 km in Gujarat, the Tapi River joins the Arabian Sea in the Gulf of Cambay after flowing past the Surat city. The Tapi River is joined by several tributaries on both the banks. There are fourteen major tributaries, each having a length more than 50 km. On the right bank, four tributaries, namely, the Vaki, Gomai, Arunavati and Aner join the Tapi River. On the left bank, ten important tributaries, namely, the Nesu, Amravati, Buray, Panjhra, Bori, Girna, Waghur, Purna, Mona and Sipna drain into the main channel (Fig 3.1). The drainage system on the left bank of the Tapi river is, therefore, more extensive as compared to the right bank area. The Purna and the Girna, the two important left bank tributaries together account for nearly 45 percent of the total catchment area of the Tapi River. The Purna is the principal tributary of the Tapi River originating in Betul district in Gawilgarh hills of the Satpura range, mostly drains the three districts Amravati, Akola and Buldhana of Vidharbha Region. The Girna, another major tributary, rises in the Western Ghats and drains Nasik and Jalgaon districts of Maharashtra. The Multai, Dharni, Nepanagar, Burhanpur, Sindhkheda, Talode, Mandvi and Surat are some of the important towns that lie along the banks of Tapi River.

3.2 MAJOR TRIBUTARIES OF TAPI RIVER

Some of the important rivers of Tapi basin are described below (Jain et al. 2007):

i) **The Purna**: The Purna is one of the principal tributaries of the Tapi river. It is the only river in the upper basin, which has a perennial flow. Raising in the Gawilgarh hills at an elevation of 900m, the Purna flows in a south westerly direction for about 60 km. through hills and forests, and enters into the Purna plains. The Purna drains a total area of 18,929 km^2.

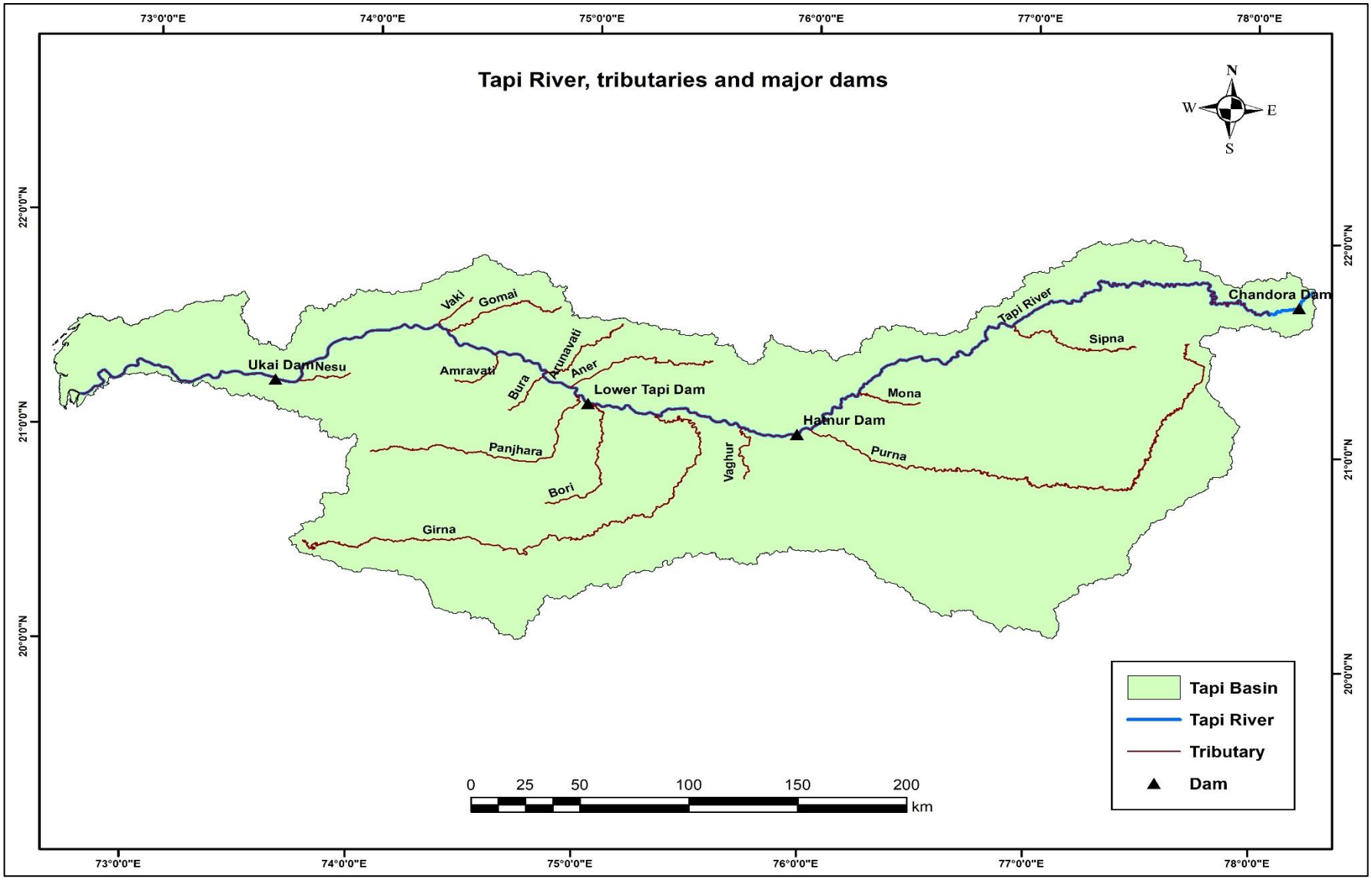


Fig 3.1 Tapi River, tributaries and major dams

ii) **The Girna:** The Girna rises in Western Ghats and flows in an easterly direction up to Jamda and then turns north. It takes a westerly turn at Nandra to join the Tapi from the left near Nanded. The river flows for a total distance of 260 km and drains a total area of 10,061 km^2, which is nearly one-sixth of the total catchment of Tapi river.

iii) **The Panjhra:** The Panjhra rises near Pimpalner from the crest of the Sahyadri hills and flows easterly for about 99 km, then takes a turn to the north and join the Tapi from the left, south of Thalner. The river flows for a total distance of 138 km and drains an area of 3,257 km^2.

iv) **The Vaghur:** The Vaghur rises from the Ajanta hills, flows northerly for 96 km to join Tapi on the left. The Vaghur drains a total area of 2,592 km^2.

v) **The Bori:** The Bori rises in the Malegaon sub-division of Nasik district at North and flows first in the easterly direction and then in a northerly direction to join the Tapi from the left, east of Betavad. The Bori flows for a total length of 130 km and drains an area of 2,580 km^2.

vi) **The Aner:** The Aner is the longest right bank tributary of the Tapi River; originate from the southern slope of the Satpura hills and flows generally in south-westerly direction for a total length of 74 km, to join the Tapi River from the right, south of Hol. The river drains a total area of 1,702 km^2.

vii) **The Bura:** The Bura rises in the Satmala hills and flows generally in easterly direction for a total distance of 64 km. and then turns north-east and flows for another 23 km. to join the Tapi from the left, north-east of Sindhkheda. The river drains a total area of 1,419 km^2.

viii) **The Gomai:** The Gomai also rises from the Southern slopes of the Satpura hills, and flows in a generally south-westerly direction for a length of 72 km to join the Tapi from the right bank near village Prakasha. It drains a total area of 1,148 km^2.

ix) **The Arunavati:** The Arunavati It originates and flows from the Sangvi village and merges into the Tapi river from the right bank near Uparpind village in Shirpur tehsil. The river flows mostly in monsoon period and has a length of 61km.

3.3 WATER RESOURCES PROJECTS ALONG THE TAPI RIVER

Water resources projects are broadly categorized into irrigation projects and hydroelectric projects. Upper Tapi (Hatnur) Irrigation Project, Ukai - Kakrapar Irrigation Project and Ukai Hydroelectric Project are the major water resources projects that fall along the Tapi River.

Also, the construction of Lower Tapi Dam (Padalse Dam) is in progress. The details are as given below:

i) **Hatnur Dam** (Maharashtra) - This is the first stage of Upper Tapi Project. The dam is constructed across Tapi River near Bhusaval City in Jalgaon District of Maharashtra. The construction of the dam was completed in 1982, and is maintained by Water Resources Department (WRD), Government of Maharashtra (GOM). The dam has a length of 2580 m and a maximum height of 25.5 m above the foundation. The spillway type is Ogee spillway of length 604.75 m, with 41 radial gates of size 12 m × 6.5 m. The dam has been constructed with a major purpose of irrigating the nearby areas. It is having a live storage capacity of 255 MCM & Gross Storage capacity of 388.0 MCM to irrigate 3,78,384 hectares of land in Raver, Yawal and Chopda Taluka of Jalgaon district by a right bank canal of 95 km length. The dam falls in Seismic Zone- III and the design flood is 26145 m^3/s.

ii) **Ukai Dam** (Gujarat) - This is stage - II of the multipurpose Ukai Project. It consists of 4928 m long and 81 m high composite earth - cum - masonry dam across the Tapi River near Ukai village in Surat district of Gujarat State. The Ukai Dam, constructed across the Tapi River, is the largest reservoir in Gujarat. It is also known as Vallabh Sagar. Constructed in 1972, the dam is meant for irrigation, power generation and flood control. Having a catchment area of about 62,255 km^2 and a water spread of about 52,000 hectares, its capacity is almost same as that of the Bhakra Nangal Dam. The site is located 94 km from Surat. The gross storage capacity and Live Storage Capacity are 8511.0 MCM and 7092.0 MCM respectively. The storage capacity of Ukai dam is almost 46% of the total capacity of all the other existing dams in Gujarat if put together. Thus, it can be concluded that the rest of the dams have as little as 0.1% average storage capacity. During the last 40 years, the actual irrigation potential is attained through all the major and medium water resources projects in the State, which comprises only 14 million hectares. The dam is an earth-cum-masonry dam. Its embankment wall is 4,927 m long. Its earth dam is 80.77 meters high, whereas the masonry dam is 68.68 meters high. The dam's left bank canal feeds water to an area of 1,522 km^2 and its right canal provides water to 2,275 km^2 of land.

iii) **Ukai Hydroelectric Project** is associated with two power houses, i.e., Ukai power house & Ukai LBC power house. Ukai power House has four operational turbines with a total installed capacity of 300 MW, while Ukai LBC Powerhouse has 2

operational turbines with total installed capacity of 5 MW. All the above units were made by Bharat Heavy Electricals Ltd. (BHEL). Commissioning dates of units 1 to 4 are: 8 July 1974, 13 December 1974, 22 April 1975 and 4 March 1976. The Minimum draw down level (MDDL) for the powerhouse is 84 m. The turbine is of Kaplan type with a rated speed of 300 rpm. There are four penstocks of 60 m length and internal diameter 6.9 m. The design discharge of each penstock is 188 m^3/s.

iv) **Kakrapar (Maharashtra):** Kakrapar barrage, constructed across Tapi River, is located near Mandvi Village in Surat District of Gujarat. The construction was done during 1952 – 1954 as part of the Kakrapar Barrage Major Irrigation Project. The barrage has a length of 633.5 m, with five number of bays. The average width of Tapi River at the barrage location is 621.18 m. The crest level of the spillway is 160 m, with a High Flood Level (HFL) of 185 m. There are six under sluice gates, three on right bank and three on left bank. The culturable command area of Kakrapar Barrage Major Irrigation Project is 204000 hectares, with an ultimate irrigation potential of 222000 hectares. The project benefits four districts of Gujarat, Navsari, Bharuch, Surat and Valsad. The barrage is situated in seismic zone-III.

v) **Lower Tapi Dam (Padalse Dam):** The Lower Tapi Dam, which is under construction, falls in the city of Amalner in Jalgaon District of Maharashtra. It is an earthen dam, which has a length of 1876.5 m and a maximum height of 29 m above the foundation. The major purpose of the dam is irrigation. The dam, which is to be maintained by Water Resources Department, Maharashtra, would pass a design flood of 50881 m^3/s and can carry a a total volume of 303.72 TCM. It is also proposed to have an ogee shaped spillway (crest level = 139.24 m) with 23 radial spillway gates of size 18.30 m × 16.76 m.

4.1 TAPI RIVER BASIN

The Tapi basin, situated in the northern part of the Deccan Plateau, falls in longitudes of 72˚38' E to 78˚18' E and latitudes of 20˚5' N to 22˚3' N (Fig 4.1). The basin extends over states of Madhya Pradesh, Maharashtra and Gujarat having an area of 65,145 km^2 out of which nearly 80% area lies in Maharashtra state. Situated in the Deccan plateau, the Satpura range forms its northern boundary whereas the Ajanta and Satmala hills form its southern extremity. Mahadeo hills form its eastern boundary. The basin finds its outlet in the Arabian Sea in the west. The entire Tapi basin can be divided in three sub-basins: Upper Tapi basin up to Hatnur, confluence of Purna with the main Tapi (29,430 km^2), Middle Tapi basin from Hatnur up to the Ukai Dam (32,097 km^2), and Lower Tapi basin from the Ukai Dam up to the sea (3,618 km^2). The average annual rainfall for upper, middle, and lower Tapi basins are 935.55 mm, 631.5 mm, and 1,042.33 mm respectively.

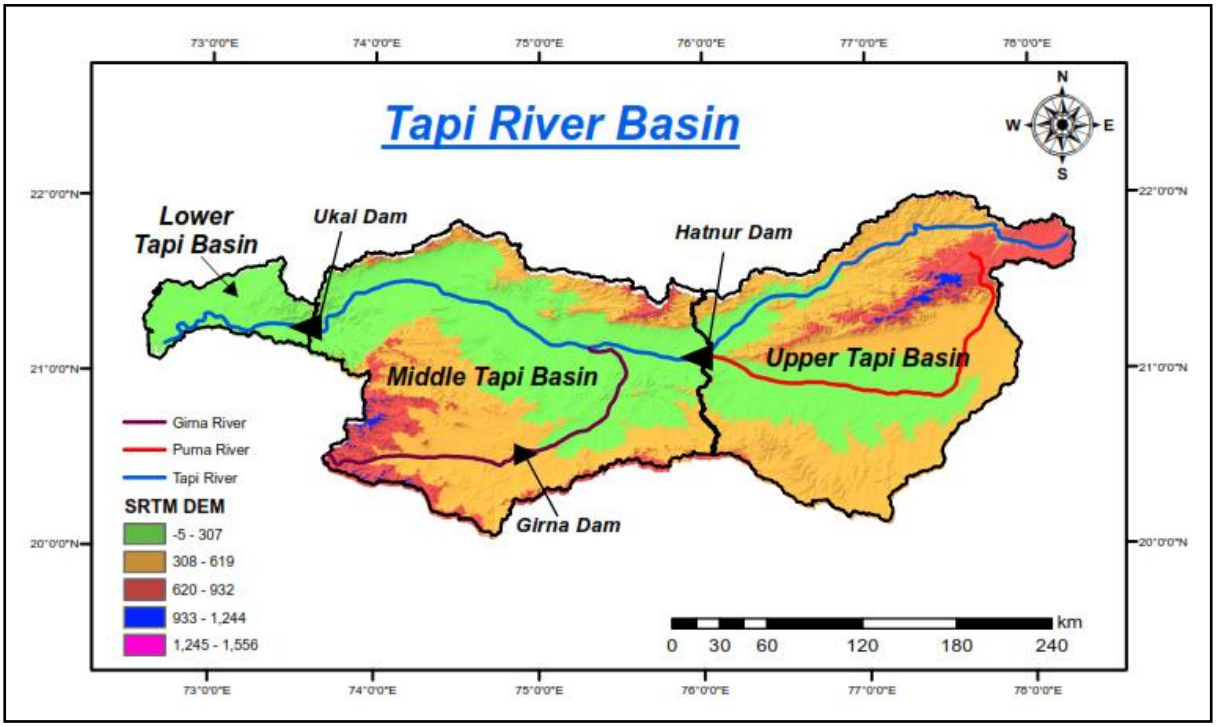


Fig 4.1 Index map of Tapi river basin

Physiographically, the area is a basaltic landscape with major physiographic units of plateau lands, escarpments, hills, piedmont plains, colluvium-alluvial plains and valley plains. Bounded on the three sides by the hill ranges, the river Tapi, along with its tributaries, flows

over the plains of Vidharbha, Khandesh and Gujarat. The major part of basin is covered with agriculture accounting to 66.19% of the total area and 2.99% of the basin is covered by water bodies. The forest cover is about 25% of the area in the basin. About 90% of total rainfall is received during the monsoon months.

The main river in the Tapi basin is the river Tapi, which originates from Tapi Kund at Naveen Mandir situated near Multai of Betul District in Madhya Pradesh. Several tributaries join the Tapi river on both banks. There are fourteen major tributaries having a length more than 50 km. On the right bank, four tributaries, namely, the Vaki, Gomai, Arunavati and Aner join the Tapi river. On the left bank, ten important tributaries namely, the Nesu, Amravati, Buray, Panjhra, Bori, Girna, Waghur, Purna, Mona and Sipna drain into the main channel (The details are discussed in Chapter 3, Section 3.2). The river drainage map showing the entire river network in the basin (including major and minor tributaries), sub-basins and the stream order of each river is shown in Fig 4.2. The Tapi river starts as young river of order 1 and attains its full strength and emerges out as fifth order stream in its middle reaches.

4.2 FLOOD PROTECTION MEASURES

Owing to frequent flooding in the Lower Tapi river Reaches, particularly in the downstream of Ukai Dam, several initiatives were undertaken for controlling the river flood by means of constructing levees on both banks of river. Starting from Kholvad Bridge in Ambola, Gujarat, 65 left bank levees and 53 right bank levees were constructed upto Rundh Magdalla in Surat, Gujarat (Fig 4.3).

4.3 DAMS, BARRAGES/WEIRS AND WATER RESOURCES PROJECTS

Water resources structures are man-made structures to store the water for hydropower, irrigation, drinking water supply etc. The major man-made hydraulic structures include dams, weirs and barrages. The layout of dams along with the tables showing their Gross Storage Capacity (GSC) in Million Cubic Meters (MCM), weirs/barrages and water resources projects that fall within 10×10 km buffer zone of Tapi basin are shown in Fig 4.4. The basin buffer zone consists of twenty-seven dams, five barrages, one weir and three water resources projects as shown in Fig 4.4. Majority of the dams are used for irrigation purpose. The highest and longest dam in the buffer zone is Ukai Dam having the height and length of 81m and 4927 m respectively.

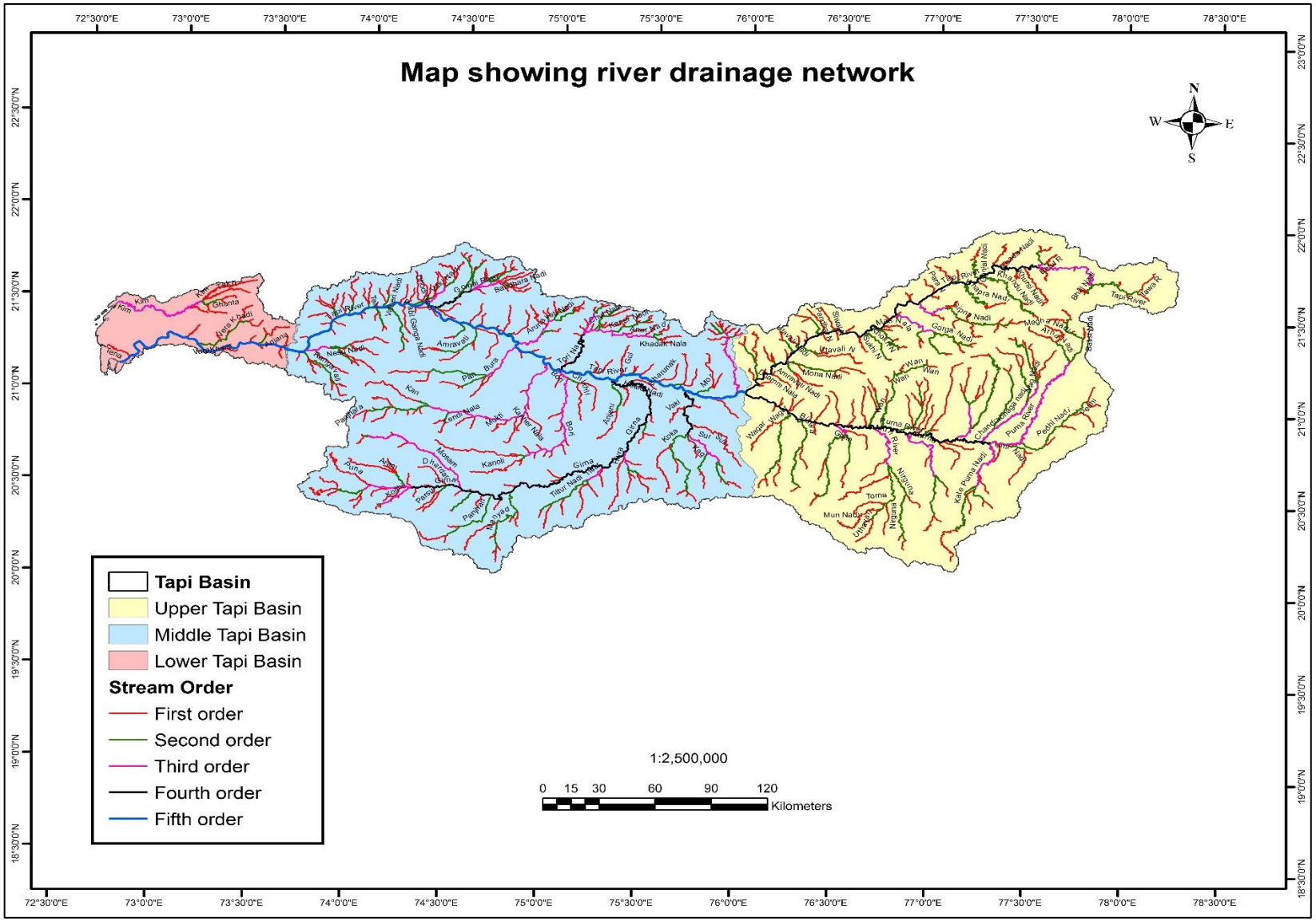


Fig 4.2 River drainage map

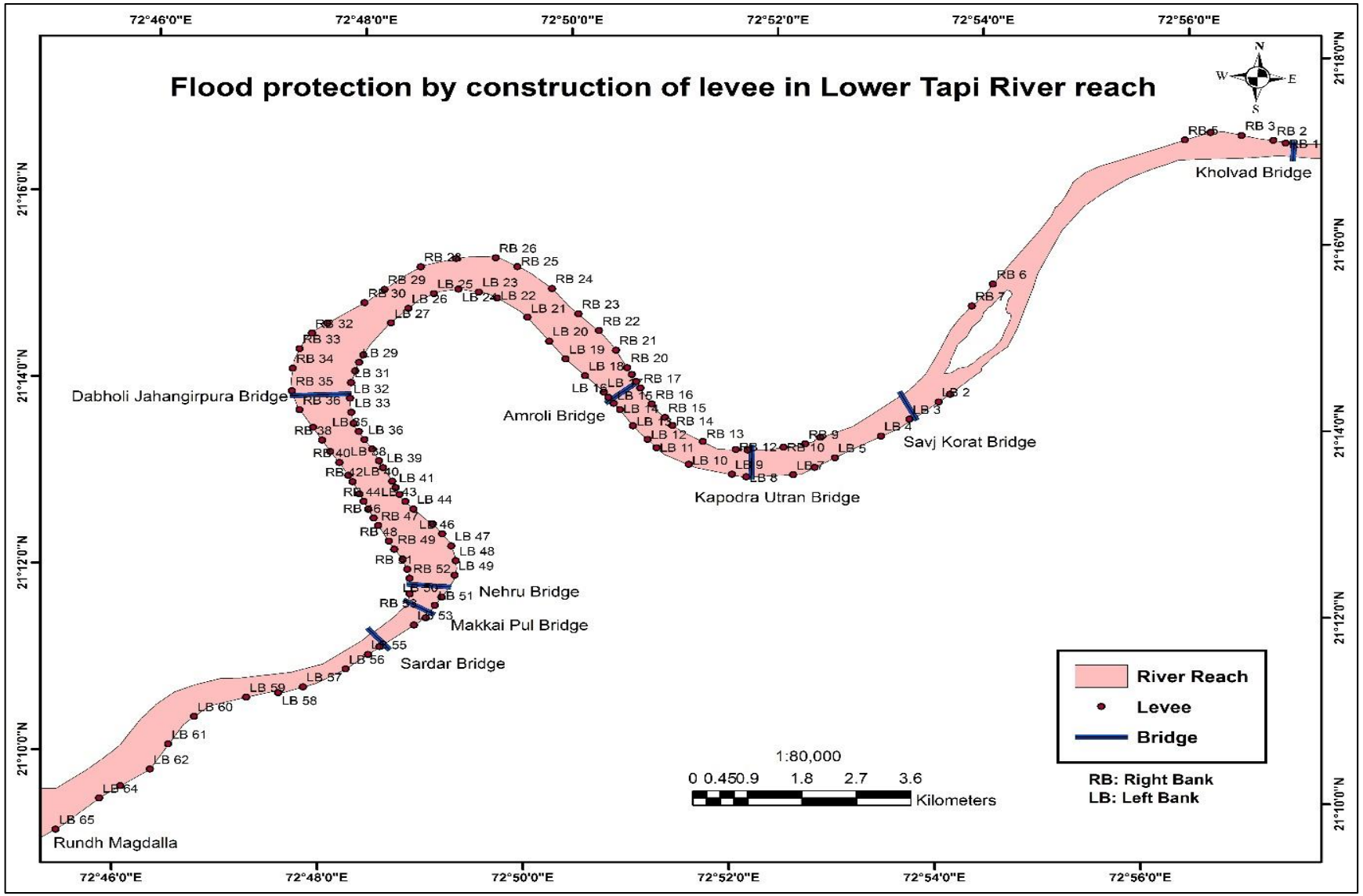
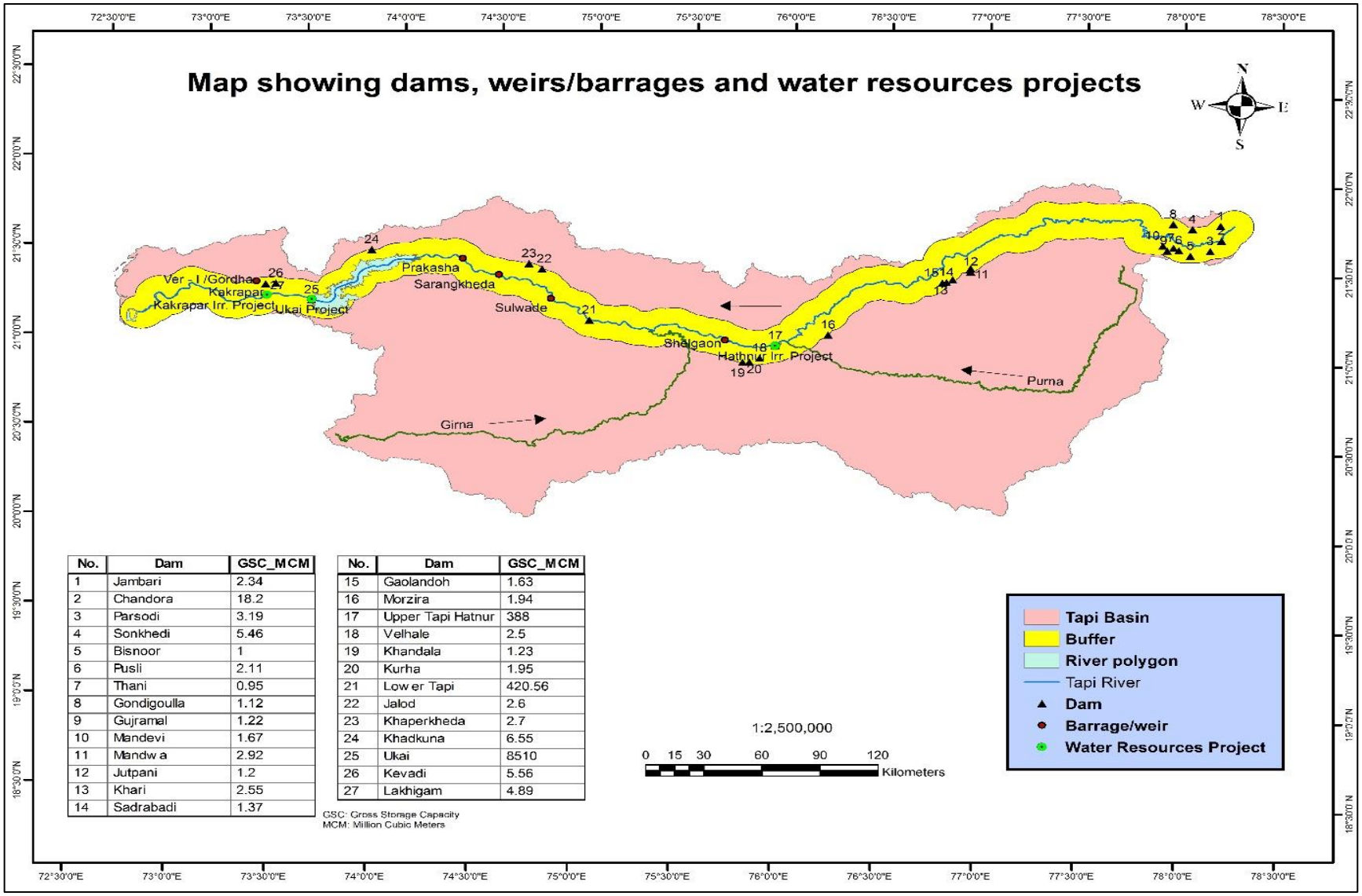


Fig 4.3 Levee constructed in Lower Tapi river reach (Source: Surat Irrigation Circle (SIC))



No.	Dam	GSC_MCM
1	Jambari	2.34
2	Chandora	18.2
3	Parsodi	3.19
4	Sonkhedi	5.46
5	Bisnoor	1
6	Pusli	2.11
7	Thani	0.95
8	Gondigoulla	1.12
9	Gujramal	1.22
10	Mandevi	1.67
11	Mandwa	2.92
12	Jutpani	1.2
13	Khari	2.55
14	Sadrabadi	1.37

No.	Dam	GSC_MCM
15	Gaolandoh	1.63
16	Morzira	1.94
17	Upper Tapi Hatnur	388
18	Velhale	2.5
19	Khandala	1.23
20	Kurha	1.95
21	Lower Tapi	420.56
22	Jalod	2.6
23	Khaperkheda	2.7
24	Khadkuna	6.55
25	Ukai	8510
26	Kevadi	5.56
27	Lakhigam	4.89

GSC: Gross Storage Capacity
MCM: Million Cubic Meters

Fig 4.4 Dams, weirs/barrages and water resources projects in the 10 km × 10 km buffer zone of Tapi basin

Out of the five barrages, Shelgaon barrage is the highest and the longest barrage in the buffer zone having length 1134.65m and height 35.04 m. The details of dams and weirs/barrages that fall within the buffer zone are appended in Tables 4.1-4.2. The details of existing major water resources projects have already been discussed in Section 3.3 of Chapter 3.

Table 4.1 Details of dams that fall within the buffer zone of Tapi basin

Sl No.	Dam	Year of completion	GSC (MCM)	river	Type	Length (m)	Height above foundation (m)
1	Jambari	1977	2.34	Local	*TE	472	14.30
2	Chandora	1986	18.20	Tapti	*TE + PG	2043	17.26
3	Parsodi	1978	3.19	Local Nallah	TE	1125	15.69
4	Sonkhedi	1984	5.46	Hatodoh Nallah	TE	1116	16.50
5	Bisnoor	1976	1.00	Local	TE	510	12.66
6	Pusli	1976	2.11	Local	TE	671	13.50
7	Thani	1979	0.95	Local	TE	690	14.48
8	Gondigoulla	1982	1.12	Local	TE	629	15.00
9	Gujramal	1982	1.22	Local	TE	701	10.44
10	Mandevi	1999	1.67	Local	TE	645	15.05
11	Mandwa	1990	2.92	Shankambari	TE	304	15.90
12	Jutpani	1988	1.20	Local Nallah	TE	715	12.00
13	Khari	1968	2.55	Local Nallah	TE	528	19.45
14	Sadrabadi	1973	1.37	Local Nallah	TE	491	17.52
15	Gaolandoh	1974	1.63	Local Nallah	TE	445	17.60
16	Morzira	1981	1.94	Local	TE	770	15.55
17	Upper Tapi Hatnur	1982	388	Tapi	TE	2580	25.50
18	Velhale	1955	2.50	Datapadi nalla	TE	446	16.24
19	Khandala	1978	1.23	Local Nallah	TE	290	12.10
20	Kurha	1980	1.95	Local Nallah	TE	1020	10.55
21	Lower Tapi	Ongoing	420.56	Tapi	TE	1877	29.00
22	Jalod	1998	2.60	Local Nallah	TE	1077	22.73
23	Khaperkheda	1976	2.70	Kasari	TE	495	18.30
24	Khadkuna	1981	6.55	Kangali	TE	1162	19.53
25	Ukai	1972	8510	Tapi	TE + PG	4927	81.00
26	Kevadi	1977	5.56	Mandavi Khadi	TE	126	18.14
27	Lakhigam	1983	4.89	Dhanki-Khadi	TE	662	17.90

*TE: Earthen Dam; *TE + PG: Gravity/Masonry

4.4 IMPORTANT CITIES/TOWNS, CWC HO STATIONS AND AIRPORTS

The layout of important cities/towns, CWC Hydrological Observation (HO) stations and airports that fall within the Tapi basin buffer zone are shown in Fig 4.5. The relevant details of the cities/towns and CWC HO stations are shown in Tables 4.3-4.4.

Table 4.2 Details of barrages/weirs that fall within the buffer zone of Tapi basin

Sl No.	Barrage/weir	river	Length (m)	Height upto crest (m)
1	Kakrapar Weir	Tapi	633.50	Not available
2	Prakasha Barrage	Tapi	503.00	19.10
3	Sulwade Barrage	Tapi	503.00	13.00
4	Sarangkheda Barrage	Tapi	484.50	11.00
5	Shelgaon Barrage	Tapi	1134.65	35.04
6	Ver - I /Gordha Weir	Ver	158.00	Not available

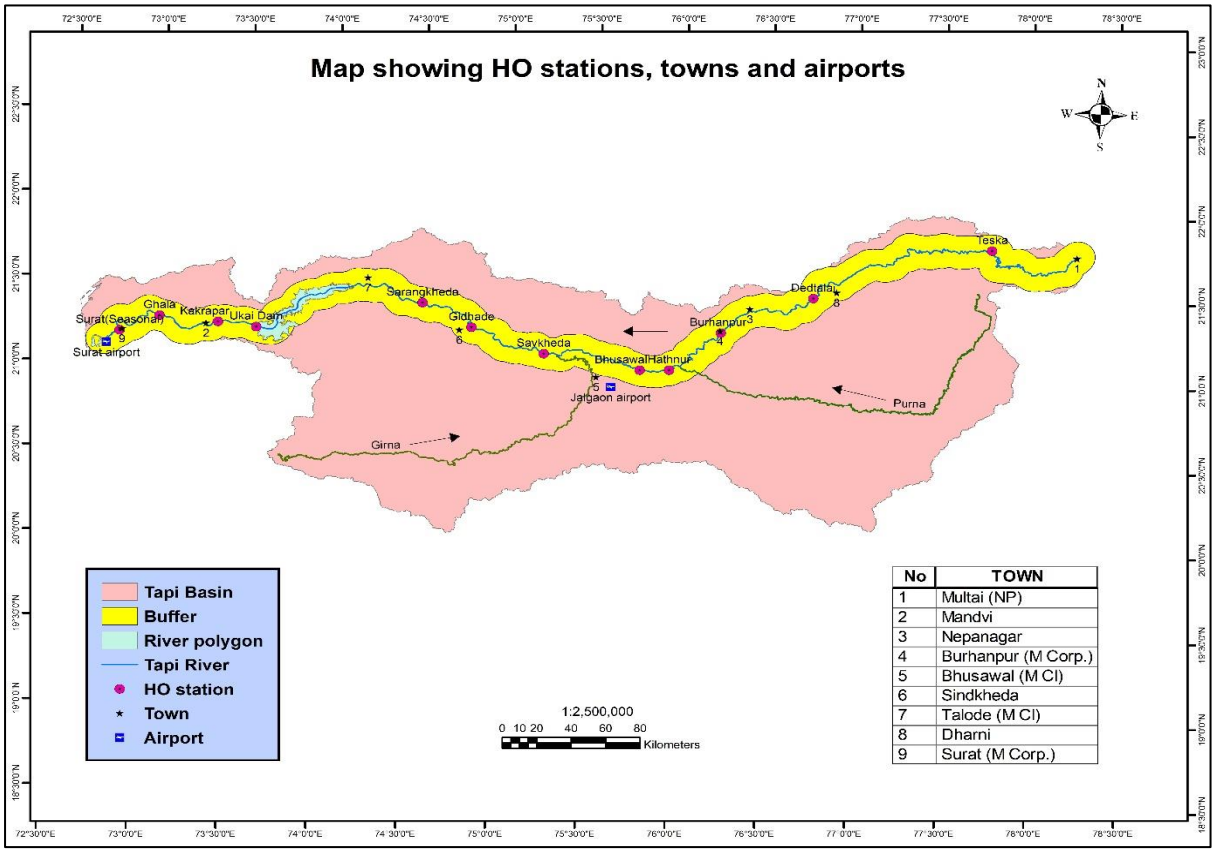


Fig 4.5 Cities/towns, CWC Hydrological Observation (HO) stations and airports in the buffer zone of Tapi basin

4.5 TOPOGRAPHY OF TAPI BASIN

The Tapi basin has two well-defined physical regions, viz. the hilly regions and the plains. The hilly regions cover the Satpura, the Satmala, the Mahadeo, the Ajanta and the Gawilgarh hills with predominant forest cover. The culturable area of the basin is considered as the total of the land under miscellaneous crops and trees, current fallows, other fallows, culturable wasteland and net area sown.

Table 4.3 Details of HO Stations that fall within the buffer zone of Tapi basin

Sl No.	Station	Station Type	Status	River	State	Flood Forecast (*Y/N)	Flood Forecast Type
1	Sarangkheda	*GDSQ	Existing	Tapi	Maharashtra	N	
2	Savkheda	G	Existing	Tapi	Maharashtra	N	
3	Gidhade	GD	Existing	Tapi	Maharashtra	N	
4	Hatnur	G	Existing	Tapi	Maharashtra	Y	Inflow Forecast
5	Kakrapar	G	Closed	Tapi	Gujarat	N	
6	Ukai Dam	G	Existing	Tapi	Gujarat	Y	Inflow Forecast
7	Bhusawal	G	Existing	Tapi	Maharashtra	N	
8	Burhanpur	GDSQ	Existing	Tapi	Madhya Pradesh	N	
9	Dedtalai	G	Existing	Tapi	Madhya Pradesh	N	
10	Ghala	G	Existing	Tapi	Gujarat	N	
11	Surat(Seasonal)	G	Existing	Tapi	Gujarat	Y	Level Forecast
12	Teska	G	Existing	Tapi	Madhya Pradesh	N	

*GDSQ: Gauge, Discharge, Sediment and Water Quality; *Y/N: Yes/No

Table 4.4 Details of towns that fall within the buffer zone of Tapi basin

Sl No.	Town	District	State
1	Multai (NP)	Betul	Madhya Pradesh
2	Mandvi	Kachchh	Gujarat
3	Nepanagar	East Nimar	Madhya Pradesh
4	Burhanpur (M Corp.)	Burhanpur	Madhya Pradesh
5	Bhusawal (M Cl)	Jalgaon	Maharashtra
6	Sindkheda	Dhule	Maharashtra
7	Talode (M Cl)	Nandurbar	Maharashtra
8	Dharni	Amravati	Maharashtra
9	Surat (M Corp.)	Surat	Gujarat

Most of the catchment area is covered in the range of elevation 200-300 m (25.39% of the total area). The catchment area corresponding to highest elevation range (1000-1500 m) is 204.55 km^2 only, see Table 4.5 and Fig 4.6.

4.6 SOIL AND GEOLOGY OF TAPI BASIN

The Tapi is underlain by Cretaceous–Eocene basalts and late Quaternary alluvium. The hilly regions cover the Satpura, the Satmala, the Mahadeo, the Ajanta and the Gawilgarh hills and are well forested. The plains cover the Khandesh plains which are broad and fertile areas suitable for cultivation. The middle and lower parts of the Tapi and Purna basins are thickly

covered with alluvium of the late Pleistocene period. Primarily, the basin consists of black soils. The coastal plains of Gujarat are composed of alluvial clays with a top layer of black soil above. Lands on the right side of the river lying on southern slopes of Satpura hills consist of black soils. The soils in the Tapi basin up to Ukai dam can be broadly classified into three groups: 1) coarse shallow soils, 2) medium black soils, and 3) deep black soils. The area covered by these three groups of soils in the basin is tabulated in Table 4.6.

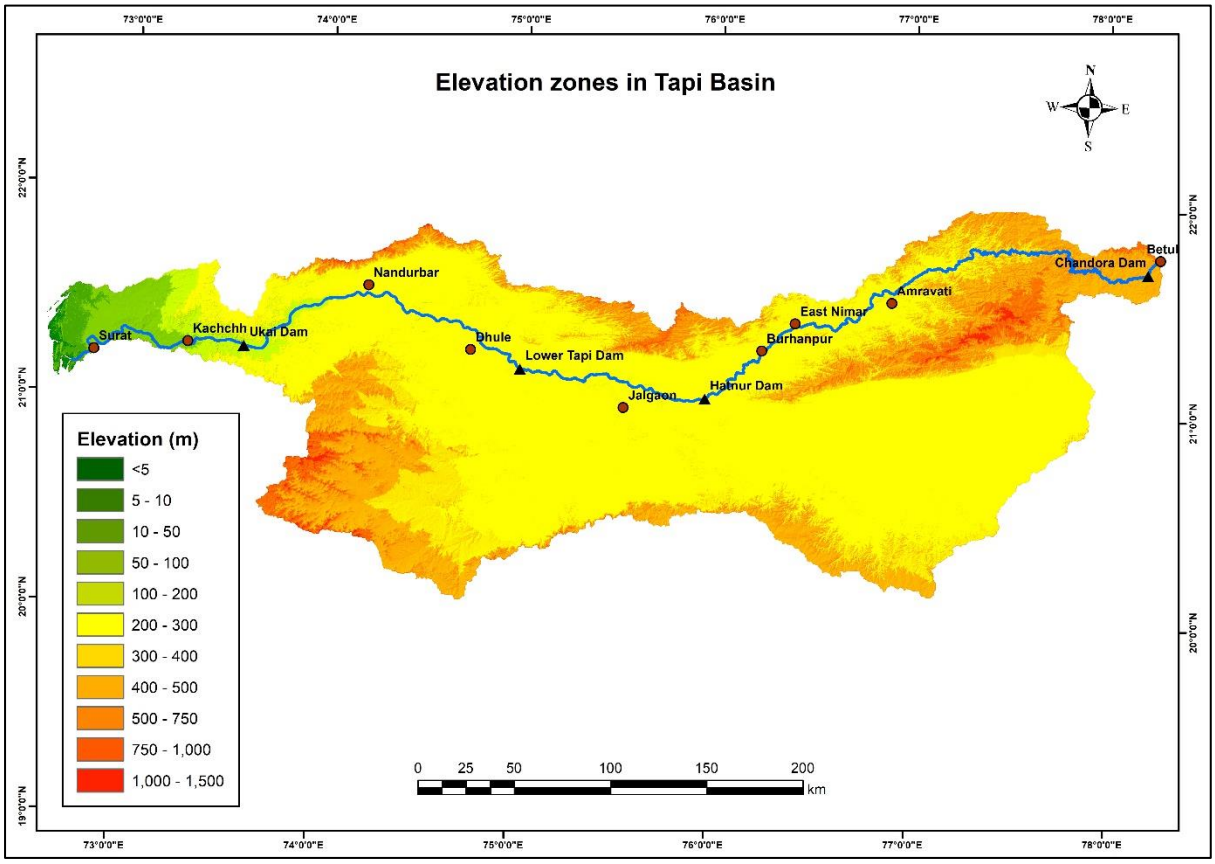


Fig 4.6 Elevation zones in Tapi basin

Table 4.5 Elevation zones in Tapi basin

Sl No.	Elevation (m)	Area (km^2)	% of Total Area
1	<5	333.67	0.51
2	5-10	651.42	1.00
3	10-50	1640.17	2.52
4	50-100	1264.03	1.91
5	100-200	6981.73	10.72
6	200-300	16540.58	25.39
7	300-400	15549.11	23.87
8	400-500	7536.85	11.57
9	500-750	12339.79	18.94
10	750-1000	2123.10	3.26
11	1000-1500	204.55	0.31

Table 4.6 Area covered by various soils in Tapi basin (Jain et al, 2007)

Sr. No.	Type of soil	Districts covered
1	Coarse shallow soil (basaltic Deccan traps, Depth between 25 cm to 50 cm, texture varies from silty loam to clay)	Betul, Khandwa, Khargon, Amrawati, Akola, Buldhana, Jalgaon, Dhule, Aurangabad and Nasik.
2	Medium black soil (Deccan traps, Depth between 50 cm to 1 m, texture varies from silty loam to clay)	Khandwa, Amrawati, Akola, Buldhana, Jalgaon, Dhule and Nasik
3	Deep black soil (Alluvium, Depth between 1 m to 6 m, texture extremely high clay content)	Amravati, Akola, Buldhana, Jalgaon, Dhule, Nasik, Surat and Bharuch.

Further, the Tapi river flows through both bedrock and alluvial reaches. The bedrock channel is in upstream and predominantly in basalt. The channel is bounded by high rocky banks and occasionally by coarse alluvium (on the bed and/or banks). As the channel is deeply carved either in alluvium or bedrock, large floods hardly ever overtop their banks (Kale et al., 1994) and almost all the flows are confined within the channel banks. The channel geometry, therefore, appears to play a role of considerable importance in determining the role of floods. The geology of Tapi basin is discussed in detail in Chapter 7.

CHAPTER 5
INPUT DATA

5.1 PHYSIOGRAPHIC DATA PROCESSING AND ANALYSIS

The Survey of India (SOI) toposheets on 1:50,000 scale along the Tapi River were procured from the Map Archive and Dissemination Centre (MADC), Dehradun in hard format and georeferenced with respect to WGS 1984 datum. Further, aforesaid georeferenced toposheets have been projected with reference to Lambert Conformal Conic (LCC) projection with projection parameters as specified by India-Water Resources Information System (WRIS) as resolved in the minutes of 5th CEMC meeting at CWC, New Delhi. These maps have been used as the base with respect to which the analysis of bank line migration and bank erosion in Tapi River were undertaken in present study. The base years for different river reaches are different (during period 1971-1978) due to the non-availability of SOI Toposheets for a fixed survey year. The details of toposheets with its survey year are tabulated in Table 5.1. Also, the details of the projection parameters as specified by India-WRIS for LCC Projection System are given in Table 5.2.

Table 5.1 SOI toposheets along Tapi River, procured from MADC, SOI, Dehradun

Sl. No.	Sheet No.	Year of survey	Sl. No	Sheet No.	Year of survey
1	55G2	1977-78	17	46K11	1973-74
2	55K5	1976-77	18	46K15	1971-72, 1975-76
3	55C11	1977-78	19	46K16	1971-72, 1975-76
4	55C4	1977-78	20	46K2	1972-73
5	55G1	1978-79	21	46K6	1972-73
6	55C10	1977-78	22	46K7	1972-73
7	55C14	1978-79	23	46K3	1972-79
8	55C3	1977-78	24	46O12	1977-78
9	55C7	1977-78	25	46O16	1977-78
10	55G13	1978-79	26	46O4	1978-79
11	55G14	1977-78	27	46O8	1978-79
12	55G2	1978-79	28	46G4	1971-72
13	55G9	1978-79	29	46G8	1971-72
14	55K1	1976-77	30	46G11	1972-73
15	55K2	1977-78	31	46G12	1971-72
16	46G15	1972-73			

Table 5.2 Projection parameters for LCC Projection System (Source: ArcGIS 10.4©)

Projection	Lambert Conformal Conic
False Easting	4000000
False Northing	4000000
Central Meridian	80
Standard Parallel 1	12.4729444
Standard Parallel 2	35.17280555
Latitude of Origin	24
Linear Unit	Meter

5.2 SATELLITE DATA

Due to non-availability of satellite imagery captured by Indian Space Research Organization (ISRO) satellite mission, the Landsat-3 satellite imagery have been downloaded from the United States Geological Survey (USGS) Earth Explorer website (owned by National Aeronautics and Space Administration (NASA)) for the year 1981 at a resolution of 60 m (Table 5.3). The imagery for the years, 1990, 2000 and 2010 have been procured from National Remote Sensing Centre (NRSC), Hyderabad with resolution 36.25 m, 23.5 m and 23.5 m respectively. The details are appended in Tables 5.4-5.6. The satellite imagery have been orthorectified, georeferenced under WGS 1984 Datum and projected using LCC Projection System as directed by India-WRIS.

Table 5.3 Satellite imagery downloaded for the year 1981
(Source: https://earthexplorer.usgs.gov/)

Mission	**Date**	**Path**	**Row**	**Agency**
Landsat-3	19/10/1981	160	45	NASA
Landsat-3	18/10/1981	159	45	NASA
Landsat-3	18/10/1981	159	46	NASA
Landsat-3	17/10/1981	158	45	NASA
Landsat-3	17/10/1981	158	46	NASA
Landsat-3	25/05/1981	157	45	NASA
Landsat-3	25/05/1981	157	46	NASA
Landsat-3	15/10/1981	156	45	NASA
Landsat-3	15/10/1981	156	46	NASA

Table 5.4 Satellite imagery collected for year 1990

Satellite	Camera	Product	Date	Path	Row	Agency
IRS 1A Scene A1, A2, B1, B2	LISS-II	STPC0027J	25/01/1990	27	53	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	25/01/1990	27	54	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	17/10/1990	28	53	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	17/10/1990	28	54	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	01/12/1990	29	53	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	01/12/1990	29	54	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	28/01/1990	30	53	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	28/01/1990	30	54	NRSC
Scene A1, A2, B1, B2	LISS-II	STPC0027J	29/01/1990	31	53	NRSC

Table 5.5 Satellite imagery collected for year 2000

Satellite	Camera	Product	Date	Path	Row	Agency
IRS 1D Scene 1	LISS-III	STUC00GTJ	20/04/2000	93	57	NRSC
Scene 2	LISS-III	STUC00GTJ	17/04/2000	94	57	NRSC
Scene 3	LISS-III	STUC00GTJ	17/04/2000	94	58	NRSC
Scene 4	LISS-III	STUC00GTJ	14/04/2000	95	57	NRSC
Scene 5	LISS-III	STUC00GTJ	14/04/2000	95	58	NRSC
Scene 6	LISS-III	STUC00GTJ	11/04/2000	96	57	NRSC
Scene 7	LISS-III	STUC00GTJ	21/02/2000	96	58	NRSC
Scene 8	LISS-III	STUC00GTJ	18/02/2000	97	57	NRSC
Scene 9	LISS-III	STUC00GTJ	18/02/2000	97	58	NRSC
Scene 10	LISS-III	STUC00GTJ	11/03/2000	98	57	NRSC
Scene 11	LISS-III	STUC00GTJ	11/03/2000	98	58	NRSC

Table 5.6 Satellite imagery collected for year 2010

Satellite	Camera	Product	Date	Path	Row	Agency
IRS P6 Scene 1	LISS-III	STUC00GTV	07/01/2010	93	57	NRSC
Scene 2	LISS-III	STUC00GTV	18/04/2010	94	57	NRSC
Scene 3	LISS-III	STUC00GTV	18/04/2010	94	58	NRSC
Scene 4	LISS-III	STUC00GTV	19/12/2010	95	57	NRSC
Scene 5	LISS-III	STUC00GTV	19/12/2010	95	58	NRSC
Scene 6	LISS-III	STUC00GTV	04/04/2010	96	57	NRSC
Scene 7	LISS-III	STUC00GTV	04/04/2010	96	58	NRSC
Scene 8	LISS-III	STUC00GTV	16/03/2010	97	57	NRSC
Scene 9	LISS-III	STUC00GTV	16/03/2010	97	58	NRSC
Scene 10	LISS-III	STUC00GTV	21/03/2010	98	57	NRSC
Scene 11	LISS-III	STUC00GTV	21/03/2010	98	58	NRSC

5.3 HYDROLOGIC AND HYDRAULIC DATA

The following data were procured from Tapi division, CWC Surat (Table 5.7). The collected data were used for developing exceedance probability curves at various CWC HO stations as well as developing hydraulic geometry equations which relates the discharge and the average cross-sectional geometry at the respective stations.

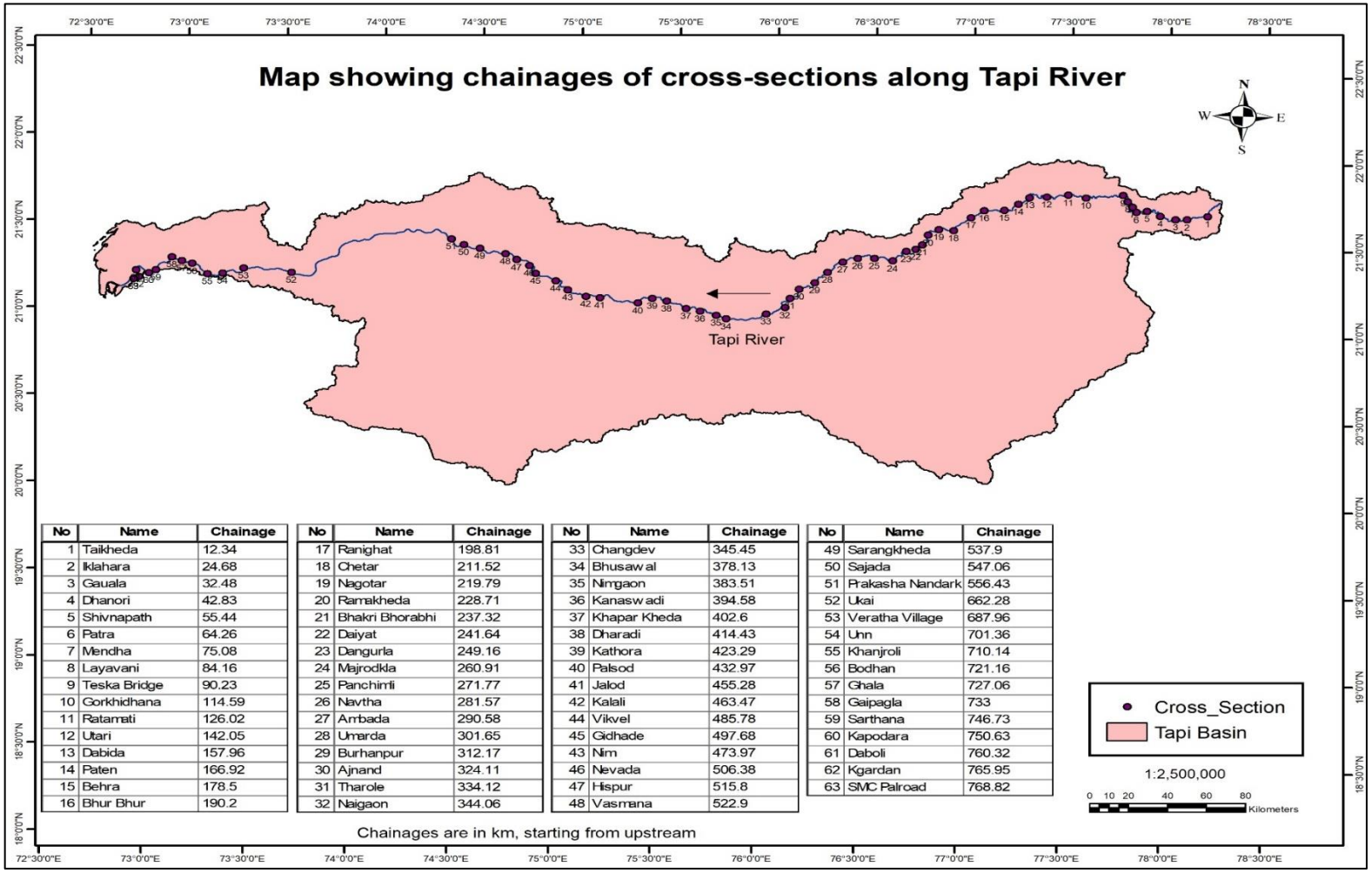
Table 5.7 Hydraulic data collected in present investigation

Sr. No.	Station	Data characteristic	Period of data collection
1	Lakhpuri	Discharge and water level	1972-2004
2	Gopalkheda	Discharge and water level	1980-2013
3	Yerli	Discharge and water level	1972-2013
4	Dedtalai	Discharge and water level	1977-2005
5	Burhanpur	Discharge and water level	1972-2013
6	Teska	Hourly water level	1977-2012
7	Hatnur Dam	Hourly water level	1977-2012
8	Bhusaval	Discharge and water level	1972-2004
9	Sarangkheda	Discharge and water level	1978-2011
10	Savkheda	Discharge and water level	1973-2000
11	Morane	Discharge and water level	1979-2004
12	Malkheda	Water level	1979-2004
13	Gidhade	Discharge Hourly level	1990-2012 1990-2007
14	Savkheda	Discharge water level	1972-2004 1972-2013
15	Girna Dam	Hourly water level	1977-2012
16	Dahigaon	Hourly water level	1977-2012
17	Ukai Dam	Hourly Discharge and Hourly water level during monsoon*	1972-2009
18	Kakrapar	Hourly water level during monsoon	1980-2004
19	Ghala	Hourly water level (up to 2008) and discharge during monsoon	1980-2004
20	Nehru bridge	Hourly water level during monsoon	1980-2008
21	Mandavi	Hourly water level	1977-2012
22	Dapuri	Hourly water level	1977-2012

5.4 CROSS-SECTION DATA

The surveyed cross-sections for Upper, Middle and Lower Tapi rivers were obtained from Central Water Commission (CWC) during the years 2011-2017, at every 10 km chainages (Fig 5.1). Also, the contours of Lower Tapi River at 1m interval for the years 2007 and 2009 were

collected from Surat Municipal Corporation (SMC) and used to generate the Digital Elevation Model (DEM) to evaluate the deposition pattern in Lower Tapi River near Surat City.



No	Name	Chainage
1	Taikheda	12.34
2	Iklahara	24.68
3	Gauala	32.48
4	Dhanori	42.83
5	Shivnapath	55.44
6	Patra	64.26
7	Mendha	75.08
8	Layavani	84.16
9	Teska Bridge	90.23
10	Gorkhidhana	114.59
11	Ratamati	126.02
12	Utari	142.05
13	Dabida	157.96
14	Paten	166.92
15	Behra	178.5
16	Bhur Bhur	190.2

No	Name	Chainage
17	Ranighat	198.81
18	Chetar	211.52
19	Nagotar	219.79
20	Ramakheda	228.71
21	Bhakri Bhorabhi	237.32
22	Daiyat	241.64
23	Dangurla	249.16
24	Majrodkla	260.91
25	Panchimli	271.77
26	Navtha	281.57
27	Amrbada	290.58
28	Umarda	301.65
29	Burhanpur	312.17
30	Ajnand	324.11
31	Tharole	334.12
32	Naigaon	344.06

No	Name	Chainage
33	Changdev	345.45
34	Bhusawal	378.13
35	Nimgaon	383.51
36	Kanaswadi	394.58
37	Khapar Kheda	402.6
38	Dharadi	414.43
39	Kathora	423.29
40	Palsod	432.97
41	Jalod	455.28
42	Kalali	463.47
44	Vikvel	485.78
45	Gidhade	497.68
43	Nim	473.97
46	Nevada	506.38
47	Hispur	515.8
48	Vasmana	522.9

No	Name	Chainage
49	Sarangkheda	537.9
50	Sajada	547.06
51	Prakasha Nandark	556.43
52	Ukai	662.28
53	Veratha Village	687.96
54	Unn	701.36
55	Khanjroli	710.14
56	Bodhan	721.16
57	Ghala	727.06
58	Gaipagla	733
59	Sarthana	746.73
60	Kapodara	750.63
61	Daboli	760.32
62	Kgardan	765.95
63	SMC Palroad	768.82

Fig 5.1 CWC cross-sections along Tapi River

5.5 METEOROLOGICAL DATA

The following data related to rainfall were collected from Tapi division, CWC Surat (Table 5.8).

Table 5.8 Meteorological data collected in present investigation

Sl. No	Station	Year from	Year upto	Frequency	Source
1	Bhusaval	1975	2005	Daily	CWC
2	Burhanpur	1970	2007	Daily	CWC
3	Chikhaldhara	1999	2007	Daily	CWC
4	Dahigaon	1999	2007	Daily	CWC
5	Dapuri	1985	2004	Daily	CWC
6	Dedtalai	1985	2004	Daily	CWC
7	Gidhade	1971	2007	Daily	CWC
8	Girna	1992	2007	Daily	CWC
9	Gopalkheda	1991	2007	Daily	CWC
10	Hatnur	2003	2007	Hourly	CWC
11	Lakhpuri	1982	2007	Daily	CWC
12	Malkheda	1987	2004	Daily	CWC
13	Morane	1991	2007	Daily	CWC
14	Sarangkheda	1987	2007	Daily	CWC
15	Savkheda	1982	2007	Daily	CWC
16	Teska	2001	2007	Daily	CWC
17	Ukai	1970	2007	Daily	CWC
18	Yerli	1980	2007	Daily	CWC

5.6 WATER QUALITY DATA

The data regarding water quality, i.e., physical parameters (discharge, colour, total suspended solids, total dissolved solids, turbidity etc.), chemical parameters (Calcium, Magnesium, Sodium, Potassium, Sulphate, Nitrate, Nitrite etc.), biological parameters (BOD and dissolved Oxygen), Aluminium trace, and chemical indices like total hardness and Calcium hardness were collected for Gopalkheda, Burhanpur, Sarangkheda and Ghala for a period of 1990-2013 from Central Water Commission, and data regarding the same for Ukai, Surat and Kakrapar were collected for the period of 1999-2015 from State Water Data Centre (SWDC) (Table 5.9). Also, the water quality data for nine sites, namely Mandvi, KAPP Bridge, Kathor, Varachha, Rander, Weir cum causeway, Swami Vivekanand Bridge, Sardar Bridge and ONGC Bridge was collected from Gujarat Pollution Control Board (GPCB).

Table 5.9 Data regarding water quality

Sl. No.	Station	Data characteristic	Period of data collection	Agency
1	Gopalkheda	Water Quality	1990-2013	CWC
2	Burhanpur	Water Quality	1990-2013	CWC
3	Sarangkheda	Water Quality	1990-2013	CWC
4	Ukai	Water Quality	1999-2015	SWDC
5	Surat	Water Quality	1999-2015	SWDC
6	Ghala	Water Quality	1990-2013	CWC
7	Kakrapar	Water Quality	1999-2015	SWDC

5.7 SOIL AND GEOLOGY DATA

The soil data related to Tapi basin were procured from National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur. Total 19 analogue soil maps with detailed information for Gujarat, Maharashtra and Madhya Pradesh states were procured and have converted in digital form. The geological data related to Tapi basin were procured from Geological Survey of India (GSI), Nagpur. The detailed information about geology are available in these maps separate for each district.

5.8 SEDIMENT DATA

The daily suspended sediment data in g/L at various stations maintained by CWC were downloaded from India-WRIS. The details are shown in Table 5.10.

Table 5.10 Data regarding suspended sediment (g/L)

Sl. No.	Station	Data characteristic	Period of data collection	Agency
1	Yerli	Suspended Sediment	1973-2013	CWC
2	Gopalkheda	Suspended Sediment	1979-2014	CWC
3	Dedtalai	Suspended Sediment	1984-2004	CWC
4	Burhanpur	Suspended Sediment	1980-2014	SWDC
5	Savkheda	Suspended Sediment	1972-2004	SWDC
6	Morane	Suspended Sediment	1982-2004	CWC
7	Sarangkheda	Suspended Sediment	1984-2014	SWDC

In addition to the above data, data related to temperature and evaporation were procured from State Water Data Centre (SWDC), Gujarat, Maharashtra and Madhya Pradesh and their water

resources departments. The inflow and outflow data of Hatnur and Girna reservoirs were obtained for years 1987 to 2013 and 2006 to 2013 from Govt. of Maharashtra. The data related to Ukai reservoir were made available from SWDC, Govt. of Gujarat, Irrigation Department from 1975 to 2013.

CHAPTER 6
HYDROLOGICAL DATA PROCESSING AND ANALYSIS

6.1 GENERAL

The present chapter discusses the climatic conditions that prevail in the Tapi Basin, including the historic trend of total annual rainfall (TAR) and number of rainy days (RD) for various IMD and SWDC rain gauge stations in Tapi Basin during the period 1977-2010. Also, rainfall-runoff analysis has been carried out to obtain the decadal variations in runoff coefficients at Hatnur and Ukai Reservoirs. Exceedance Probability Curves have been developed using the daily annual maximum discharge time series for various CWC HO stations that fall along Tapi River as well as the annual maximum inflow time series at Hatnur Reservoir and Ukai Reservoir. By fitting, Gumbel's Extreme Value type-I Distribution, flow rates corresponding to return periods of 1.5 and 2 years are estimated. The flow corresponding to 2-year return period has been widely accepted as the channel forming discharge/dominant discharge. The hydraulic geometry equations which relate the channel discharge with the mean cross-sectional geometry of the channel are developed on a decadal basis at Dedtalai, Burhanpur, Gidhade and Sarangkheda stream gauging stations. Also, the sediment rating curves at Burhanpur and Sarangkheda stations have been developed and the decadal variations in total suspended sediment load concentration (tonnes/day) with discharge (m^3/s) are analysed.

6.2 CLIMATIC CONDITIONS THAT PREVAIL IN TAPI BASIN

Four distinct seasons prevail in the Tapi Basin. They are (i) cold weather, (ii) hot weather, (iii) south-west monsoon and (iv) post-monsoon. The cold weather season commences in December and continues till the end of February. The basin experience utmost cold weather in December. The season is characterized by bright cloudless days & nights. Frost and hail are not generally observed in the basin. The basin, especially in its upper reaches, experiences precipitation in small amounts during this season. The hot weather starts in March and continues up to the middle of June. May is usually hottest month of the season. This season is generally dry except for occasional thunderstorms. The south-West of monsoon sets in by the middle of June and withdraws by the first week of October. June to September is the period of heaviest rain. During this season, the weather is somewhat sultry and oppressive, especially in areas adjoining the Tapi River. In the post-monsoon season, a few thunderstorms occur, especially in October. Thereafter, the weather clears up and it is dry and pleasant throughout the valley.

6.3 TREND ANALYSIS

There has been a humungous variability in the climatic pattern all over the globe in the recent decades and it has been a matter of concern for human kind. In present study, the temporal variability in different precipitation indices like total annual rainfall and number of rainy days have been investigated at 24 rain gauge stations in the Upper Tapi basin, 28 rain gauge stations in the Middle Tapi basin and 11 rain gauge stations in the Lower Tapi basin over the period of 34 years (1977–2010). The monotonic trends in these indices were detected by non-parametric Mann-Kendall (MK) test and their magnitude of change over time was reported by Sen's slope estimator test. Moreover, innovative trend analysis (Sen's 1:1 trend line method) was also applied, and the results were observed to agree to MK and Sen's slope estimator test. The details of the tests carried out and the results are discussed in the following paragraphs.

6.3.1 Mann-Kendall Test

The MK test is a non-parametric test for exploring a trend in a time series without specifying the type of trend, i.e., linear or non-linear. Null hypothesis proposed is that the time series has *no trend*. Alternative hypothesis is that the time series has either an upward or downward trend. Consider the annual time series X_t, t = 1, 2... n. Each value of the series X_t is compared with all subsequent values X_{t+1}, and a new series is generated, and parameter S is calculated as:

$$\boldsymbol{S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)} \qquad \mathbf{6.1}$$

$$\boldsymbol{sgn(x) = \begin{cases} +1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases}} \qquad \mathbf{6.2}$$

In case that the data is independent and uniformly distributed, the average of S is

$$\boldsymbol{E(S) = 0} \qquad \mathbf{6.3}$$

and its variance will be

$$\boldsymbol{Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18}} \qquad \mathbf{6.4}$$

where, n is the number of data, and m is the number of ties. Each tie is a set of similar consequent data in time series where number of data in each of them is t_i.

Finally, the statistic Z is computed as,

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \qquad 6.5$$

MK test is a two-tailed test, where the test statistic should be compared by a critical value of standard normal deviate, $Z_{\alpha/2}$ (Araghinejad, 2013). In case $Z_{\alpha/2} \leq Z \leq Z_{1-\alpha/2}$, the null hypothesis is accepted by α percent of error. If null hypothesis is rejected, the time series of X_t is considered to have an increasing trend, if S is positive, or a decreasing trend, if S is negative.

6.3.2 Sen's Slope Estimation Test

The non-parametric robust estimate for quantifying monotone trend in hydrologic time series given by Hirsch et al. (1982), is given by:

$$\beta = Median\left(\frac{X_j - X_i}{(j-i)}\right) \qquad \forall\ i < j \qquad 6.6$$

where, β = slope between data points X_i and X_j, X_i = data measurement at time i, X_j = data measurement at time j; and j = time after time i. A positive value of β connotes an 'upward trend', and negative value for a 'downward trend' (Xu et al., 2007).

6.3.3 Innovative Trend Analysis

Şen (2012) proposed a new methodology by considering the 1:1 (45°) straight line on the Cartesian coordinate system to detect the trend. In this methodology, the recorded hydrological time series is divided into two equal halves, and both the sub-series are sorted in ascending order. Thereafter, the first half of the time series is plotted as abscissa against the second half of the time series as ordinate based on Cartesian coordinate system.

If the data are plotted on the 1:1 (45°) line, it can be said that there is no trend. If data are in the lower triangular area of 1:1 line, a decreasing trend can be ascertained, while if the data are in the upper triangular area of 1:1 line, an increasing trend is detected, illustrated in Fig. 6.1

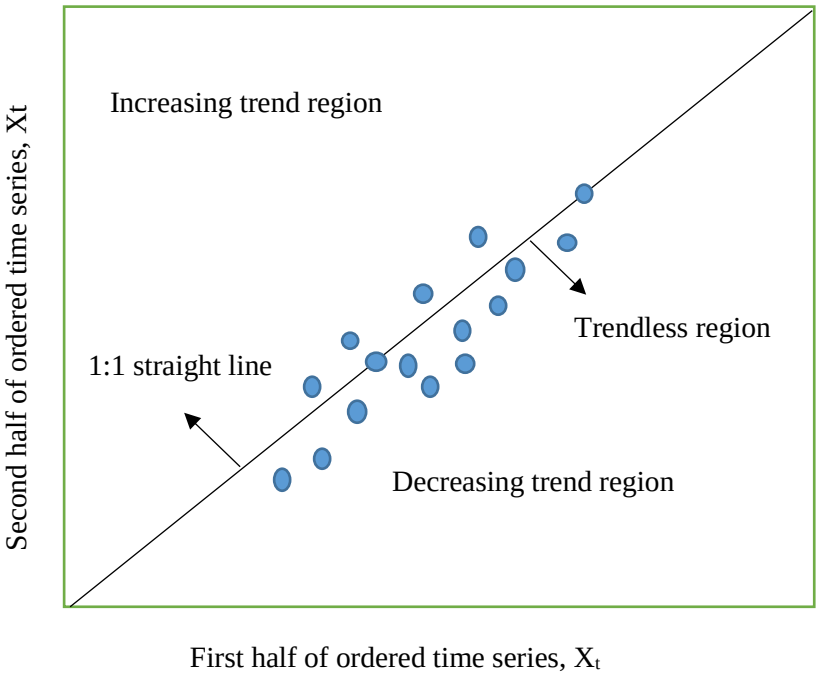


Fig. 6.1 Illustration of decreasing, increasing and trendless regions (Şen 2012)

6.3.4 Rainfall Indices

The following time series were prepared from the recorded daily rainfall data of rain gauge stations that fall in Tapi Basin. The analysis was carried out at a sub-basin level, i.e., for Upper Tapi Basin, Middle Tapi Basin and Lower Tapi Basin separately.

(a) Total annual rainfall (AR): It is the total amount of rainfall received during the entire year from starting of January to end of December at a rain gauge station.

(b) Number of rainy days (RD): It is the total number of days with rainfall amount greater than or equal to 2.5 mm (Sonar, 2014) during the entire year at a rain gauge station.

6.3.5 Results of Trend Analysis in Upper Tapi Basin

The null hypothesis being tested for MK test is that the time series has no trend. For independent sample data, the probability values (p-value) closer to 0.50 indicate no trend, while those close to 0.0 and 1.0, indicate downward and upward trend respectively (Yue et al., 2002). The slope of n pairs of data points was estimated using Sen's slope estimator. The positive value of Sen's slope (β) at seven stations indicated increasing trend. The results of the trend analysis for 1977-2010 are presented along with Z statistics of MK test and p-value for different stations for all rainfall indices, along with results of Sen's slope estimator test and innovative trend analysis, see Table 6.1.

Table 6.1 Results of trend analysis carried out in rain gauge stations of Upper Tapi Basin

Station	MK Test						Sen's Slope Estimator Test				Innovative Trend Analysis	
	TAR			RD			TAR		RD		Nature of Trend	
	Z	P	Nature of Trend	Z	P	Nature of Trend	β	Nature of Trend	β	Nature of Trend	AR	RD
Achalpur	-1.17	0.45	↓*	-1.90	0.03	↓	-9.80	↓	-0.33	↓	↓	↓
Akola	-1.45	0.07	↓	-1.01	0.15	↓	-6.17	↓	-0.18	↓	↓	↓
Akot	0.23	0.59	↑*	-1.27	0.10	↓	0.86	↑	-0.21	↓	↑	↓
Amraoti	-2.31	0.01	↓	-3.00	0.01	↓	-9.60	↓	-0.54	↓	↓	↓
Anjangaon	2.10	1.98	↑	0.07	0.53	↑	10.13	↑	0.05	↑	↑	↑
Atner	-0.25	0.39	↓	-0.19	0.42	↓	-1.97	↓	-0.09	↓	↓	↓
Balapur	0.01	0.50	↑	0.00	0.50	**No Trend**	0.17	↑	0.00	**No Trend**	↑	**No Trend**
Bhainsdehi	1.46	0.92	↑	-1.06	0.14	↓	4.43	↑	-0.25	↓	↑	↓
Buldana	1.54	0.93	↑	-0.71	0.23	↓	6.60	↑	-0.09	↓	↑	↓
Burhanpur	0.97	0.83	↑	1.90	0.97	↑	4.60	↑	0.37	↑	↑	↑
Chandur bazar	-0.28	0.38	↓	1.45	0.92	↑	-0.90	↓	0.21	↑	↓	↑
Chikhalda	-0.97	0.16	↓	-0.50	0.30	↓	-7.37	↓	-0.15	↓	↓	↓
Daryapur	0.80	0.78	↑	0.69	0.75	↑	2.12	↑	0.14	↑	↑	↑
Dharni	-2.81	0.00	↓	0.06	-2.48	↓	-12.25	↓	-0.46	↓	↓	↓
Edalabad	1.73	0.95	↑	1.57	0.94	↑	6.40	↑	0.28	↑	↑	↑
Khamgaon	-0.77	0.22	↓	0.11	0.54	↑	-2.84	↓	0.10	↑	↓	↑
Malkapur	0.17	0.57	↑	1.78	0.96	↑	1.50	↑	0.27	↑	↑	↑
Multai	0.50	0.69	↑	0.50	0.69	↑	1.72	↑	0.15	↑	↑	↑
Murtajpur	-0.20	0.41	↓	0.00	0.50	**No Trend**	-1.14	↓	0.00	**No Trend**	↓	**No Trend**
Nandura	-1.54	0.06	↓	-2.88	0.01	↓	-7.32	↓	-0.40	↓	↓	↓
Patur	0.85	0.80	↑	-1.14	0.12	↓	4.04	↑	-0.25	↓	↑	↓
Raver	-0.45	0.32	↓	-0.20	0.41	↓	-1.77	↓	-0.06	↓	↓	↓
Shegaon	-0.69	0.24	↓	-1.29	0.09	↓	-2.33	↓	-0.22	↓	↓	↓
Telhara	0.32	0.62	↑	0.63	0.73	↑	1.51	↑	0.17	↑	↑	↑

*↑ indicates increasing trend and ↓ indicates decreasing trend

The trend analysis results of Total Annual Rainfall (TAR) show that, out of twenty-four rain gauge stations, twelve stations, i.e., Achalpur, Akola, Amraoti, Atner, Chandurbazar, Chikhalda, Dharni, Khamgaon, Murtajpur, Nandura, Raver and Shegaon exhibit decreasing trend during the period 1977-2010, whereas the rest of the stations, exhibit an increasing trend. Stations like Burhanpur and Bhainsdehi have undergone a significant increase in rainfall. A significant decrease in total rainfall can be observed in stations like Akola, Amraoti, Dharni, Chikhalda and Nandura. Rain gauge stations like Atner and Chikhalda, which are located in mountainous terrain, and contribute most to the runoff owing to heavy precipitation due to orographic effect, have also undergone a decreasing trend in total annual rainfall. The results obtained during innovative trend analysis also agrees with that of the rest of the tests performed. The results of innovative trend analysis for Akola, Dharni and Bhainsdehi rain gauge stations are shown in Figs. 6.2-6.5. Half of the stations exhibit decreasing trend in total annual rainfall. This may affect the discharge in the rivers, thereby, affect the storage of irrigation structures, which in turn, may result in acute water shortages at the end of lean period.

Out of twenty-four, thirteen rain gauge stations show a decreasing trend in the number of rainy days (Table 6.1) during 1977-2010. Two stations, Balapur and Murtajpur show no trend and nine stations, Anjangaon, Burhanpur, Chandurbazar, Daryapur, Edalabad, Khamgaon, Malkapur, Multai and Telhara show an increasing trend in the number of rainy days. The results of innovative trend analysis agree with that of MK Test and Sen's Slope Test. It can be seen from the innovative trend analysis results that, for stations Dharni, Atner and Chikhalda, that have undergone a decreasing trend in TAR, a significant decrease is observed in the high as well as medium values of the number of rainy days (Fig 6.6-6.8). This decrease would directly cause a lowering of the wet spells during monsoon period which will further affect the total rainfall obtained during the Indian Summer Monsoon Rainfall. There is an overall reduction in the trend of total annual rainfall in the Upper Tapi river sub-basin, and this may be attributed to the increasing anthropogenic activities that have triggered major land use changes in the basin, which may further cause serious shortages in water availability for consumption as well as irrigation purposes.

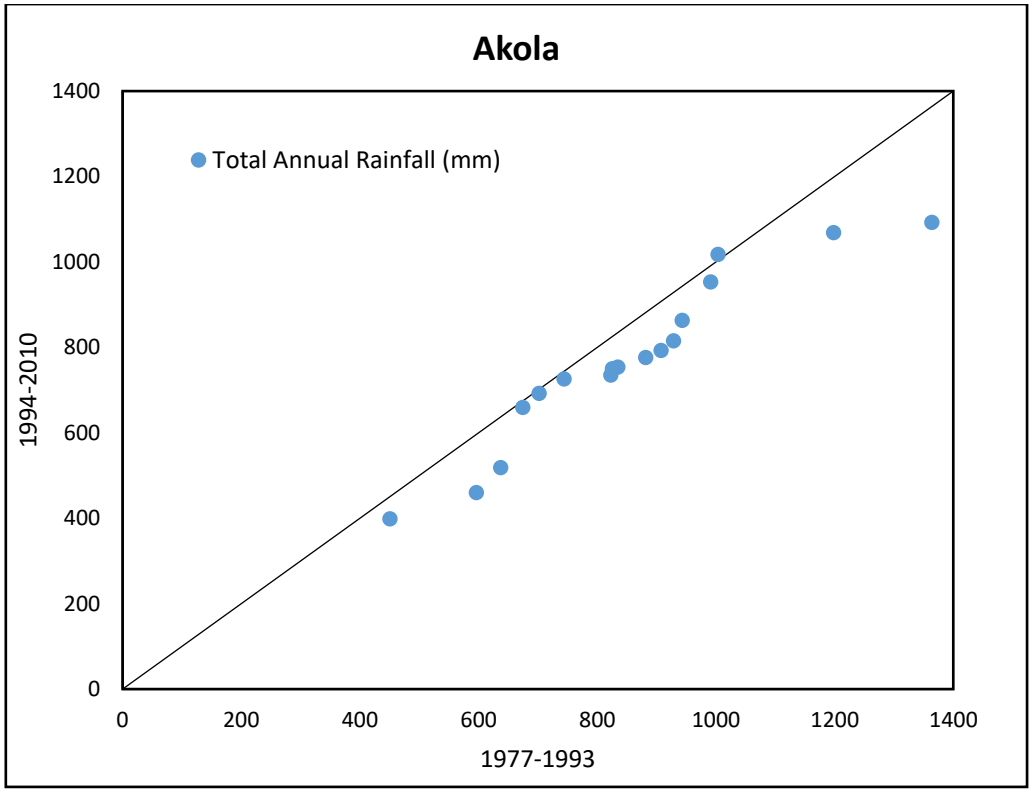


Fig 6.2 Innovative trend analysis results of total annual rainfall for Akola rain gauge station

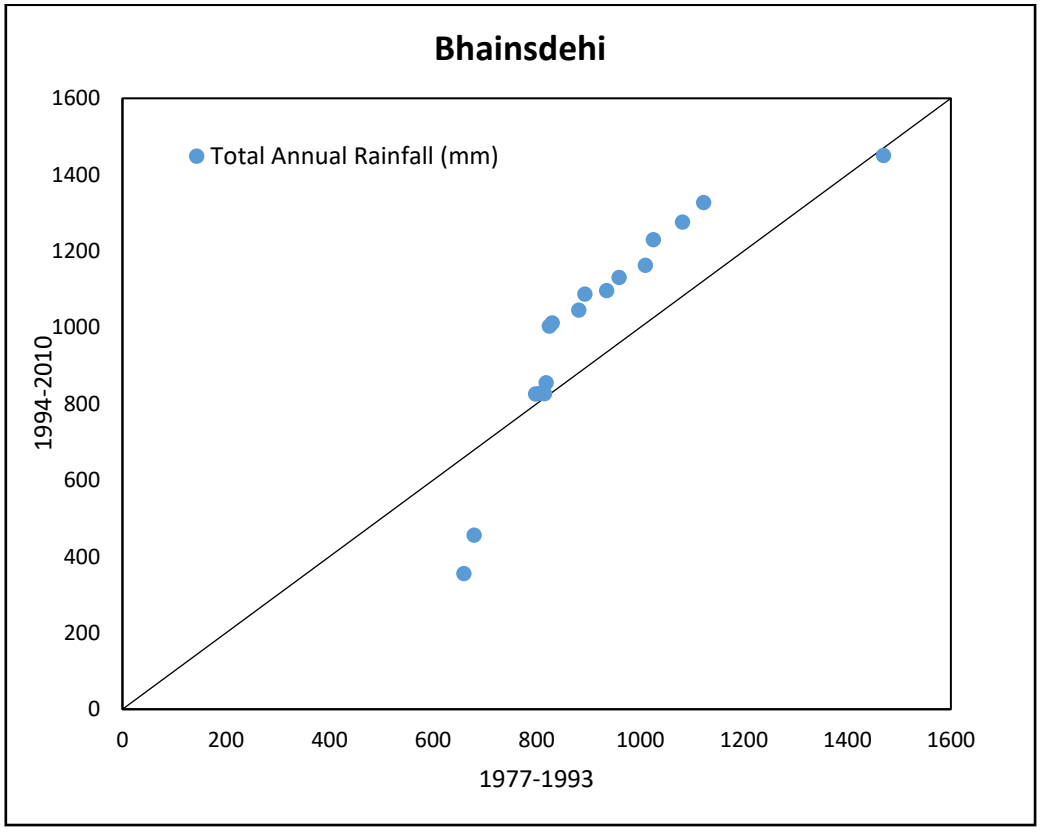


Fig 6.3 Innovative trend analysis results of total annual rainfall for Bhainsdehi rain gauge station

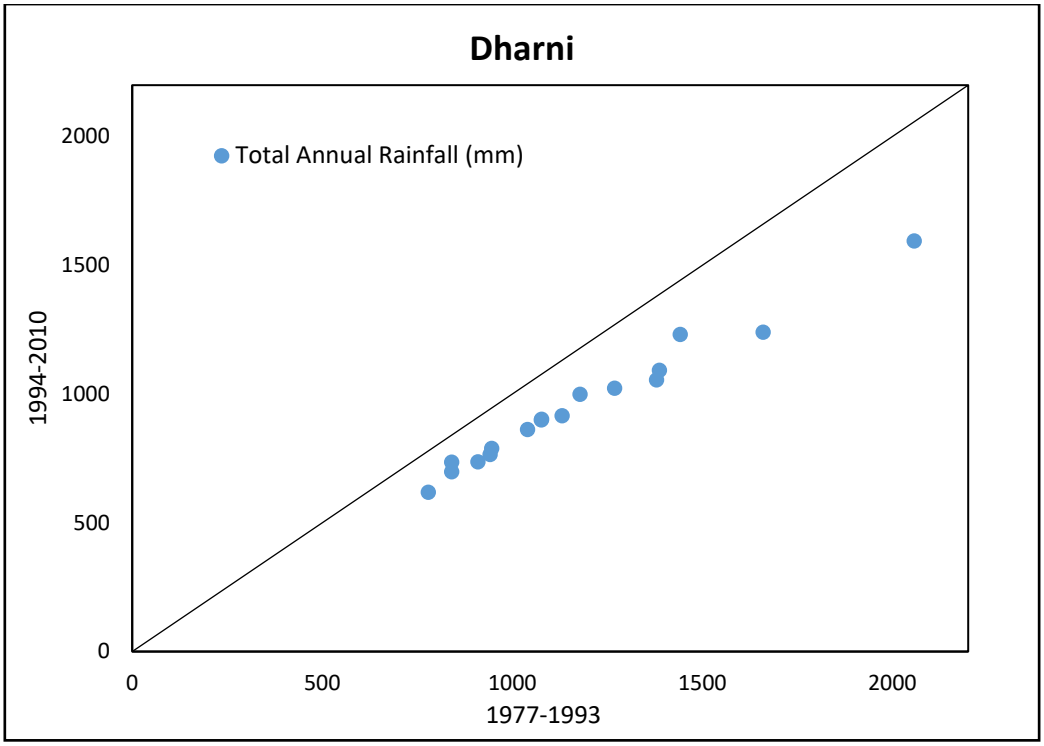


Fig 6.4 Innovative trend analysis results of total annual rainfall for Dharni rain gauge station

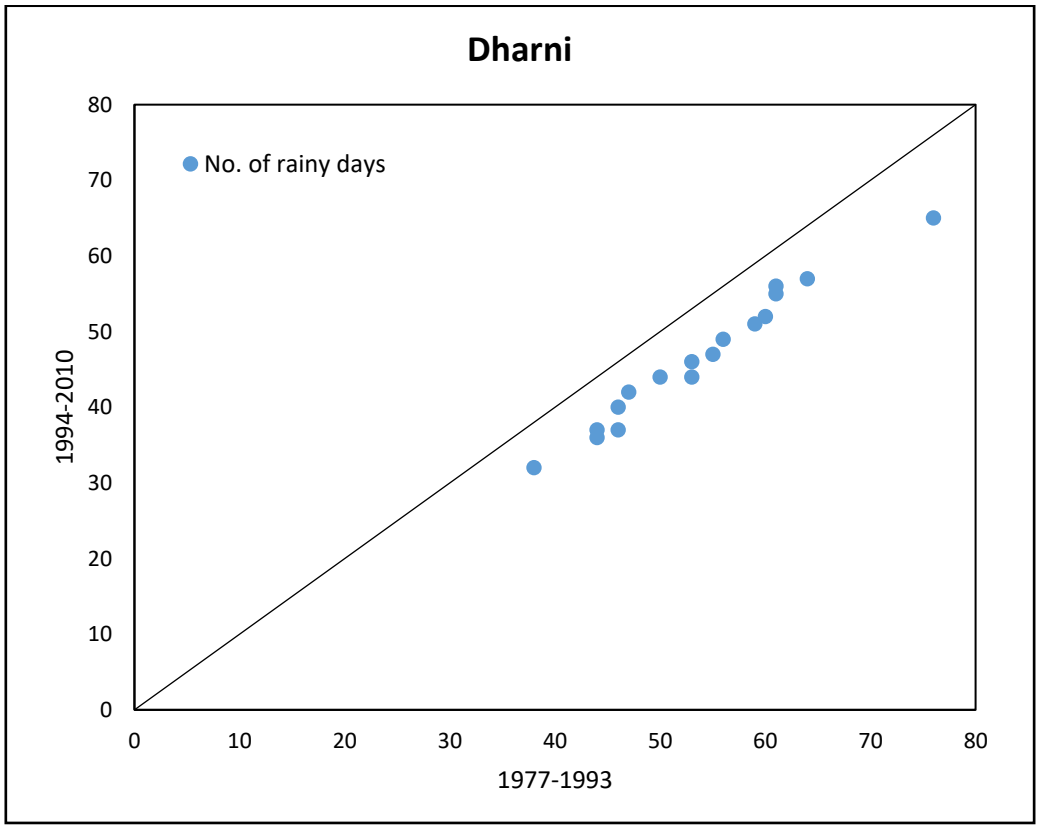


Fig 6.5 Innovative trend analysis results of number of rainy days for Dharni rain gauge station

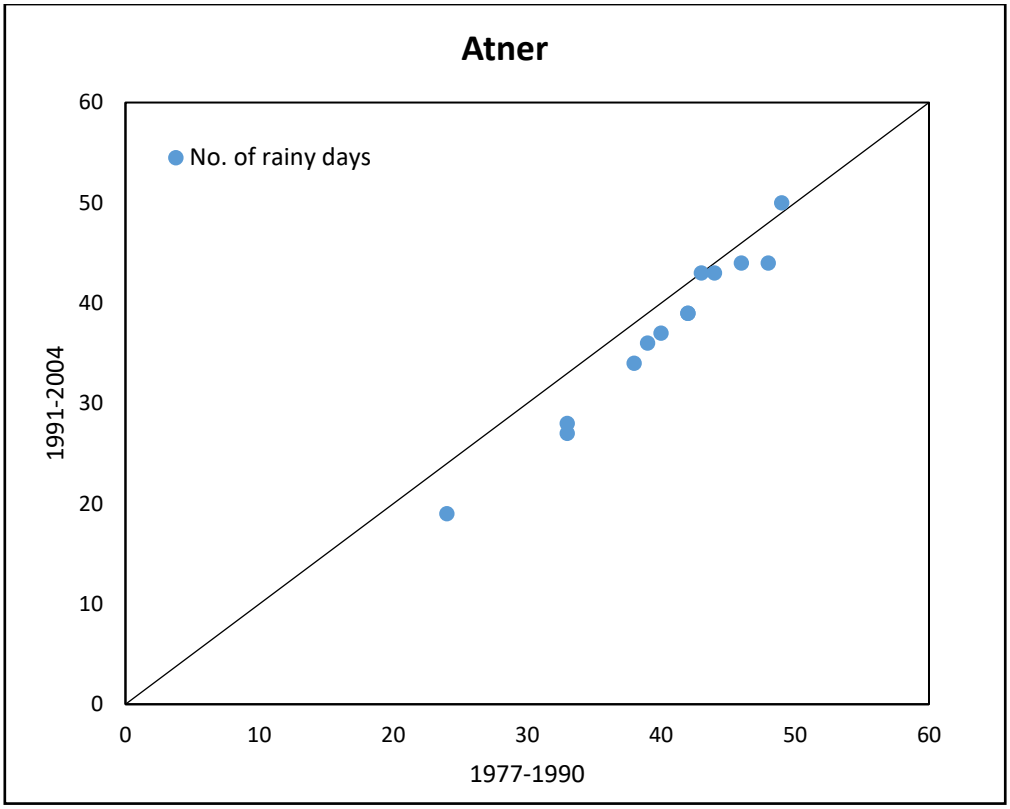


Fig 6.6 Innovative trend analysis results of number of rainy days for Atner rain gauge station

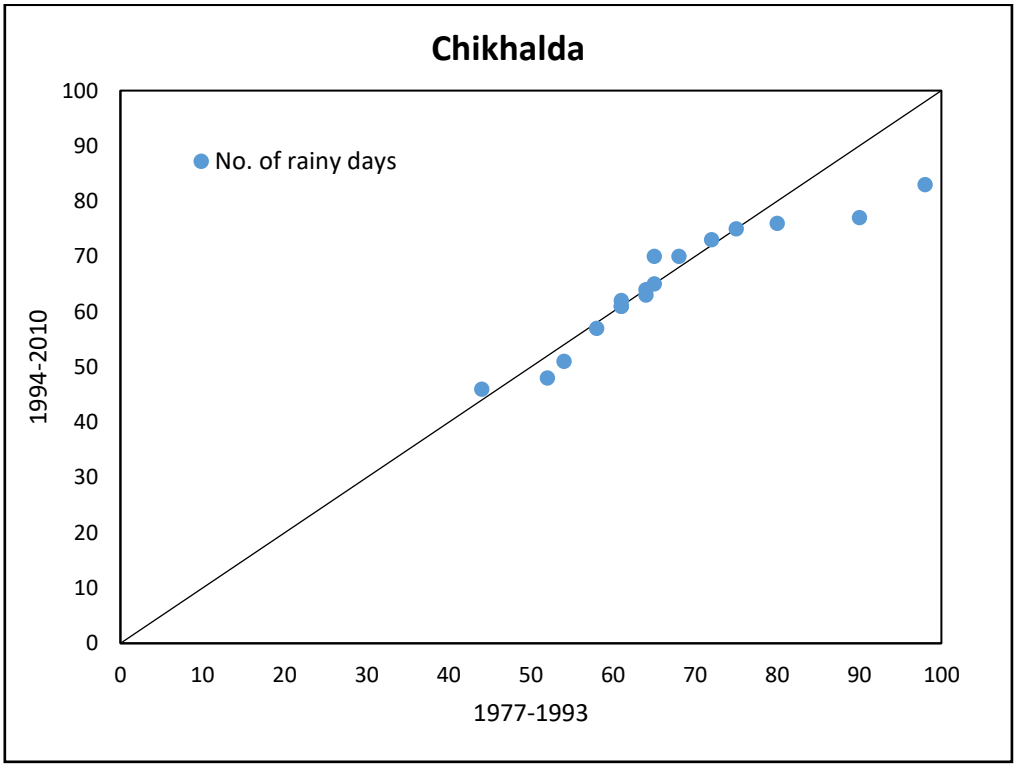


Fig 6.7 Innovative trend analysis results of number of rainy days for Chikhalda rain gauge station

6.3.6 Results of Trend Analysis in Middle Tapi Basin

The results of trend analysis carried out in Middle Tapi Basin show that out of 28 rain gauge stations, 14 exhibit a reduction in total annual rainfall (TAR). Among these stations, Chalisgaon, Jalgaon and Jamner rain gauge stations exhibit significant decreasing trend in total annual rainfall. These rain gauge stations fall in area which is thickly populated, and agriculture is the major source of income for the people. The reduction in total annual rainfall may have adverse effects on the irrigation and, thereby, crop productivity. It can also be seen that stations like Bhadgaon, Kalvan and Sagbara exhibit no trends in TAR. Rest of the 11 stations exhibit an increasing trend in total annual rainfall, among which stations like Erandol, Gidhade, Dhulia, Nandgaon, Nandurbar, Navpur and Shirpur exhibits significant increase in rainfall. Similar results are obtained while carrying out Innovative Trend analysis. The results are as tabulated in Table 6.2. Innovative trend analysis results for Jalgaon and Nandurbar rain gauge stations are shown in Figs. 6.8-6.9.

Table 6.2 shows that in contrast to the results obtained for Upper Tapi Basin, 14 rain gauge stations out of 28, show an increasing trend in the number of rainy days in Middle Tapi Basin. Stations like Dhulia, Erandol, Kalvan and Sindhkheda show a significant increase in the number of rainy days. Stations like Jalgaon, Talod and Satna exhibit no trend in number of rainy days. Among the stations which exhibit decreasing trend, none of the stations exhibit a reduction in number of rainy days which can be termed as significant. When compared with the results obtained for Upper Tapi Basin, it is observed that the Middle Tapi Basin is comparatively less vulnerable to the decrease in number of rainy days. Similar results are obtained for Innovative Trend analysis. Innovative trend analysis results for Kalvan rain gauge station is shown in Fig. 6.10.

6.3.7 Results of Trend Analysis in Lower Tapi Basin

Trend analysis tests carried out on eleven rain gauge stations in Lower Basin reveals that except Kathor station, all rain gauge stations exhibit an increasing trend in the total annual rainfall. This increase is significant at Kamrej, Olpad, Bodhan and Kholavad rain gauge stations, which can be observed clearly from the high positive values of MK Test statistics, and Sen's Slope Estimator Test statistics (Table 6.3).

Table 6.2 Results of trend analysis carried out in rain gauge stations of Middle Tapi Basin

Station	MK Test						Sen's Slope Estimator Test				Innovative Trend Analysis	
	TAR			RD			TAR		RD		Nature of Trend	
	z	p	Nature of Trend	z	p	Nature of Trend	β	Nature of Trend	β	Nature of Trend	AR	RD
Amalner	-0.65	0.26	*↓	-0.18	0.43	↓	-3.18	↓	-0.06	↓	↓	↓
Bhadgaon	0.00	0.50	**No Trend**	0.56	0.71	↑	0.00	**No Trend**	0.13	↑	**No Trend**	↑
Bhusaval	-0.43	0.33	↓	0.44	0.67	↑	-1.78	↓	0.13	↑	↓	↑
Chalisgaon	-1.03	0.14	↓	-0.31	0.37	↓	-3.98	↓	-0.09	↓	↓	↓
Chopda	0.08	0.77	*↑	0.80	0.78	↑	2.85	↑	0.16	↑	↑	↑
Dhulia	1.00	0.84	↑	1.38	0.91	↑	5.18	↑	0.30	↑	↑	↑
Erandol	1.48	0.93	↑	1.40	0.91	↑	5.65	↑	0.27	↑	↑	↑
Gidhade	2.12	0.98	↓	1.11	0.86	↑	6.05	↓	0.20	↑	↓	↑
Jalgaon	-1.06	0.14	↓	0.00	0.50	**No Trend**	-2.96	↓	0.05	**No Trend**	↓	**No Trend**
Jamner	-1.98	0.02	↓	-0.66	0.25	↓	-9.05	↓	-0.14	↓	↓	↓
Kalvan	0.00	0.50	**No Trend**	2.27	0.98	↑	0.00	**No Trend**	0.46	↑	**No Trend**	↑
Malegaon	-0.51	0.30	↓	-0.42	0.33	↓	-2.46	↓	-0.05	↓	↓	↓
Nandgaon	1.92	0.97	↑	0.50	0.69	↑	6.15	↑	0.11	↑	↑	↑
Nanudarbar	1.89	0.97	↑	-0.19	0.42	↓	9.11	↑	-0.07	↓	↑	↓
Navapur	1.69	0.95	↑	-0.89	0.18	↓	11.31	↑	-0.20	↓	↑	↓
Pachora	-0.69	0.24	↓	0.16	0.56	↑	-2.12	↓	0.06	↑	↓	↑
Pansemal(MED)	-0.70	0.35	↓	-0.33	0.36	↓	-2.01	↓	-0.17	↓	↓	↓
Parola	0.83	0.79	↑	1.01	0.84	↑	2.53	↑	0.16	↑	↑	↑
Raver	-0.45	0.32	↓	-0.28	0.38	↓	-1.95	↓	-0.08	↓	↓	↓
Sagbara	0.00	0.50	**No Trend**	-0.06	0.47	↓	0.00	**No Trend**	-0.08	↓	**No Trend**	↓
Sakri	1.36	0.91	↑	1.19	0.88	↑	3.52	↑	0.20	↑	↑	↑
Satna	-0.57	0.28	↓	0.00	0.50	**No trend**	9.82	↓	0.30	**No trend**	↓	**No trend**
Shahada	-0.59	0.27	↓	-0.65	0.25	↓	-2.40	↓	-0.15	↓	↓	↓
Shirpur	2.46	0.99	↑	0.47	0.68	↑	10.33	↑	0.12	↑	↑	↑
Sindkheda	0.88	0.81	↑	1.26	0.89	↑	3.50	↑	0.22	↑	↑	↑
Taloda	0.88	0.81	↑	0.00	0.50	**No trend**	5.11	↑	-0.03	**No trend**	↑	**No trend**
Yaval	-0.29	0.80	↓	0.06	0.52	↑	-1.14	↓	0.05	↑	↓	↑

*↑ indicates increasing trend and ↓ indicates decreasing trend

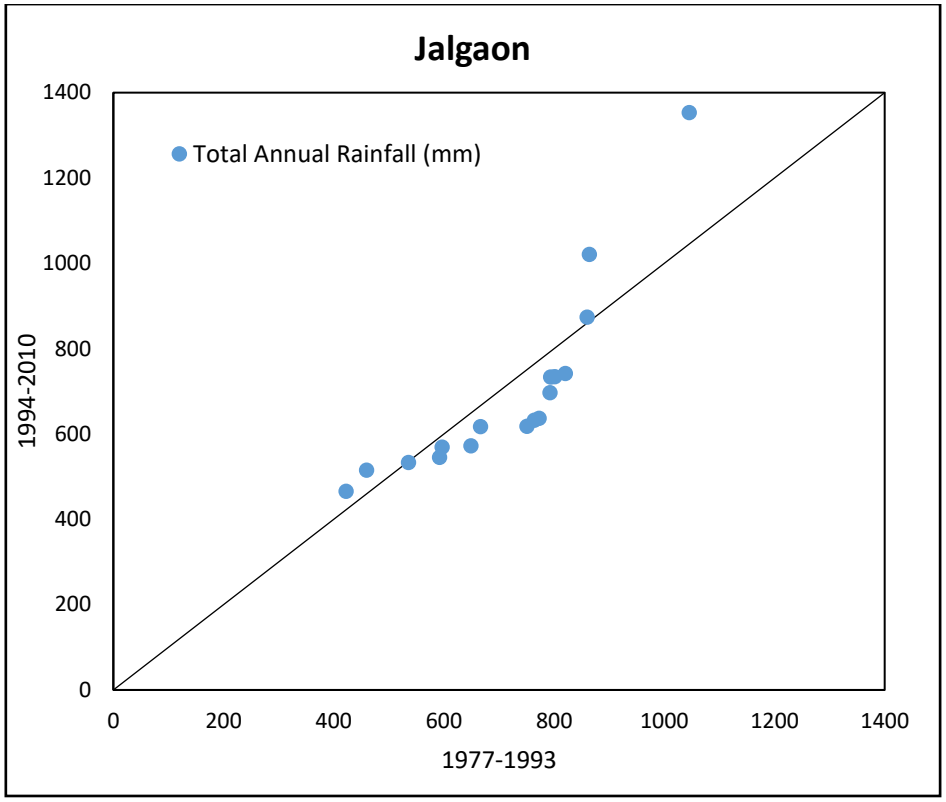


Fig 6.8 Innovative trend analysis results of total annual rainfall for Jalgaon rain gauge station

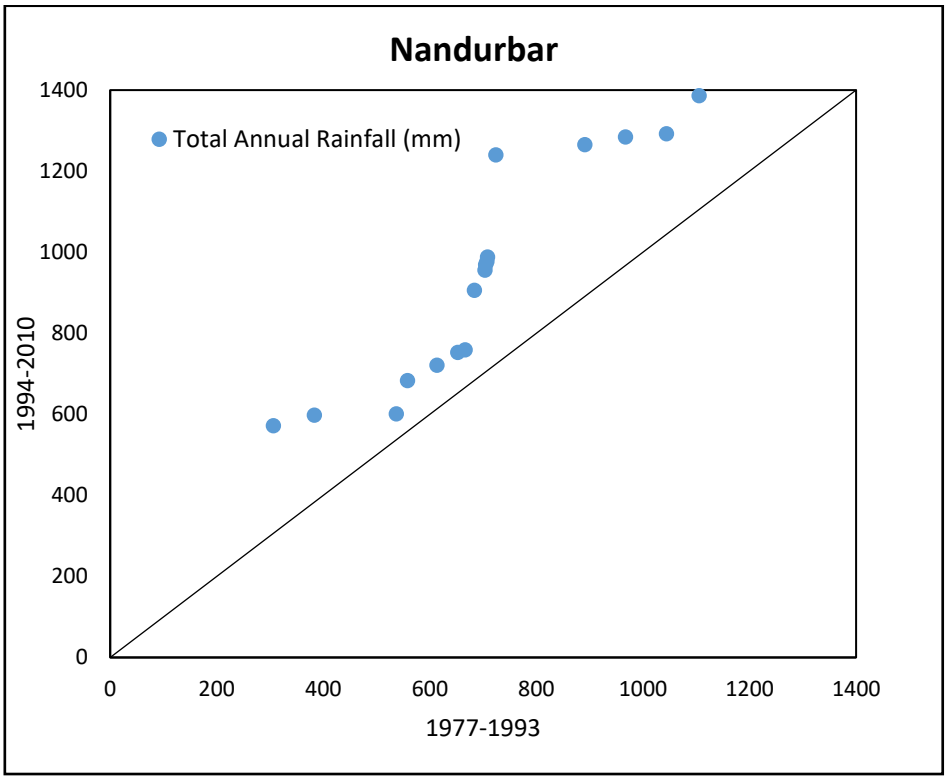


Fig 6.9 Innovative trend analysis results of total annual rainfall for Nandurbar rain gauge station

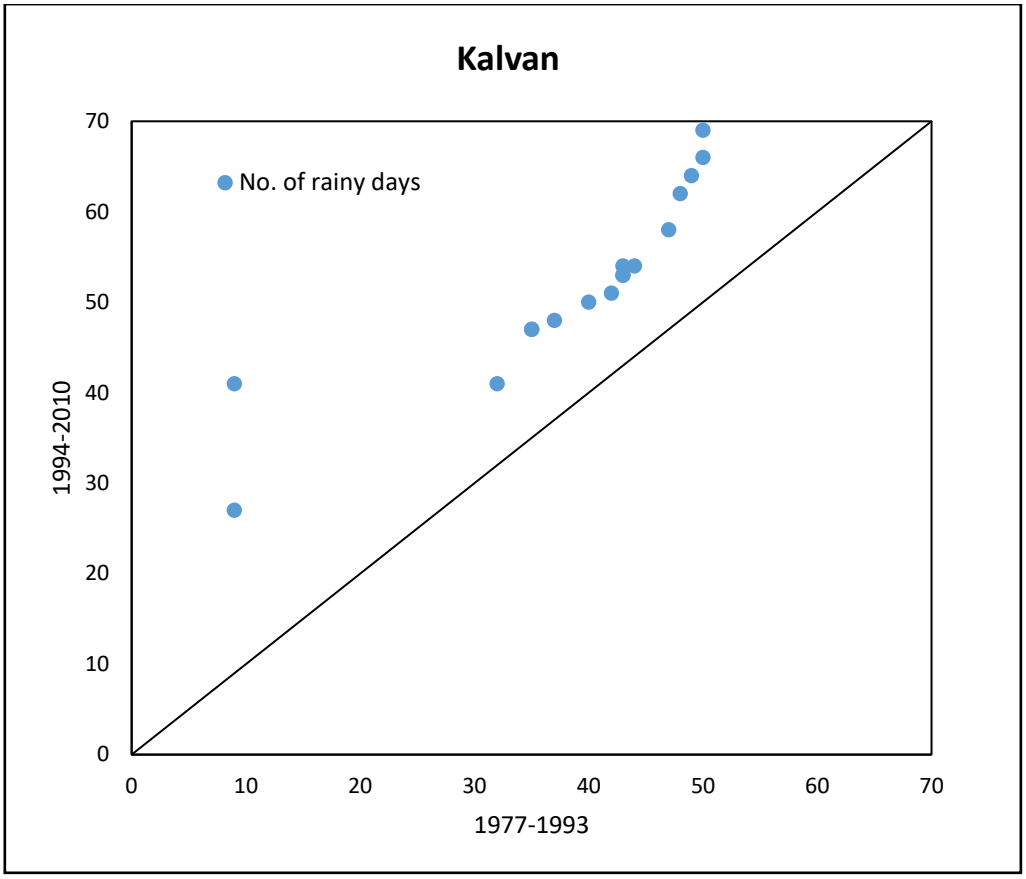


Fig 6.10 Innovative trend analysis results of no. of rainy days for Kalvan rain gauge station

The results of innovative trend analysis for Kathor and Kamrej stations are shown in Figs. 6.11-6.12. Similar results are obtained while carrying out trend analysis tests on the number of rainy days. Stations like Kamrej, Mangrol, Olpad, Surat, Bodhan, Kadod, Kathor, Kholavad and Mandvi exhibit an increase in number of rainy days during 1977-2010. Among these stations, significant increase is observed at Olpad, Kholavad and Mangrol raingauge station. It can also be observed from Table 6.3 that stations like Puna and Kakrapar exhibits a decreasing trend in the number of rainy days. The results of innovative trend analysis for Olpad and Puna stations are shown in Figs. 6.13-6.14. Lower Tapi Basin, which falls downstream of Ukai Dam is prone to frequent flooding, especially in the downstream reaches near the urban centre like Surat city. Also, more than 50% of the total area of the basin is covered with agricultural fields. The significant upward trend observed in both total rainfall and number of rainy days calls for effective water storage, management and utilization practises, which can reduce the effect of destructions caused due to flooding, owing to heavy rainfall.

Table 6.3 Results of trend analysis carried out in rain gauge stations of Lower Tapi Basin

Station	MK Test						Sen's Slope Estimator Test				Innovative Trend Analysis	
	TAR			RD			TAR		RD		Nature of Trend	
	Z	P	Nature of Trend	Z	P	Nature of Trend	β	Nature of Trend	β	Nature of Trend	AR	RD
Kamrej	1.42	0.92	*↑	0.45	0.67	↑	19.57	↑	0.14	↑	↑	↑
Mangrol	1.06	0.86	↑	1.02	0.85	↑	10.14	↑	0.26	↑	↑	↑
Olpad	3.02	0.99	↑	1.78	0.96	↑	17.19	↑	0.48	↑	↑	↑
Surat	1.42	0.92	↑	0.53	0.70	↑	14.33	↑	0.17	↑	↑	↑
Bodhan	1.96	0.98	↑	0.30	0.61	↑	14.13	↑	0.11	↑	↑	↑
Kadod	1.24	0.89	↑	0.83	0.93	↑	11.78	↑	0.29	↑	↑	↑
Kathor	-0.77	0.22	*↓	0.08	0.53	↑	-6.09	↓	0.06	↑	↓	↑
Kholavad	2.78	0.99	↑	1.23	0.89	↑	20.11	↑	0.32	↑	↑	↑
Puna	0.05	0.51	**No trend**	-0.49	0.31	↓	0.00	**No trend**	-0.14	↓	**No trend**	↓
Mandvi	1.35	0.91	↑	0.55	0.71	↑	16.41	↑	0.15	↑	↑	↑
Kakrapar	0.71	0.76	↑	-0.13	0.45	↓	7.71	↑	-0.10	↓	↑	↓

*↑ indicates increasing trend and ↓ indicates decreasing trend

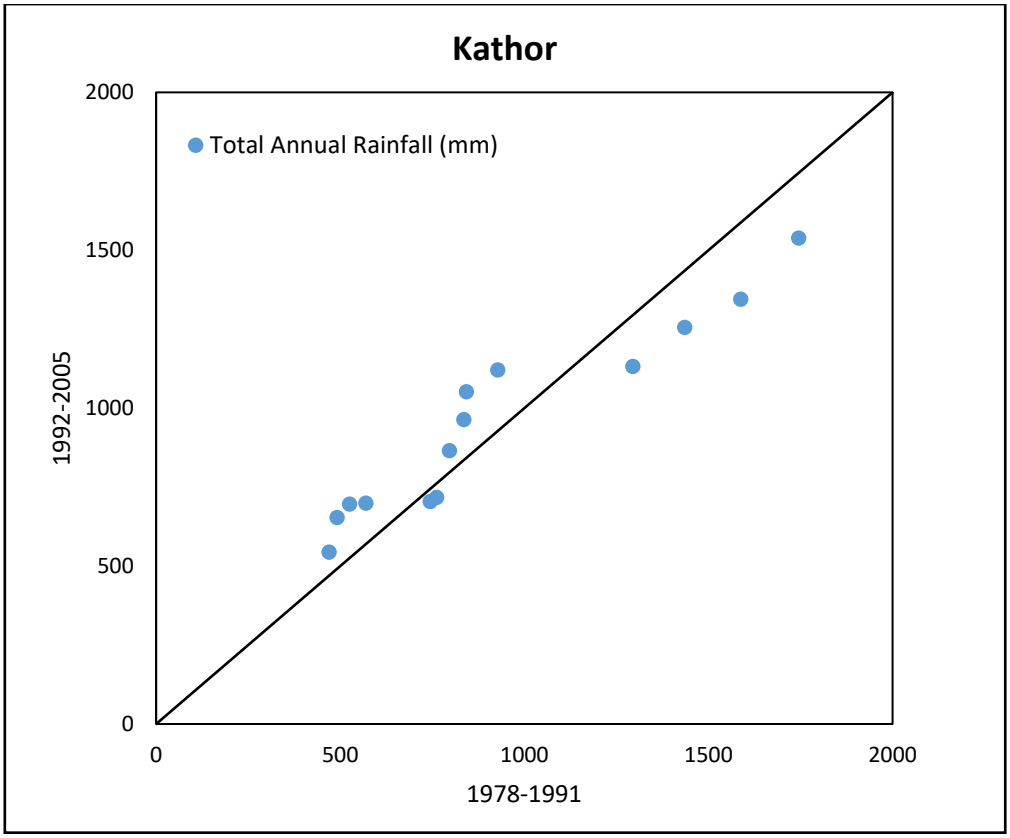


Fig 6.11 Innovative trend analysis results of total annual rainfall at Kathor rain gauge station

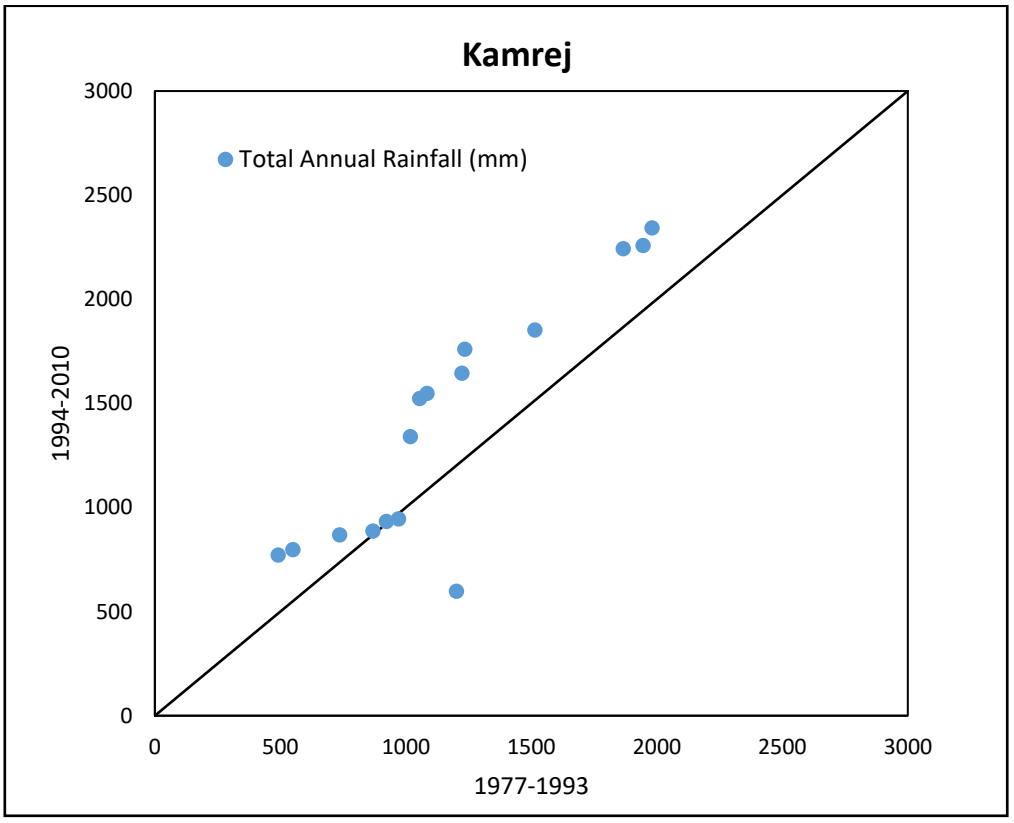


Fig 6.12 Innovative trend analysis results of total annual rainfall at Kamrej rain gauge station

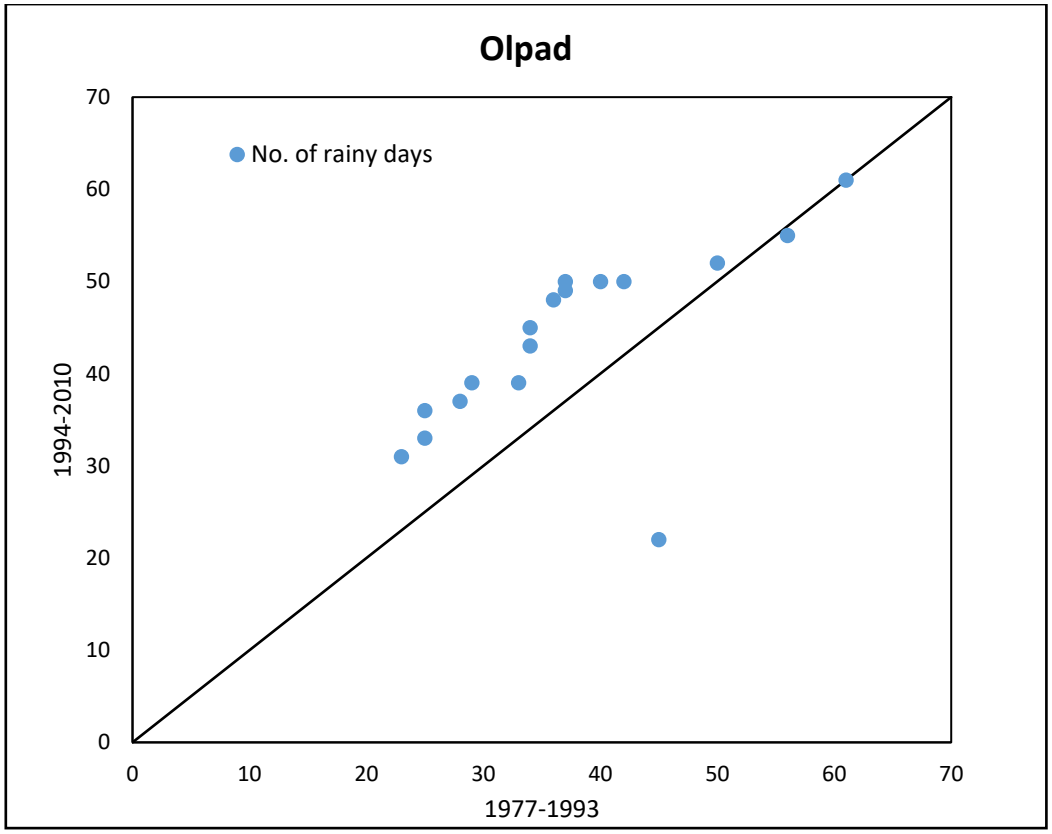


Fig 6.13 Innovative trend analysis results of number of rainy days at Olpad rain gauge station

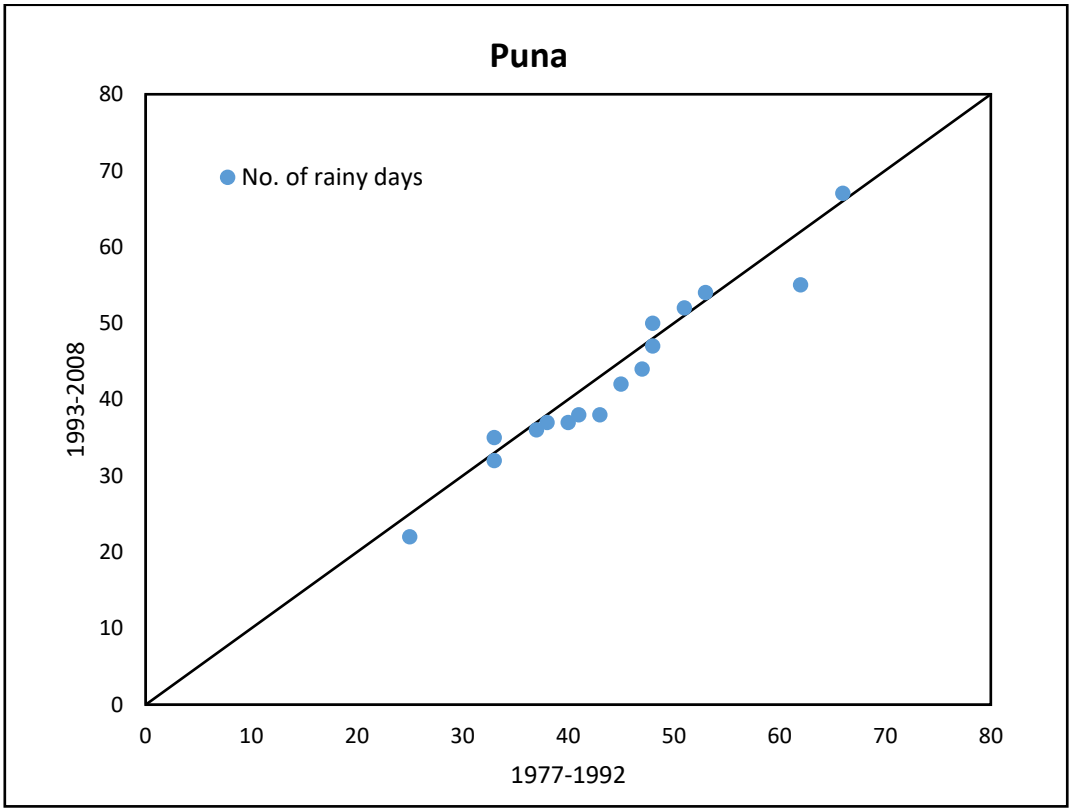


Fig 6.14 Innovative trend analysis results of number of rainy days at Puna rain gauge station

6.4 AT-SITE FLOOD FREQUENCY ANALYSIS AND RESULTS

At-site flood frequency analysis is used to predict design floods for stream gauging stations along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and return periods. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of return period or exceedance probability.

At-site flood frequency analysis involves two main assumptions:

a) The data should be stochastic in nature.
b) Data should be independently and identically distributed.

The first assumption means that the data points should have a probability associated with it and the second assumption states that the occurrence of events should be independent of each other, i.e., first event should not influence second event and so on. Also, it is suggested that the data should come from the same population (same watershed in case of hydrological problems) so that they are identical in nature.

In at-site flood frequency analysis, identical distribution refers to only time homogeneity. Space homogeneity plays role in regional flood frequency analysis. This is achieved by selecting the flood data such that they come from the same population. In hydrological analysis the watershed from which the values are observed should not drastically change with respect to time. Also, the location and type of the gauges used for measuring these values are kept the same. In regional flood frequency analysis, data series across many sites are analysed. A common model is that the distributions of these data series are the same for all sites apart from a simple scaling factor, so that the location and scale are linked in a simple way.

In present study, at-site flood frequency analysis has been carried out to develop exceedance probability curves for the daily annual maximum discharge time series of CWC HO stations, Dedtalai, Burhanpur, Savkheda, Gidhade and Sarangkheda stream gauging stations, that fall along the Tapi River as well as the annual maximum inflow time series of Ukai and Hatnur Reservoirs. The relevant statistical details of each station are shown in Table 6.4. Prior to the analysis the data were subjected to time independency test (lag-one autocorrelation test) and time homogeneity test (cumulative-deviations test). The Extreme Value-I Distribution, i.e., Gumbel Distribution has been employed for this purpose as it is mostly used for Indian Rivers

(Garde and Kothyari, 1990). Another advantage of Gumbel Distribution over other distributions is that the return periods corresponding to mean discharge and other discharges (based on mean and standard deviation) are constant, irrespective of the stations under consideration. For example, the return period corresponding to mean discharge ($\bar{x}$) is 2.33 years and the return period corresponding to mean + standard deviation ($\bar{x} + 1\sigma$) is 6.93 years. The results and findings are discussed in the following paragraphs.

Table 6.4 Statistical details computed for various stations

Station	Time Series considered	Period of Analysis	Mean (m^3/s)	Standard Deviation (m^3/s)	Skewness	Kurtosis
Dedtalai	Annual maximum discharge	1978-2005	4191.3	3415.9	2.54	8.82
Burhanpur	Annual maximum discharge	1977-2011	7598.5	6520.5	1.68	2.41
Savkheda	Annual maximum discharge	1978-2005	8720.4	5956.5	1.33	1.34
Gidhade	Annual maximum discharge	1977-2011	8733.1	6206.0	1.32	1.11
Sarangkheda	Annual maximum discharge	1978-2011	8886.4	6317.0	1.30	1.19
Ukai	Annual maximum inflow	1977-2011	11589.1	7915.2	1.30	1.39

6.4.1 Test for Independency (Lag-one Autocorrelation Test)

The independency of the annual maximum discharge series for Dedtalai, Burhanpur, Savkheda, Gidhade, Sarangkheda and maximum annual inflow series at Ukai were checked by plotting autocorrelation function (γ) up to ten lags using Eq 6.7.

$$\gamma_t = \frac{\frac{1}{n}\sum_{t=1}^{n-1}(X_t - \bar{X})(X_{t+1} - \bar{X})}{\frac{1}{n-1}\sum_{t=1}^{n}(X_t - \bar{X})^2} \qquad 6.7$$

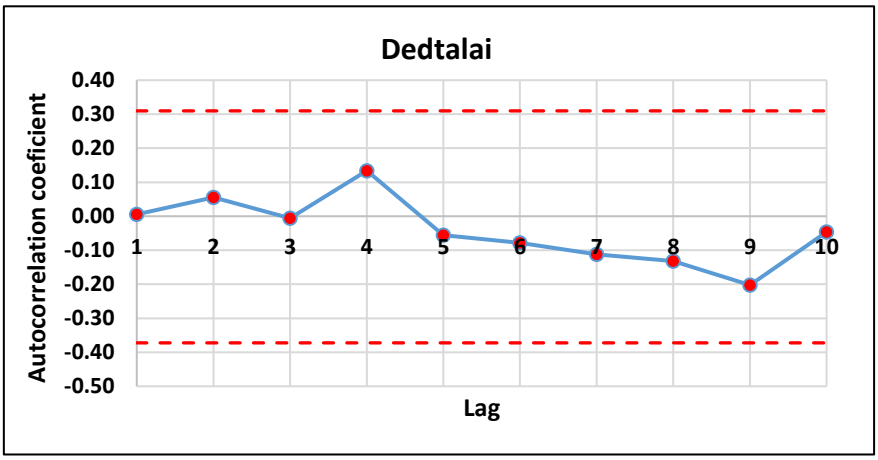
The autocorrelation function (correlogram) for the observed discharge time series for all the stations are plotted in Fig. 6.15. Tolerance band for autocorrelation is constructed at 5% level of significance (Fig 6.15) and checked against the observed autocorrelation for each station. The results are tabulated in Table 6.5.

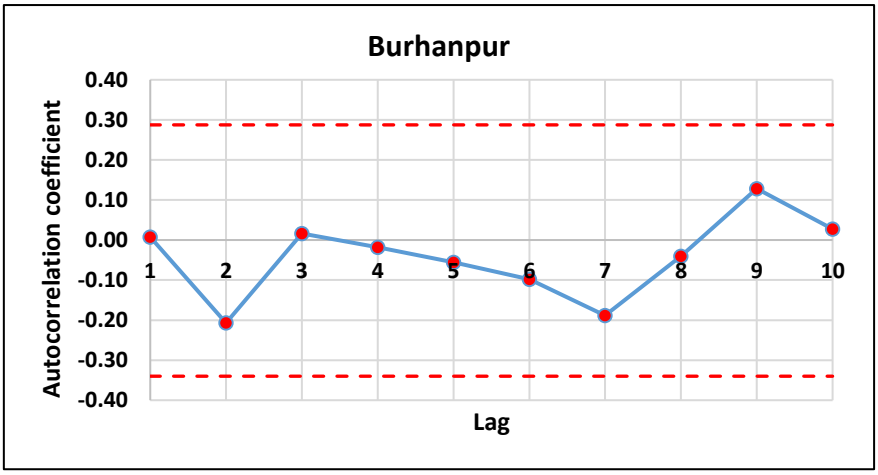
The calculated values of autocorrelation coefficients for all stations lie within this tolerance band as shown in Fig 6.15.

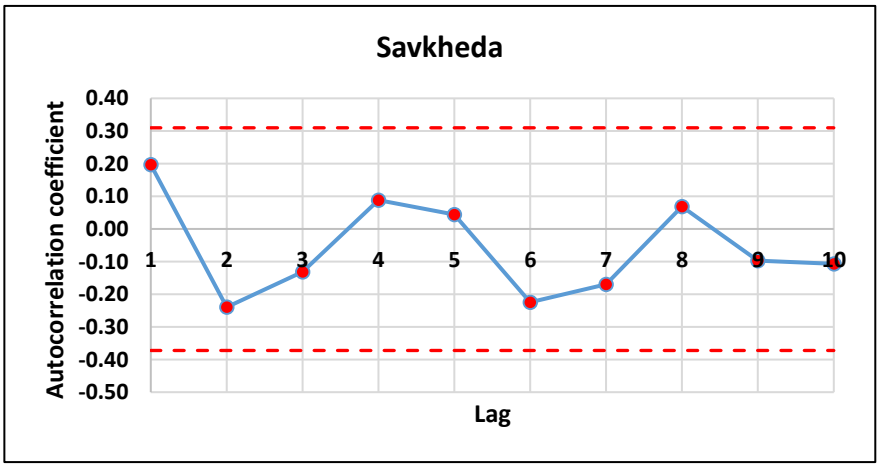
$$\gamma_1(5\%) = \frac{-1 \pm 1.96\sqrt{n-2}}{(n-1)} \qquad 6.8$$

Table 6.5 Autocorrelation coefficients for first 10 lags

Station	AUTOCORRELATION COEFFICIENTS FOR FIRST 10 LAGS									
	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_7	γ_8	γ_9	γ_{10}
Dedtalai	0.006	0.055	-0.006	0.134	-0.055	-0.078	-0.112	-0.132	-0.202	-0.046
Burhanpur	0.007	-0.207	0.016	-0.018	-0.056	-0.098	-0.188	-0.040	0.128	0.028
Savkheda	0.197	-0.240	-0.131	0.088	0.044	-0.224	-0.169	0.069	-0.097	-0.107
Gidhade	0.148	-0.110	-0.101	0.025	0.079	-0.091	-0.124	0.143	-0.017	-0.014
Sarangkheda	-0.032	-0.317	-0.216	0.142	0.127	-0.217	-0.187	0.230	0.094	-0.021
Ukai	0.217	-0.104	-0.034	0.072	-0.068	-0.287	-0.140	0.219	-0.038	-0.150







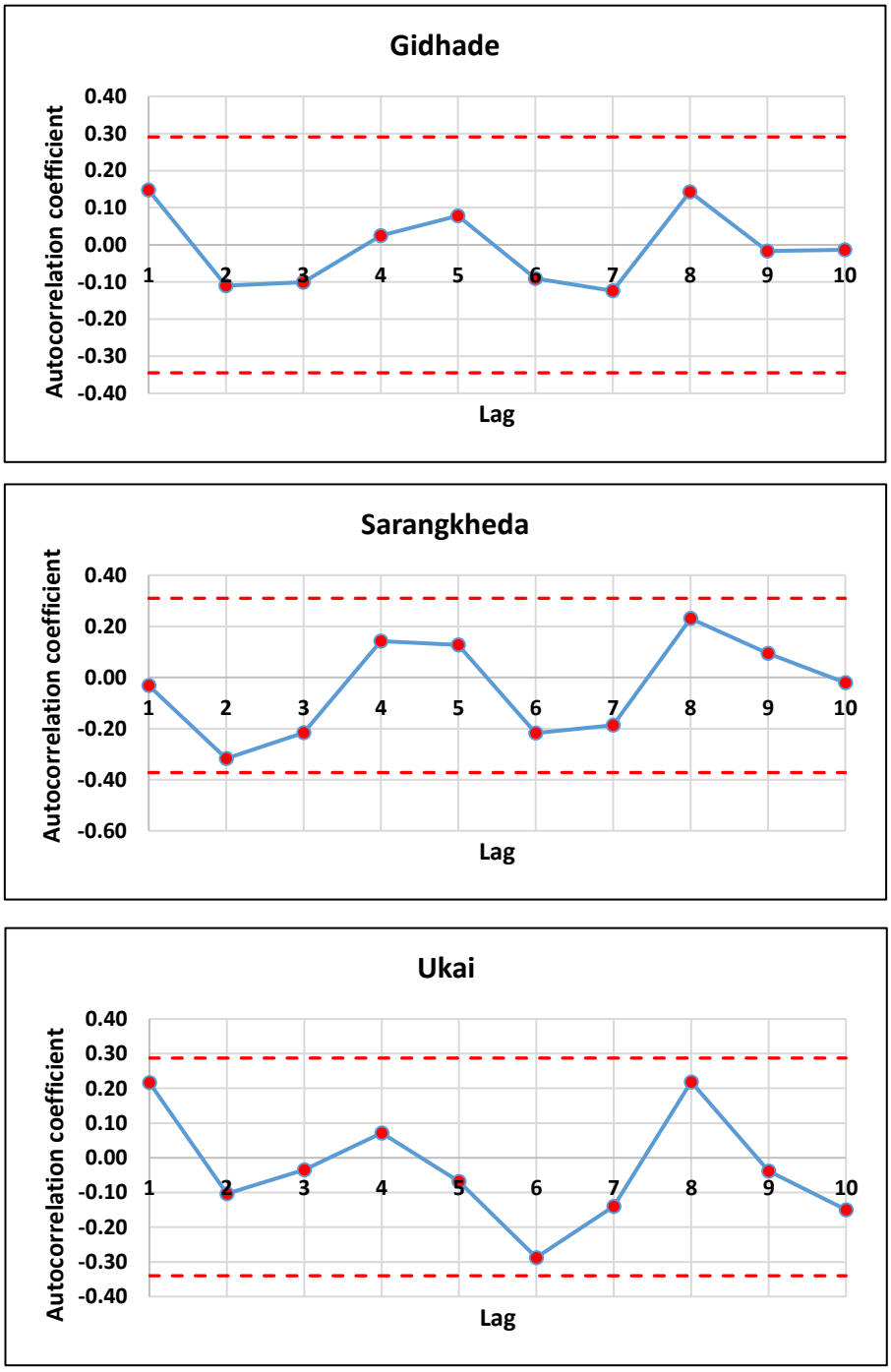


Fig 6.15 Autocorrelation function (correlogram) with 5% significance tolerance band for the observed discharge time series

Hence, it can be inferred that the annual maximum discharge series at all stations in the study area come from a population that is independently distributed.

6.4.2 Test for Homogeneity (Cumulative Deviations Test)

To make sure that the observed discharge data at all the stations come from populations that haven't undergone any serious change over time due to changes in the type of gauge used, rapid

urbanization etc. homogeneity test were conducted. In the present study a non-parametric cumulative deviations test is adopted.

Cumulative deviations test for homogeneity is based on adjusted partial sums or cumulative deviations from the mean, which is expressed as:

$$S_k^* = \sum_{t=1}^{k}(X_t - \bar{X}), \qquad k = 1, 2, \dots, n \tag{6.9}$$

Rescaled adjusted partial sums (S_k^{**}) are obtained by dividing (S_k^*) by the sample standard deviation (σ) is given by:

$$S_k^{**} = S_k^*/\sigma,\ k = 1, 2, \dots, n \tag{6.10}$$

Sensitivity to the departures (Q) from homogeneity is defined by the following statistic:

$$Q = \max_{0 \le k \le n} |S_k^{**}| \tag{6.11}$$

High values of Q are an indication of non-homogeneity in the time series. Another statistic which can be used for testing homogeneity is the range (R), which is defined as:

$$R = \max_{0 \le k \le n} |S_k^{**}| - \min_{0 \le k \le n} |S_k^{**}| \tag{6.12}$$

The test statistic is calculated as per Eq. 12 and compared with that of the critical value of the same at 5% level of significance given by Machiwal and Jha, (2012). The results are as tabulated in Table 6.6.

Table 6.6 Test statistics computed for Cumulative Deviations test

Station	Dedtalai	Burhanpur	Savkheda	Gidhade	Sarangkheda	Ukai
$Q/\sqrt{n}$	1.01	0.53	0.81	1.04	0.43	0.70
$\left(Q/\sqrt{n}\right)critical$	1.123	1.129	1.123	1.128	1.123	1.129

It can be observed from Table 6.6 that none of the stations' test statistics exceed the critical value at 5% level of significance. Hence, it can be concluded that the data come from homogenous populations.

6.4.3 **Estimation of Flood Discharges using Gumbel's Distribution**

The annual maximum series for observed floods for stream gauging stations, included in Table 6.4, have been used to compute the flood of different return periods using Gumbel's Distribution. The flow rate corresponding to a return period of 2 years is also computed for each station which is the bankfull/channel forming discharge at that station. These flow rates

are the ones which contribute maximum to the channel geometry, and are subsequently used to develop hydraulic geometry equations at various stations.

The magnitude of a flood event of *T*- years return period is given as:

$$x_T = u + \alpha y_T \qquad \mathbf{6.13}$$

Here, x_T is the flood quantile corresponding to a return period of *T*. The parameter *u* is the mode of the distribution (point of maximum probability density)**,** α is related to the standard deviation of the sample (*s*), which can be expressed as:

$$\alpha = \frac{\sqrt{6}s}{\pi} \qquad \mathbf{6.14}$$

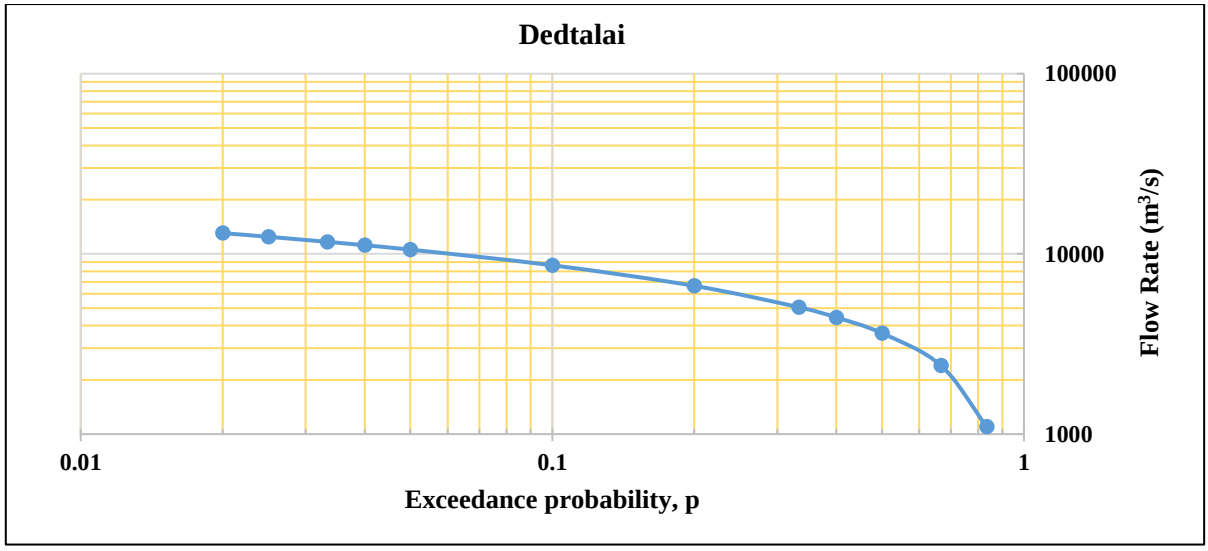
and y_T is the reduced variate related to the return period *T* as

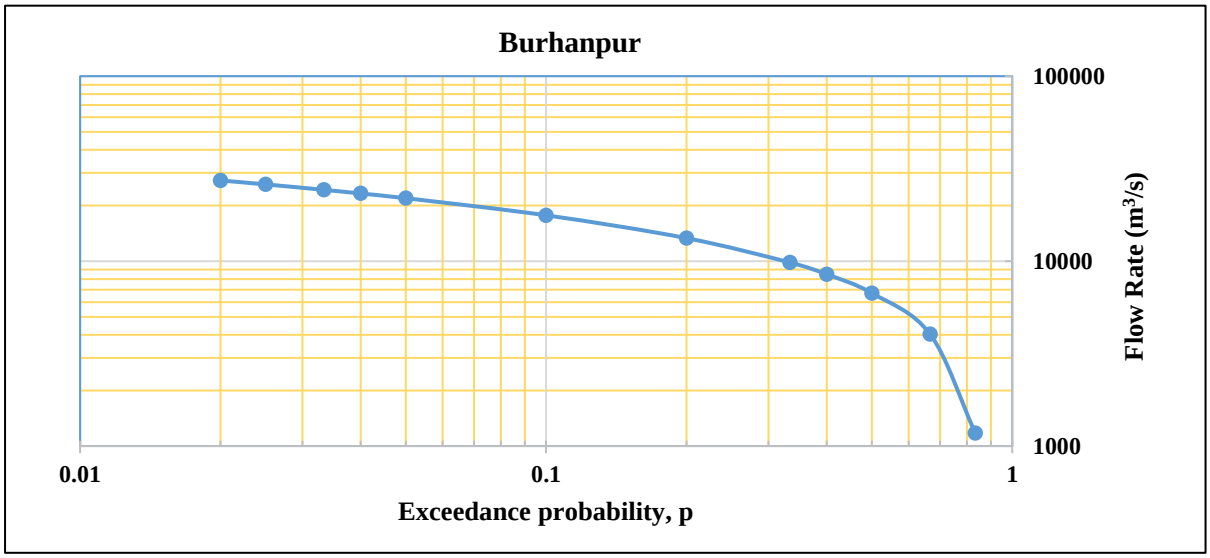
$$y_T = -ln\left[ln\left(\frac{T}{T-1}\right)\right] \qquad \mathbf{6.15}$$

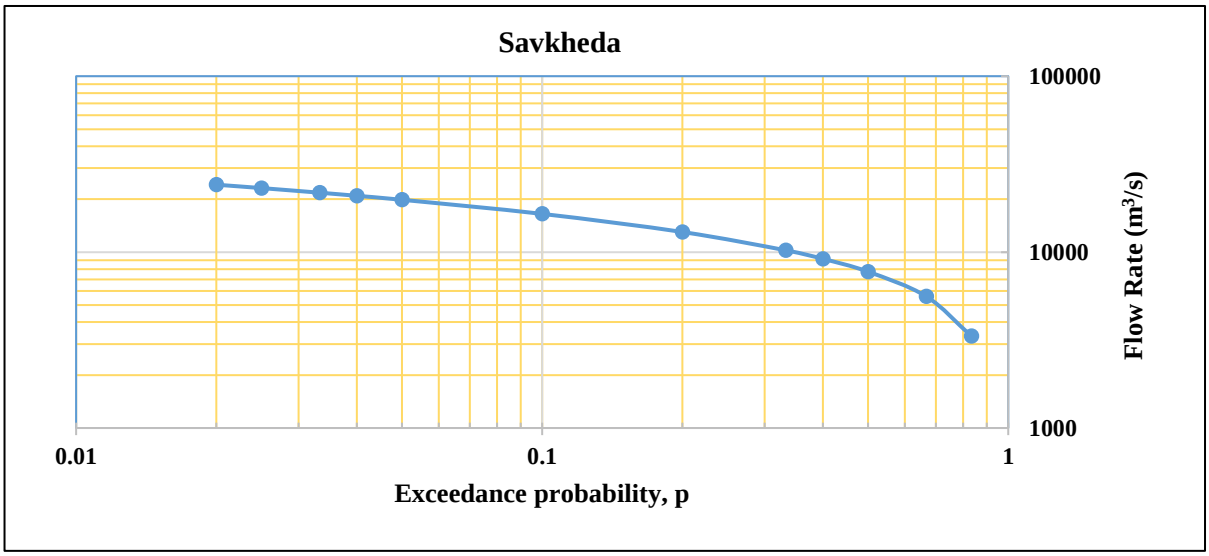
Using Eqns. 6.13 to 6.15, flood quantiles corresponding to different return periods, ranging from 1.5 years to 50 years have been obtained at all the stations (Table 6.7), and the exceedance probability curves, showing the variation between the flood quantiles and their probability of exceedance are been plotted in Fig 6.16.

Table 6.7 At-site flood quantiles for various return periods

Return Periods (*T*)	Flood Quantiles (m^3/s)	Station					
		Dedtalai	**Burhanpur**	**Savkheda**	**Gidhade**	**Sarangkheda**	**Ukai**
1.2		1100.71	1699.01	3331.21	3118.22	3171.09	4427.83
1.5		**2403.51**	**4185.87**	**5602.95**	**5485.11**	**5580.31**	**7446.58**
2		**3630.18**	**6527.38**	**7741.91**	**7713.66**	**7848.73**	**10288.90**
2.5		4443.09	8079.10	9159.40	9190.53	9352.01	12172.50
3		5058.32	9253.48	10232.19	10308.25	10489.73	13598.06
5		6648.96	12289.76	13005.83	13198.07	13431.23	17283.75
10		8647.65	16104.96	16491.01	16829.22	17127.34	21914.95
20		10564.85	19764.59	19834.08	20312.31	20672.73	26357.31
25		11173.01	20925.48	20894.54	21417.19	21797.37	27766.48
30		11667.76	21869.89	21757.26	22316.04	22712.30	28912.89
40		12445.35	23354.19	23113.16	23728.74	24150.27	30714.65
50		13046.46	24501.61	24161.33	24820.81	25261.87	32107.48


Dedtalai
100000
10000
1000
Flow Rate (m3/s)
0.01
0.1
1
Exceedance probability, p


Burhanpur
100000
10000
1000
Flow Rate (m3/s)
0.01
0.1
1
Exceedance probability, p


Savkheda
100000
10000
1000
Flow Rate (m3/s)
0.01
0.1
1
Exceedance probability, p

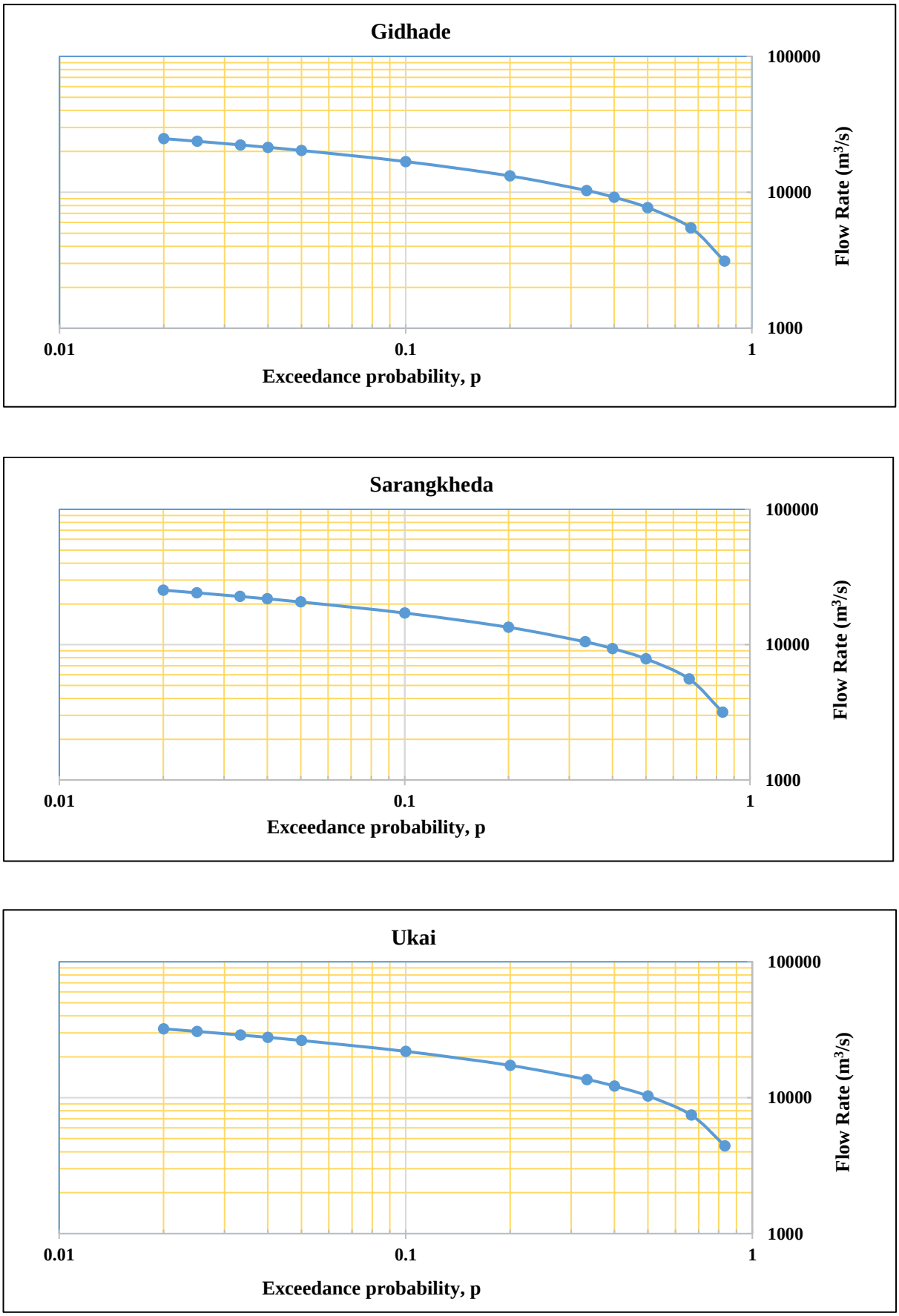


Fig 6.16 Exceedance probability curves at various stations

The exceedance probability curves which shows the variation between the maximum flows and their corresponding probability of exceedance, at different hydrological observatory sites located on the Tapi River, can be used to predict the channel discharge corresponding to 1.5 year and 2-year return period.

6.5 DEVELOPMENT OF HYDRAULIC GEOMETRY EQUATIONS

The term "hydraulic geometry" signifies the relationships between the mean stream channel form and discharge both at-a-station and downstream along a stream network in a hydrologically homogeneous basin (Singh, 2003). Hydraulic geometry is of utmost importance in planning, design, and management of river engineering and training works. Also, these equations are of great practical value in prediction of channel evolution; layout of river training works; design of stable canals and intakes, river flow control works, irrigation schemes, and river improvement works; and so on. The concepts of hydraulic geometry were proposed toward the end of the nineteenth century, the real formulation of the theory was put forth by Leopold and Maddock (1953). The problem undertaken in this study is to identify the rates at which the water surface width, mean depth of flow and mean velocity changes with water discharge at particular stations and cross-sections. The relationship between water surface width, mean depth of flow and mean velocity with discharge at stations were established using field observed data. The average, maximum and minimum stream power values are also computed for the stations under consideration. The theoretical background and data used for developing foregoing equations are discussed in subsequent paragraphs.

6.5.1 Hydraulic Geometry Equations

Empirical relationships were given by Leopold and Maddock (1953) which give the hydraulic geometry equations as power functions of discharge as:

$$W = a\,Q^{b}$$
$$D = c\,Q^{f} \qquad \textbf{6.16}$$
$$V = k\,Q^{m}$$

W is the river width in meters, and D is mean depth of flow in meters, V is the mean velocity in m/s and Q is the river flow in m^3/s. a, c, k, b, f and m are numerical constants. The hydraulic variables, width, depth and mean velocity satisfy continuity equation for a rectangular channel:

$$Q = WDV \qquad \textbf{6.17}$$

The coefficients and exponents in Eq. 16 satisfy the following two criteria:

$$ack = 1 \qquad \textbf{6.18}$$

$$b + f + m = 1 \qquad 6.19$$

6.5.2 Stream Power and Sediment Transport Competence

The flood power is defined in terms of discharge in m^3/s, and channel geometry which can be expressed as:

$$\omega = \frac{\gamma Q S}{W} \qquad 6.20$$

Here, ω is the unit stream power in W/m^2; γ is the specific weight of clear water (9800 N/m^2); Q is the discharge in m^3/s; S is the water surface slope and W is the top width in meters. Also,

$$\Omega = \int \frac{\gamma Q S}{W} dt \qquad 6.21$$

Here, Ω is the total energy expenditure over the period of consideration in Joules which can be computed by estimating the area under the stream-power graph; t is the time period in seconds.

The significant changes in channel geometry occur when the flood power exceeds threshold resistance. In order to express the ability of the flows to be geomorphically effective, empirical relations between unit stream power (ω) and critical entrainment threshold for cobbles and boulders are used (Kale and Hire, 2004).

$$\omega = 0.079 d^{1.27} \quad (10 \leq d \leq 1500\ mm) \qquad 6.22$$

Theoretical estimates indicate that the minimum unit stream powers required to move cobbles (>64 mm), boulders (>256 mm) and larger 0.5 m boulders are 16, 90 and 212 Wm^{-2} respectively (Kale and Hire, 2007).

6.5.3 Hydraulic Geometry Equations at Dedtalai, Burhanpur, Gidhade and Sarangkheda Stream-gauging Stations

Hydraulic geometry equations have been developed for stream gauging stations Dedtalai, Burhanpur, Gidhade and Sarangkheda, on a decadal basis, i.e., 1980-1990, 1990-2000 and 2000-2010, using the flows that ranges between return periods 1.2 years and 2 years, with the help of flood frequency relationships developed for the stations under consideration. The range of such discharges were considered as they are most likely to form the channel section. The variation in channel geometry, i.e., width of flow (W), mean depth of flow (D) and mean velocity (V) with varying discharge were analysed. The developed equations are presented in

Tables 6.8 to 6.11. The variations of exponents of Eqs. 6.16 for different stream gauging stations for periods 1980-1990, 1990-2000 and 2000-2010 are included in Tables 6.12-6.14. Further, the average and maximum stream power values were calculated using Eq. 6.20 for all the stations on decadal basis, and the results are tabulated in Table 6.15.

Table 6.8 Hydraulic geometry equations at Dedtalai stream gauging station

Time period	Dedtalai				
	W* vs *Q	***V* vs *Q***	***D* vs *Q***	***b + f + m***	***ack***
1980-1990	$W = 170.390Q^{0.04}$	$V = 0.222Q^{0.27}$	$D = 0.026Q^{0.69}$	1	0.999
1991-2000	$W = 173.200Q^{0.04}$	$V = 0.165Q^{0.32}$	$D = 0.035Q^{0.64}$	1	1
2001-2010	$W = 139.070Q^{0.07}$	$V = 2.204Q^{-0.03}$	$D = 0.0033Q^{0.96}$	1	1.010

Table 6.9 Hydraulic geometry equations at Burhanpur stream gauging station

Time period	Burhanpur				
	W* vs *Q	***V* vs *Q***	***D* vs *Q***	***b + f + m***	***ack***
1980-1990	$W = 29.329Q^{0.24}$	$V = 0.044Q^{0.52}$	$D = 0.773Q^{0.24}$	1	0.998
1991-2000	$W = 49.126Q^{0.17}$	$V = 0.145Q^{0.36}$	$D = 0.141Q^{0.47}$	1	1
2001-2010	$W = 43.740Q^{0.20}$	$V = 0.100Q^{0.39}$	$D = 0.228Q^{0.41}$	1	0.997

Table 6.10 Hydraulic geometry equations at Gidhade stream gauging station

Time period	Gidhade				
	W* vs *Q	***V* vs *Q***	***D* vs *Q***	***b + f + m***	***ack***
1980-1990	N/A	N/A	N/A	N/A	N/A
1991-2000	$W = 343.720Q^{0.02}$	$V = 0.080Q^{0.38}$	$D = 0.036Q^{0.60}$	1	0.990
2001-2010	N/A	N/A	N/A	N/A	N/A

Table 6.11 Hydraulic geometry equations at Sarangkheda stream gauging station

Time period	Sarangkheda				
	W* vs *Q	***V* vs *Q***	***D* vs *Q***	***b + f + m***	***ack***
1980-1990	$W = 230.610Q^{0.10}$	$V = 0.176Q^{0.28}$	$D = 0.025Q^{0.62}$	1	1.01
1991-2000	N/A	N/A	N/A	N/A	N/A
2001-2010	$W = 335.130Q^{0.05}$	$V = 0.058Q^{0..40}$	$D = 0.052Q^{0.55}$	1	1.01

Table 6.12 Exponents of at-station hydraulic geometry during 1980-1990

Station	*W* (*b*)	*D* (*f*)	*V* (*m*)	*b/f*	*m/f*
Dedtalai	0.040	0.690	0.270	0.058	0.390
Burhanpur	0.240	0.240	0.520	1.00	2.17
Gidhade	N/A	N/A	N/A	N/A	N/A
Sarangkheda	0.100	0.620	0.280	0.161	0.452

Table 6.13 Exponents of at-station hydraulic geometry during 1990-2000

Station	*W* (*b*)	*D* (*f*)	*V* (*m*)	*b/f*	*m/f*
Dedtalai	0.040	0.640	0.320	0.063	0.500
Burhanpur	0.170	0.470	0.360	0.362	0.766
Gidhade	0.020	0.600	0.380	0.033	0.633
Sarangkheda	N/A	N/A	N/A	N/A	N/A

Table 6.14 Exponents of at-station hydraulic geometry during 2000-2010

Station	*W* (*b*)	*D* (*f*)	*V* (*m*)	*b/f*	*m/f*
Dedtalai	0.070	0.960	-0.030	0.073	-0.031
Burhanpur	0.200	0.410	0.390	0.488	0.951
Gidhade	N/A	N/A	N/A	N/A	N/A
Sarangkheda	0.050	0.550	0.400	0.091	0.727

Table 6.15 Stream power computed at various stations

Station	1980-1990		1990-2000		2000-2010	
	ω_{avg} (W/m^2)	ω_{max} (W/m^2)	ω_{avg} (W/m^2)	ω_{max} (W/m^2)	ω_{avg} (W/m^2)	ω_{max} (W/m^2)
Dedtalai	25.29	50.78	38.87	178.82	36.20	99.87
Burhanpur	164	512.64	41.5	92.75	37.05	87.43
Gidhade	N/A	N/A	71.74	136.17	N/A	N/A
Sarangkheda	27.51	75.60	N/A	N/A	21.32	36.77

It can be observed from Table 6.15 that compared to the stations in the middle reaches of Tapi River like Gidhade and Sarangkheda, the stream power in the stations of upper reaches is more. In Burhanpur, the maximum stream power calculated in all decades, are capable of moving sediments of the size of boulders and very large boulders. Because of narrow and incised nature of the channel in the upper reaches, flows get deeper and faster as the discharge increases. The low values of width by depth ratios (b/f) shown in Tables 6.12-6.14 is an indication of increase in depth of flow at a much faster rate. The increase in velocity enhances the stream power.

Thus, when large flows occur, the stream power and the sediment transport competence increase in upper reaches where the bed stratum is rocky.

6.6 RAINFALL RUNOFF ANALYSIS

The problem of transformation of rainfall into runoff has been a subject of scientific investigations and evaluation in the field of hydrology. Several investigators have tried to relate runoff with various governing characteristics of watersheds such as the time of concentration. Each catchment has its own runoff response and will respond differently to different rainstorm events, depending upon site-specific factors like soil type, vegetation, slope & catchment size as well as physical conditions prevailing in the catchment. The design of water harvesting schemes requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion (percentage) of the rainfall depth and is given as:

$$\boldsymbol{Runoff\ (mm) = C \times Rainfall\ depth\ (mm)} \qquad \mathbf{6.23}$$

In present study, effort has been made to relate the rainfall (mm) and runoff depth (mm), at Hatnur Dam and Ukai Dam for period 1990-2013, by calculating the rainfall-runoff coefficients using Eq. 6.23. The rainfall depth was obtained by calculating the lumped rainfall in the catchments with their outlets at Hatnur and Ukai Reservoirs. Theissen Polygon method was employed for obtaining lumped values from rainfall data at various rain gauge stations that lie within the catchment areas of Hatnur and Ukai Dams. The lumped values were calculated using Eq. 6.24.

$$\bar{P} = \frac{P_1A_1 + P_2A_2 + \cdots \ldots \ldots + P_nA_n}{A_1 + A_2 + \cdots \ldots \ldots + A_n} \qquad \mathbf{6.24}$$

Here $\bar{P}$ is the rainfall (mm) averaged over an area $A = A_1 + A_2 + \ldots . A_n$, for n rain gauge stations. $P_1, P_2 \ldots P_n$ are individual rainfall depths for the rain gauge stations that lie within the catchment area of interest. A_i/A is called the weightage factor, which prioritises the rain gauge stations according to its area of influence. The results for the period 1990-2013 are as tabulated in Table 6.16. The variation of rainfall-runoff coefficient (C) with time, for Hatnur Dam and Ukai Dam are shown in Figs. 6.17-6.18.

Table 6.16 Rainfall-Runoff coefficients at Hatnur Dam and Ukai Dam

Water Year	Hatnur Dam			Ukai Dam		
	Runoff Depth (mm)	Lumped Rainfall (mm)	*C*	Runoff Depth (mm)	Lumped Rainfall (mm)	*C*
1990-1991	357.42	1195.96	0.30	264.51	907.62	0.29
1991-1992	91.54	594.56	0.15	69.01	579.55	0.12
1992-1993	129.09	832.18	0.16	118.54	777.93	0.15
1993-1994	202.24	823.05	0.25	142.32	845.88	0.17
1994-1995	361.60	1105.90	0.33	289.80	916.46	0.32
1995-1996	136.36	751.21	0.18	80.93	635.52	0.13
1996-1997	155.08	856.86	0.18	116.88	788.10	0.15
1997-1998	151.55	961.88	0.16	144.96	884.82	0.16
1998-1999	271.12	1038.69	0.26	242.09	1029.73	0.24
1999-2000	219.06	986.48	0.22	141.66	787.15	0.18
2000-2001	71.02	615.05	0.12	57.34	542.27	0.11
2001-2002	111.42	828.43	0.13	76.58	706.21	0.11
2002-2003	237.95	1619.62	0.15	164.36	789.77	0.21
2003-2004	122.39	769.80	0.16	145.66	748.78	0.19
2004-2005	82.47	658.62	0.13	83.73	656.71	0.13
2005-2006	140.60	780.59	0.18	123.33	726.68	0.17
2006-2007	321.50	1026.31	0.31	370.85	1112.92	0.33
2007-2008	332.65	1080.31	0.31	242.83	942.16	0.26
2008-2009	89.02	651.23	0.14	76.34	653.90	0.12
2009-2010	85.42	822.76	0.10	59.30	780.62	0.08
2010-2011	233.50	961.00	0.24	146.31	865.57	0.17
2011-2012	180.67	761.23	0.24	133.45	674.71	0.20
2012-2013	323.38	936.34	0.35	174.11	699.65	0.25
Average			**0.21**			**0.18**

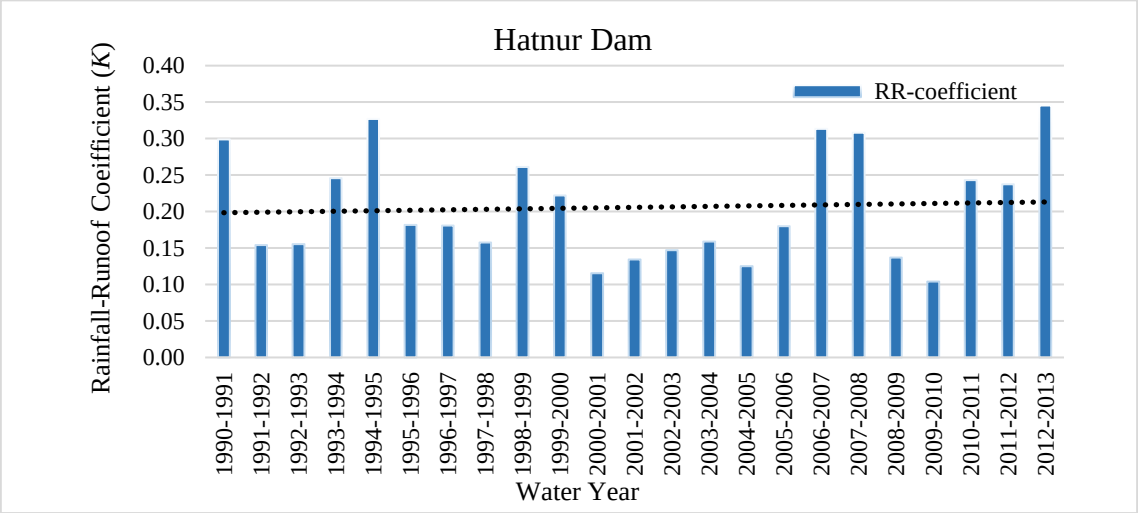


Fig 6.17 Variation of Rainfall-Runoff coefficients at Hatnur Dam during 1990-2013

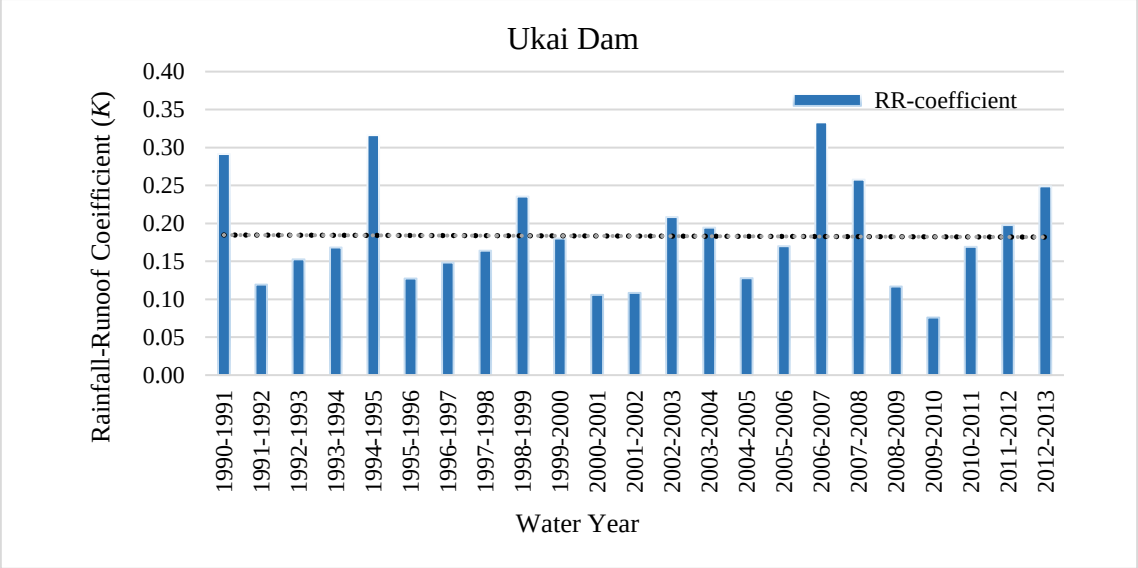


Fig 6.18 Variation of Rainfall-Runoff coefficients at Ukai Dam during 1990-2013

The average values of runoff coefficients at Hatnur Dam and Ukai Dam are 0.21 and 0.18 respectively, during 1990-2013. Also, at Hatnur a slight increase can be noted in runoff coefficients, whereas at Ukai, the variation is almost negligible over the time. The Hatnur Dam falls at the end of the Upper Tapi River reach, where the river is still in its youthful stage and flows with extremely high velocity. Also, the rain gauge stations are in high altitude zones, thereby increasing the effect of orographic precipitation.

6.7 ANALYSIS OF SUSPENDED SEDIMENT

Transport of sediment is one of the major parameters on the flow line or channels. The study of sediments and nature of its deposits on downstream are very important for management of existing water storage structures on the stream and studying the morphodynamic behaviour of the streams. Sound database on sediments are essential for policy making and planning purposes. The Central Water Commission (CWC) reports measurement of suspended sediments in three different grades, namely, coarse sediment, having particles with diameter above 0.2 mm, medium sediment with diameter ranging from 0.075 to 0.2 mm and fine sediment with diameter less than 0.075 mm.

The sediment transport rate in tonnes/day corresponding to a discharge of Q m^3/s is expressed as:

$$Q_s = Q \times C_s \times 60 \times 60 \times \frac{24}{1000000} \quad \frac{tonnes}{day} \qquad 6.25$$

Here C_s is the suspended sediment concentration in parts per million (ppm) or mg/L. The relation between Q_s and stream discharge Q is generally represented in a logarithmic plot known as sediment rating curve and can be represented in equation form as:

$$\boldsymbol{Q_s = KQ^n} \qquad \textbf{6.26}$$

The exponent n ranges between 1.0 and 3.0. In the present study, the effort has been made to observe the decadal variation in suspended sediment concentration in tonnes/day with discharge in Tapi River in m^3/s by constructing sediment rating curves at Burhanpur and Sarangkheda stations. These curves were developed for the monsoon months, i.e., June-October, separately for each decade 1980-1990, 1991-2000 and 2001-2010. The monthly average discharges (m^3/s) at each station were related to the average sediment transport rate (Q_s tonnes/day) on a decadal basis. The variation of exponents of Eq 6.26, obtained for each station for each month are evaluated and interpretations are made related to the sediment carrying capacity of the Tapi River in its Upper (Burhanpur) and Middle (Sarangkheda) reaches.

Table 6.17 Decadal variation in sediment rating curve equation exponents

Month	Burhanpur			Sarangkheda		
	1980-1990	1991-2000	2001-2010	1980-1990	1991-2000	2001-2010
June	2.33	1.94	1.87	2.80	1.82	2.02
July	1.53	1.96	1.54	1.53	1.66	1.80
August	0.98	1.74	0.88	1.02	2.36	2.30
September	2.65	1.99	1.93	2.00	1.95	1.81
October	2.46	1.68	1.73	2.21	1.71	2.00

Figs 6.19-6.24 shows the decadal variation of sediment transport rate at Burhanpur and Sarangkheda stations for the month of June. Also, the variation in exponent values of Eq 6.26 for both the stations are tabulated in Table 6.17. It can be observed that in both the stations, during monsoon months, the concentration of suspended sediment is high. In Burhanpur station which falls in Upper Tapi River, in all months except October, we can observe a decrease in sediment transport rate. The rocky bed stratum of the Tapi River as well as the construction of new hydraulic structures in the Upper Tapi Basin may be the reason for this decrease in suspended sediment transport rate. However, when it comes to Middle reaches of the river, it can be observed that in the recent decade, i.e., 2001-2010, there has been an increase in the sediment transport rate in all months except September. The Tapi River flows through alluvial plains as it enters its Middle reaches. The increase in sediment transport in Middle reaches of

Tapi River, particularly in June, July and August months, could be due to increase in agricultural areas with time in the Middle Tapi basin.

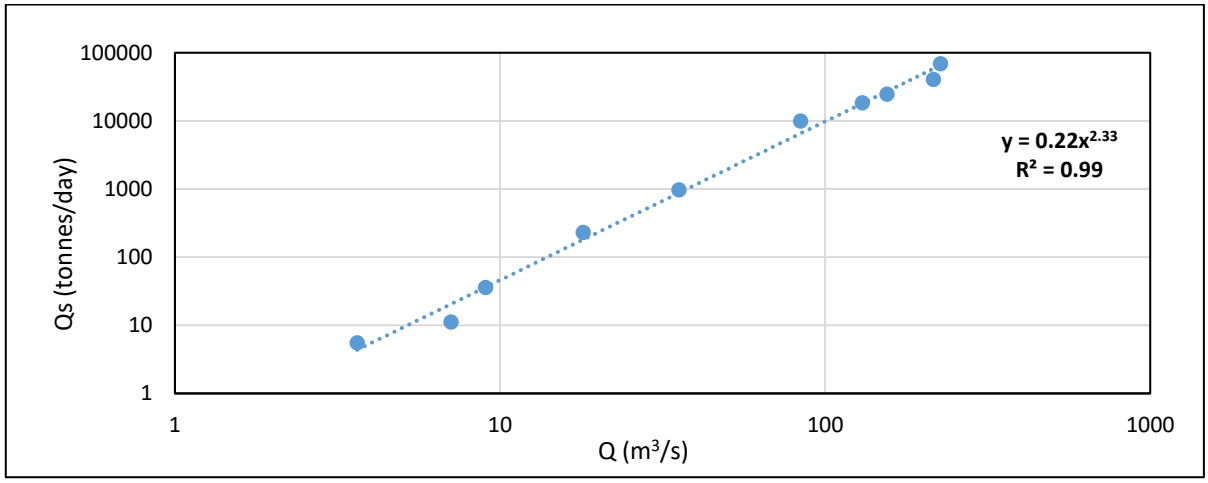


Fig 6.19 Sediment rating curve during 1980-1990 for the month June at Burhanpur station

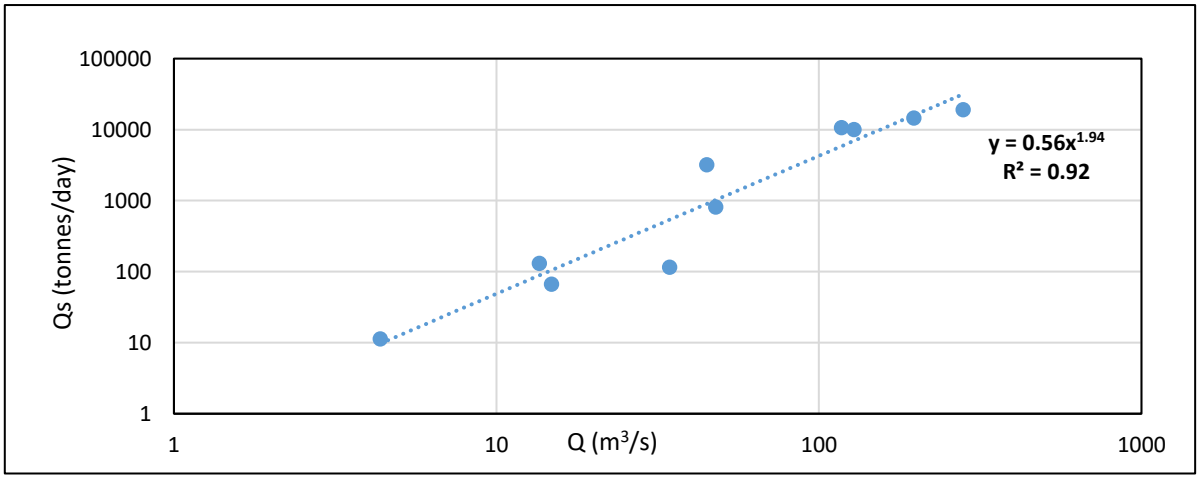


Fig 6.20 Sediment rating curve during 1990-2000 for the month June at Burhanpur station

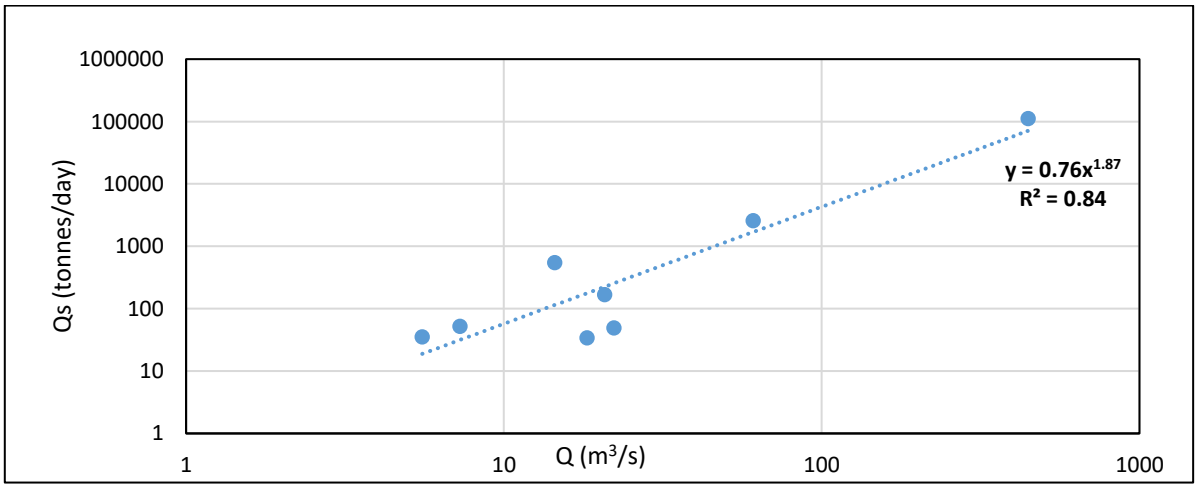


Fig 6.21 Sediment rating curve during 2000-2010 for the month June at Burhanpur station

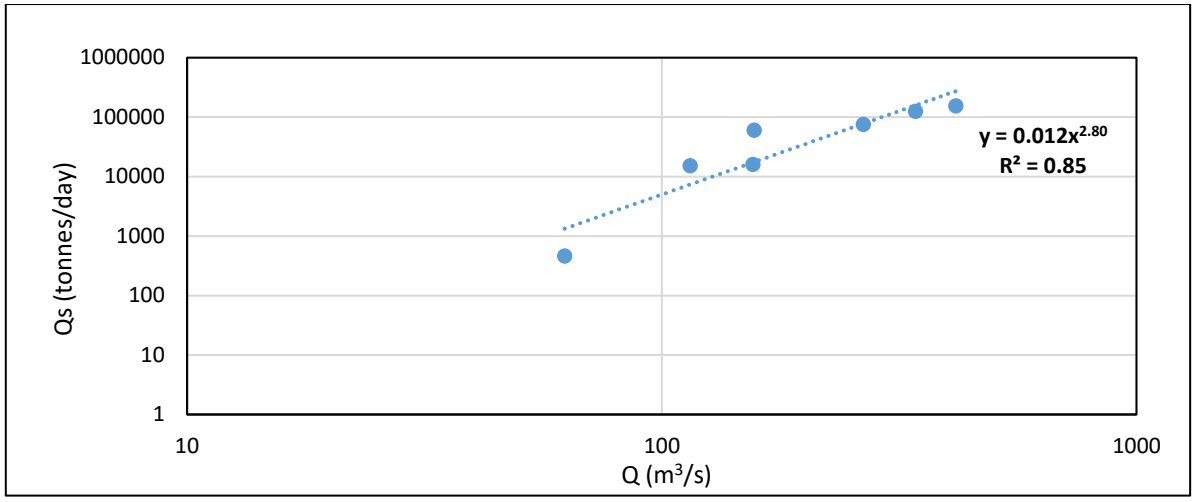


Fig 6.22 Sediment rating curve during 1980-1990 for the month June at Sarangkheda station

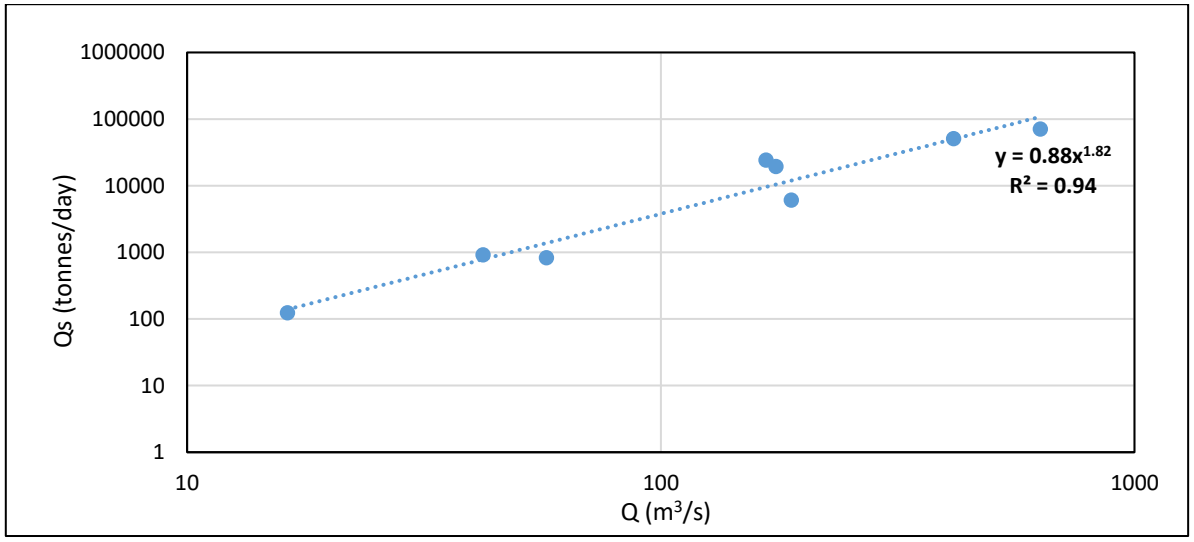


Fig 6.23 Sediment rating curve during 1990-2000 for the month June at Sarangkheda station

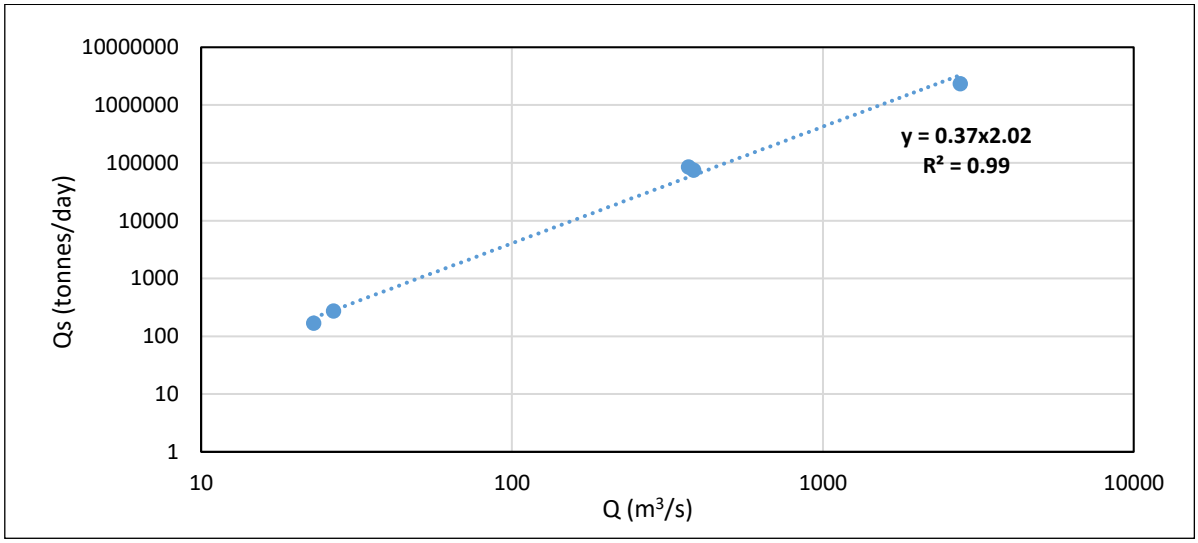


Fig 6.24 Sediment rating curve during 2000-2010 for the month June at Sarangkheda station

CHAPTER 7
BASIN GEOLOGY

7.1 GENERAL

The geological information of Tapi basin including the Betul, Burhanpur, districts of Madhya Pradesh and Amravati, Jalgaon, Dhule and Nandurbar districts of Maharashtra were collected from the Geological survey of India (GSI), Nagpur. The additional information on the hydrogeology of the catchment were downloaded from Central Ground Water Board (CGWB) website (http://www.cgwb.gov.in/District_Profile/) from report published district profile reports of Betul, Burhanpur, Amravati, Jalgaon, Dhule, Nandurbar, Tapi and Surat districts. Fig. 7.1 illustrates the spatial geological distribution along the banks of the Tapi river. Further, Fig. 7.2 explains the ground water exploration in Tapi alluvial area with fence diagram of Tapi alluvium aquifer.

7.2 GEOLOGY IN TAPI BASIN

7.2.1 Upper Tapi river

7.2.1.1 Betul district (Madhya Pradesh)

Geologically, the Tapi river basin consists of predominantly impermeable Deccan basalt of Mesozoic era and permeable recent quaternary alluvial deposits. Main geological units of the area are, Deccan traps, Granite, Laterite and soils in upper part of Tapi river from Betul and Amravati district to Burhanpur district at Dedtalai. Generally, the Deccan trap in the area occurs in the form of fractures, weathered and vesicular basalts. The Deccan traps contain diverge types of basaltic lava flows and wide-ranging rocks along upper Tapi river. These rocks are found in Betul, Multai, Bhainsdehi, and Atner blocks, see Fig. 7.3. The base flow ranging from porous layers of earthy basalt which is passed rapidly into the main body of flow consisting of great thickness of hard basalt. Occurrence and movement of ground water in hard rocks is mainly controlled by secondary porosity through joints and fractures; and primary porosity in sandstone and vesicular basalts. The groundwater resources are tapped in the fractured basalt between the depths ranging from 6 to 14.00 m below ground level (bgl). In weathered basalt, the depth of ground structures varies from 4.15 – 20 m bgl, while in vesicular type of flows the depth of ground water structures ranges from 3 to 20.00 m bgl. The yield of shallow aquifer in this formation ranges between 60 to 300 lpm.

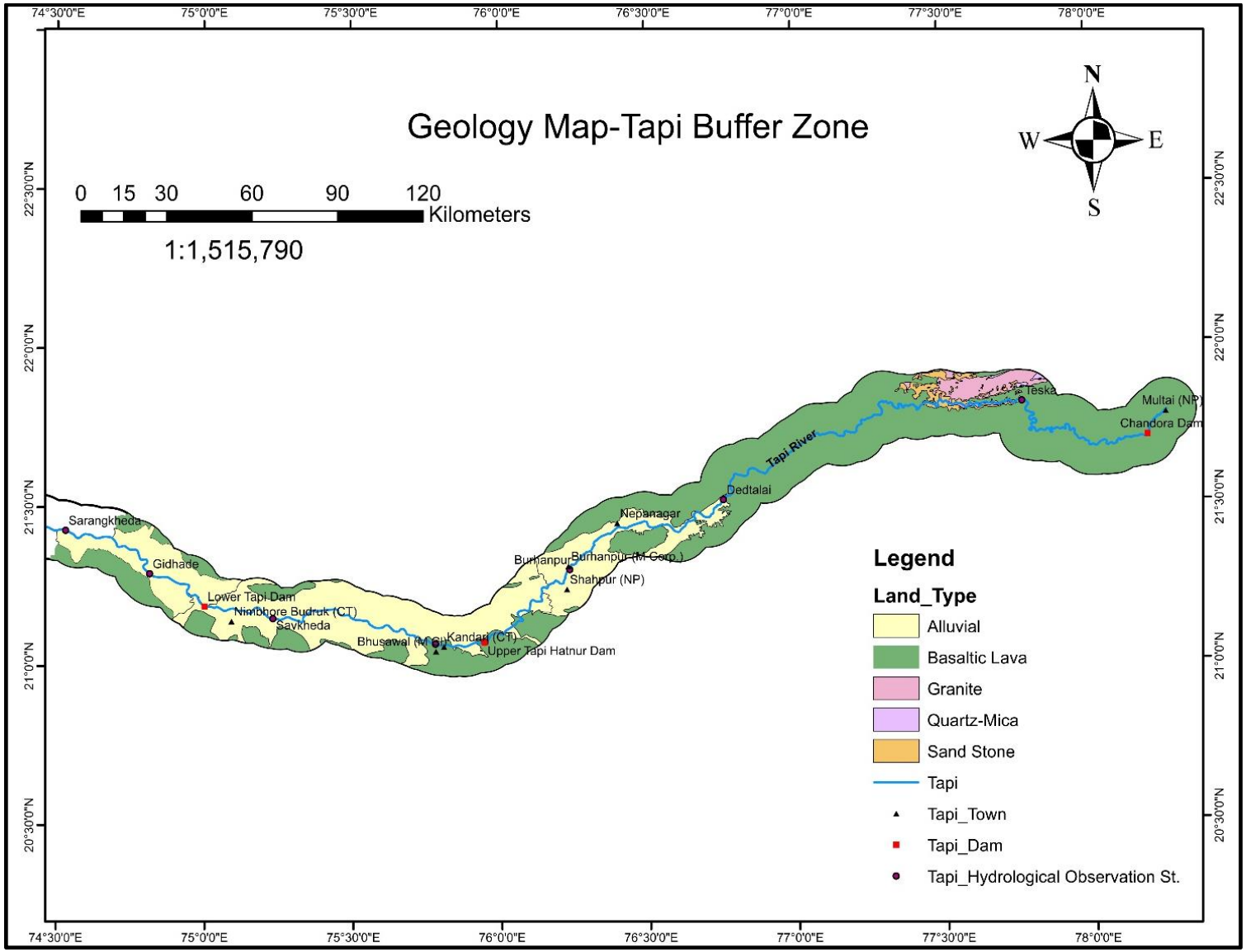


Fig. 7.1 Geological distribution along Tapi river buffer zone

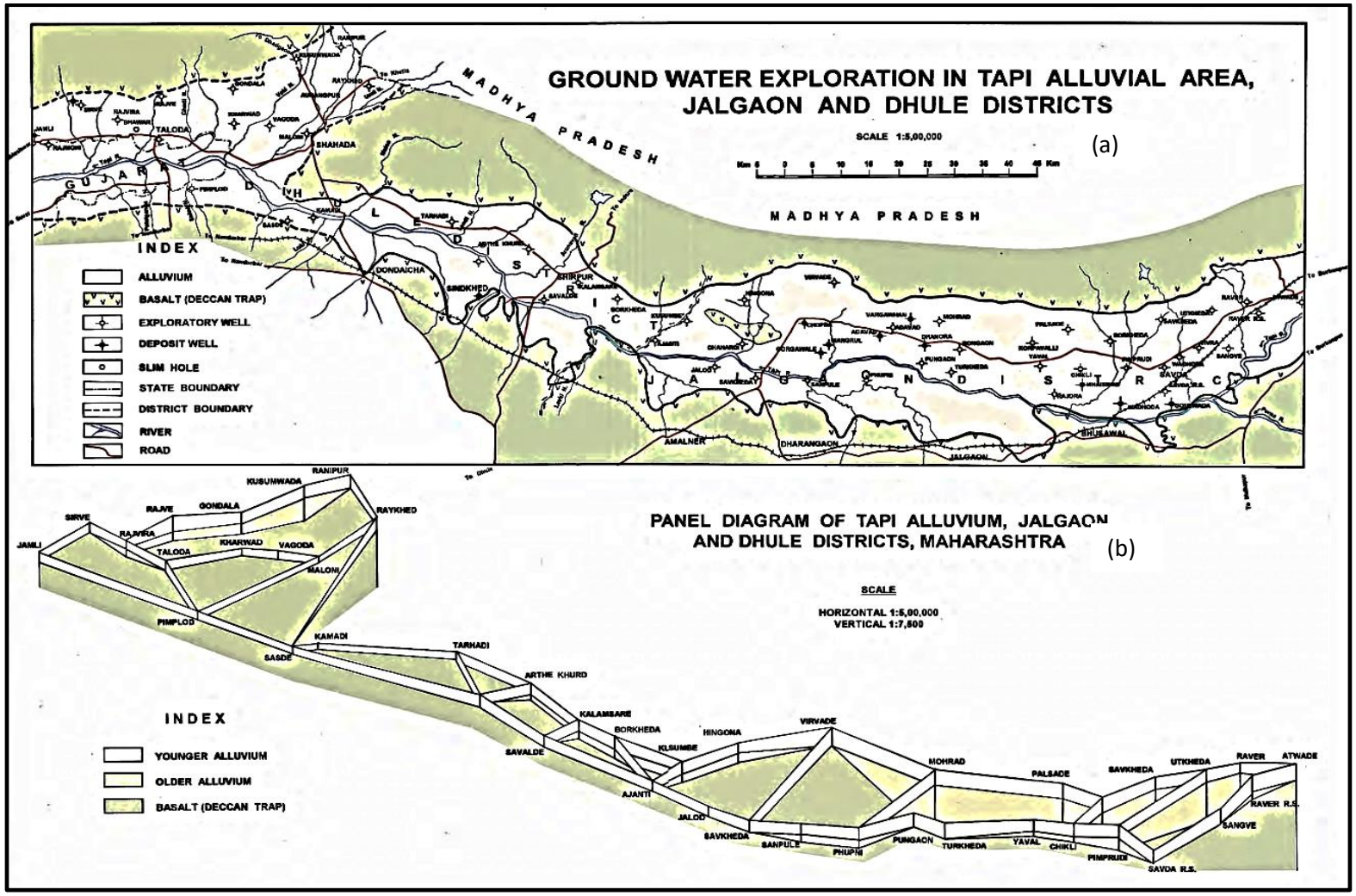


Fig. 7.2 Details of aquifer in Middle Tapi river

(a) Tapi alluvium region (b) Panel diagram of alluvium aquifer

(b) (Source: http://www.cgwb.gov.in/District_fence/CR/TAPI.pdf)

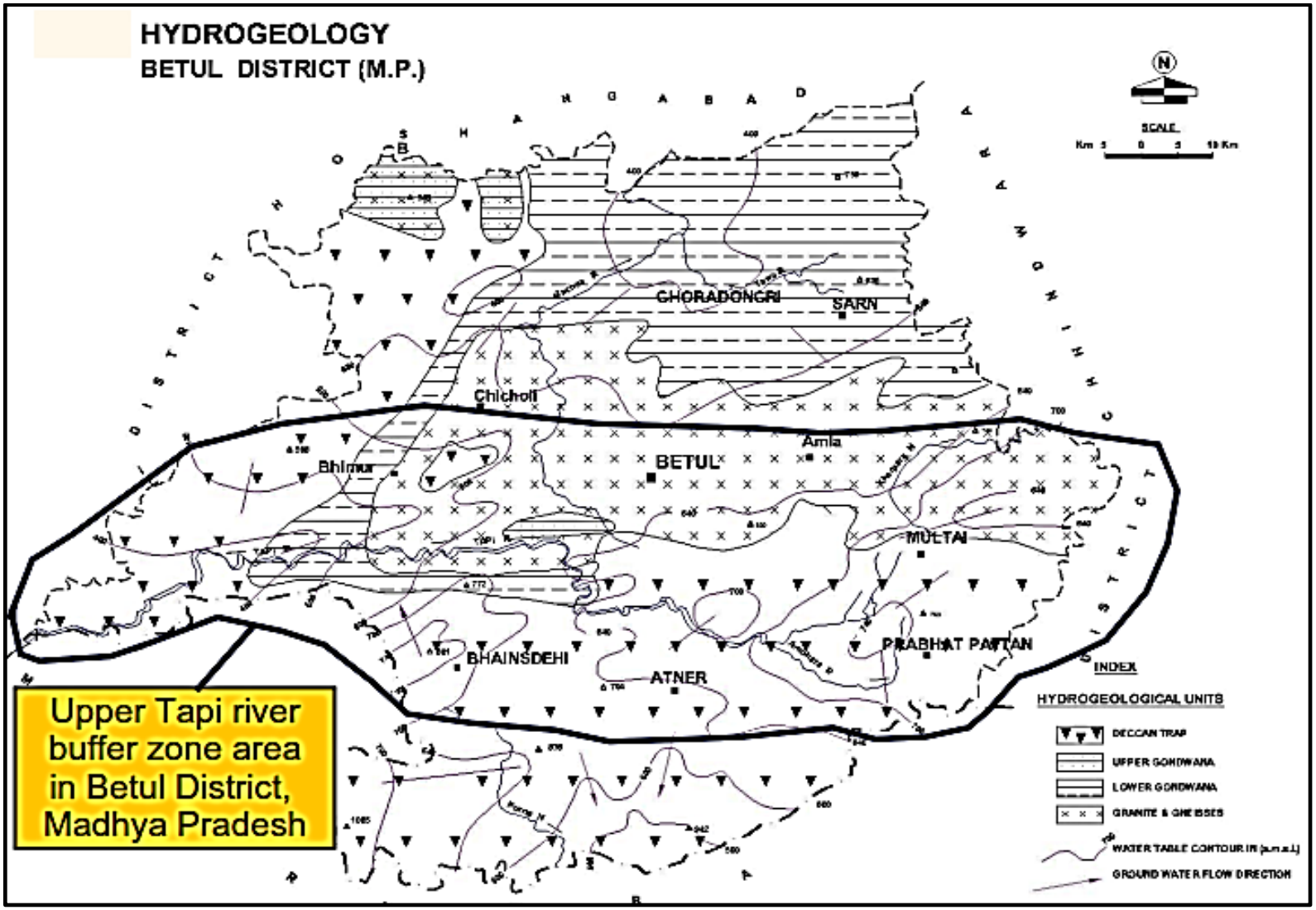


Fig. 7.3 Hydrogeology of Betul district

(Source: http://www.cgwb.gov.in/District_Profile/MP/Betul.pdf)

The Deccan traps, play significant role in ground water movement, usually occurs under unconfined and semi confined to confined conditions (CGWB, 2013a).

7.2.1.2 Amravati district (Maharashtra)

The Deccan Trap Basalt belonging to upper Cretaceous to lower Eocene age occurs in the northwestern, southeastern and eastern parts of the district. The northwestern part, i.e., Dharni and Chikaldhara talukas (see Fig. 7.4), is hilly and rugged terrain where Basalt does not form potential aquifer due to limited thickness of weathered mantle (CGWB, 2013b). The groundwater occurring in the fractures basalt formation varies between the depth ranging from 2 to 5 m bgl.

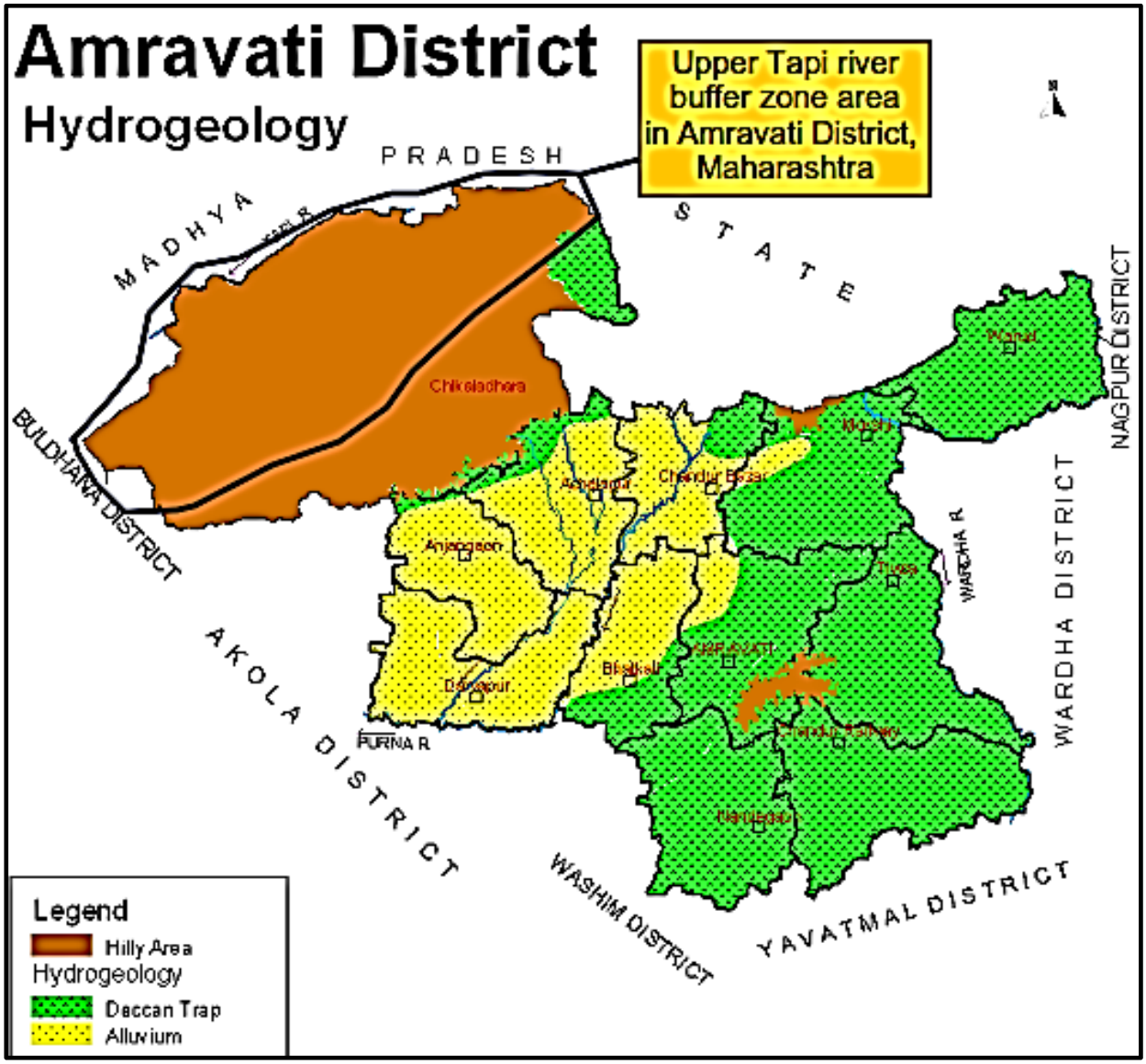


Fig. 7.4 Hydrogeology of Amravati district

(Source: http://www.cgwb.gov.in/District_Profile/Maharashtra/Jalgaon.pdf)

7.2.1.3 Burhanpur district (Madhya Pradesh)

The Tapi alluvial valley, in Burhanpur district mainly comprises of quaternary sediments, and its periphery is dominated by the Deccan basalt. Deccan Trap, consists of different lava flows whose thickness ranges between 15 m to 20 m. There are mainly two types of sedimentary deposits in the area. The predominant deposits are formed due to deposition from the river sediments transported by the Tapi river and its tributaries and is defined as alluvium. Alluvium consisting of sand, clay and gravels occurs along Tapi river course and formed unconfined, semi-confined to confined ground water conditions. Thickness of alluvium ranges from 30 to 229 m. The granular zones were met between 32 m and 42 m bgl. The yields of the bore wells constructed in the formation ranges from 4 to 20 l/s. In irrigation wells, the aquifer zone forms below thick clay of 4 to7 m in the depth ranging from 6.70 to 25.80 m bgl. The water of these wells is mainly being used in Banana cultivation with installation of drip irrigation system. The sustainable yield of wells varies from 1.5 lps to 4.0 lps. The second predominant formation is due to deposition of material (weathered, vesicular, fractured basalt) transported from the Satpura hill ranges by small streams through gravity, which is Cretaceous to Eocene age of geology rocks. The Satpura Fault (Burhanpur lineament) is a major fault towards ENE-WSE direction across the entire northern part of the watershed area along the Satpura foot hills which corresponds to the Narmada lineament. The geomorphic location of fault zone favours noticeable surface runoff and recharge to ground water. The scree is deposited at the foot hill of Satpura ranges stretching upto Tapi river, lying over Deccan Trap. The valley fill deposit is in tectonic depression resulted by concerned faults. The thickness of this formation increases towards Satpura, which is found to be more than 236 m. Basaltic lava flows of Deccan Trap is formed in Satpura, which is underlined by alluvium, see Fig. 7.5. Basaltic lava flows are fractured and jointed, constituting two aquifer systems. The unconfined aquifer is restricted up to 15 m bgl while semi- confined and confined aquifers are encountered between 45 to 190 m bgl. The potential aquifers are much diversified in nature due to structural turmoil. Higher potential aquifers occur only at the influenced zone of lineaments. The yields of the bore wells constructed in this formation ranges from 2 to 10 lps. Shallow ground water occurs in the weathered, vesicular, jointed and fractured basalts under semi-confined to confined conditions (CGWB 2013c).

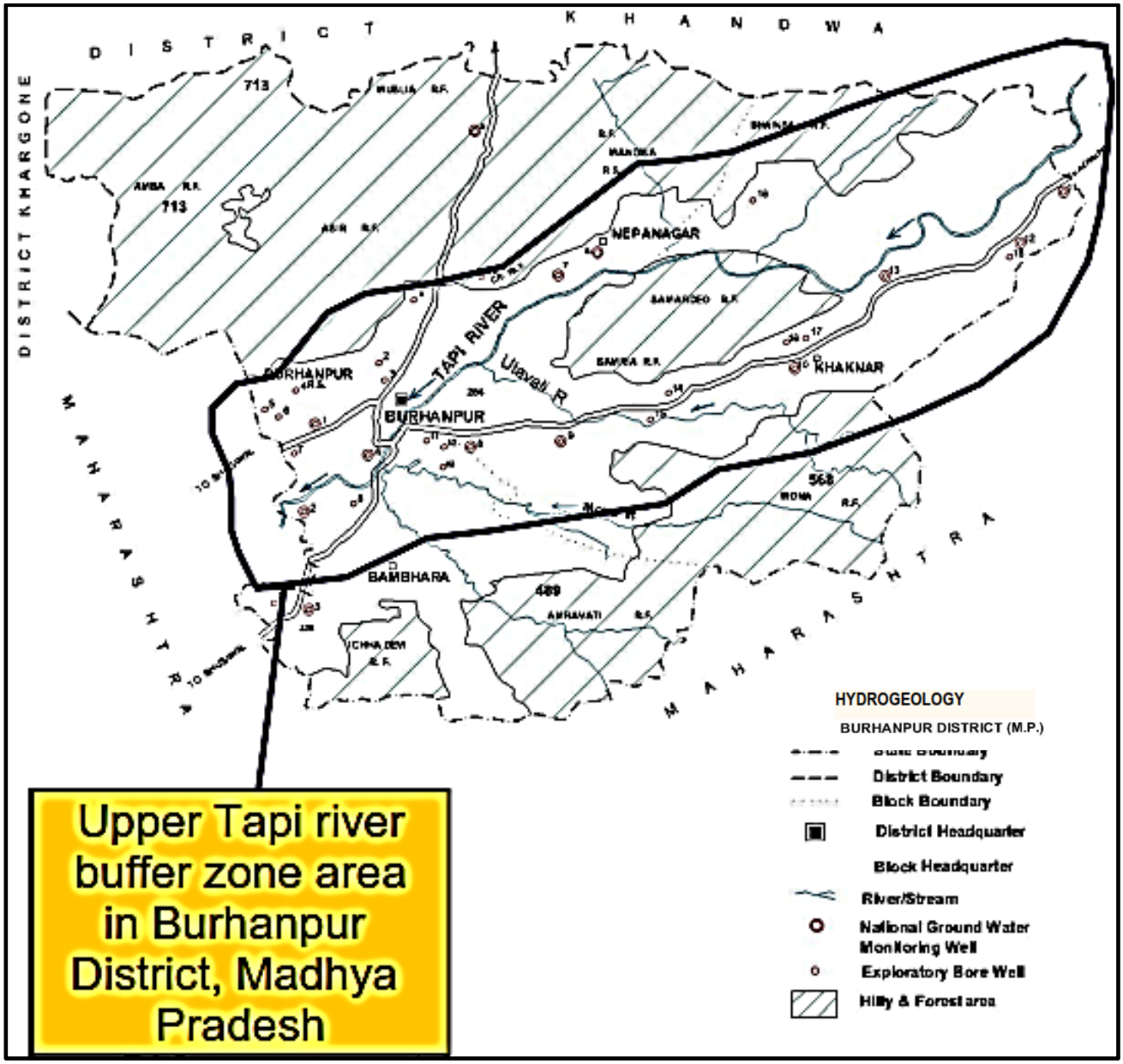


Fig. 7.5 Hydrogeology of Burhanpur district

(Source: http://www.cgwb.gov.in/District_Profile/MP/Burhanpur.pdf)

7.2.2 Middle Tapi basin

7.2.2.1 Jalgaon district

The Deccan Trap Basalt of Upper Cretaceous to Lower Eocene age, is major rock formation covering the alluvium formation in Jalgaon district. These rocks formations are intruded by the dykes of the same period. Alluvium occurs over an area of 3600 km^2 along the both banks of Tapi river. The alluvial sedimentary deposits in the Tapi valley occur as dissected alluvial cover, alluvial fans, piedmont zone, and older flood plains. Thus, main water bearing formation

in the area is alluvium wherein granular zones are encountered at various depths in unconfined as well as confined conditions. Northern part is triggered by Tapi Alluvium, see Fig. 7.6.

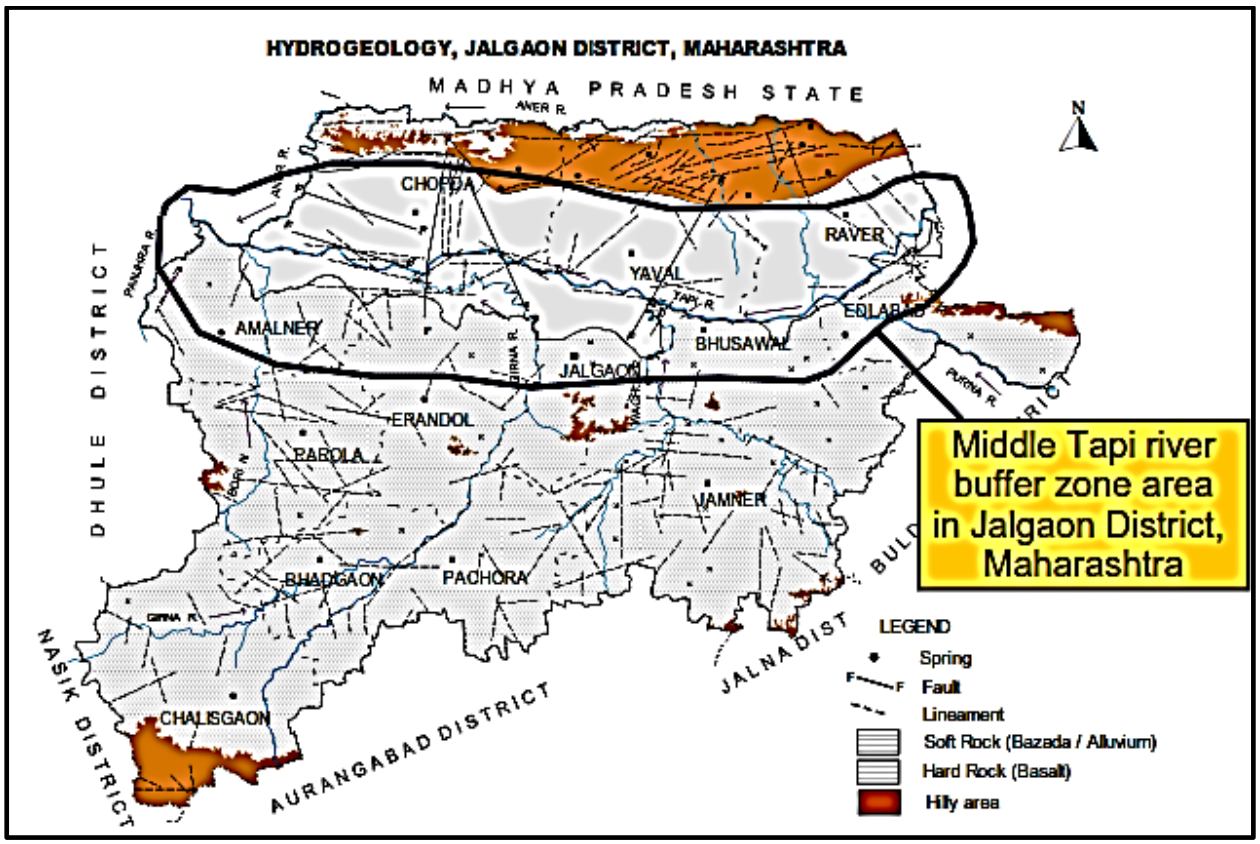


Fig. 7.6 Hydrogeology of Jalgaon district

(Source: http://www.cgwb.gov.in/District_Profile/Maharashtra/Jalgaon.pdf)

Tapi Alluvium can be divided into two sub units, i.e., the upper younger alluvium extending down to 70-80 m depth and deeper older alluvium attaining a maximum depth of 450 m. Only upper 70-80 m of younger alluvium, having 2 to 5 layers of granular zones of sand and gravel ranging in thickness from 2 to 20 m, forms the potential aquifer. At deeper levels the alluvium is mostly clayey and does not form potential aquifer. The dug wells in alluvium formations are ranging from 25 to 50 m bgl in depth with yield varying from 120 to 200 m^3/day in winter and from 100 to 150 m^3/day in summer. In Bazada aquifers, the yield of dug wells varies from 160 to 200 m^3/day in winter and 100 to 180 m^3/day in summer. Ground water in Deccan Trap Basalt occurs mostly in the upper weathered and fractured parts down to 20-25 m depths. The potential zones are encountered at deeper levels in the fractures and inter-flow zones. The upper weathered and fractured parts form phreatic aquifer, and ground water occurs under water table (unconfined) conditions. At deeper levels, the ground water occurs under semi-confined

conditions. The yield of dug wells 5-15 m bgl, tapping upper phreatic aquifer ranges between 21 and 337 m^3/day. Bore wells, drilled down to 60-150 m depths, tapping weathered and vesicular basalt, are found to yield 1.8 to 52 m^3/day (CGWB, 2013d).

7.2.2.2 Dhule district

The Deccan Traps intruded by dykes of Upper Cretaceous to Lower Eocene age Basaltic flows occupying northern parts of Shirpur, southern parts of Sindkhed covering the Tapi alluvium deposits. Tapi Alluvial deposits are observed in Tapi river valley occupying parts of Sindkhed and Shirpurtalukas, see Fig. 7.7. Alluvial deposits of Tapi river valley occurs in long narrow basin, which are probably caused by faulting. It consists of clays, silt, sand, gravels and boulders etc. The beds of sand and gravels are discontinuous. They are mixed with large proportions of clayey material rendering delimiting of individuals granular horizons difficult.

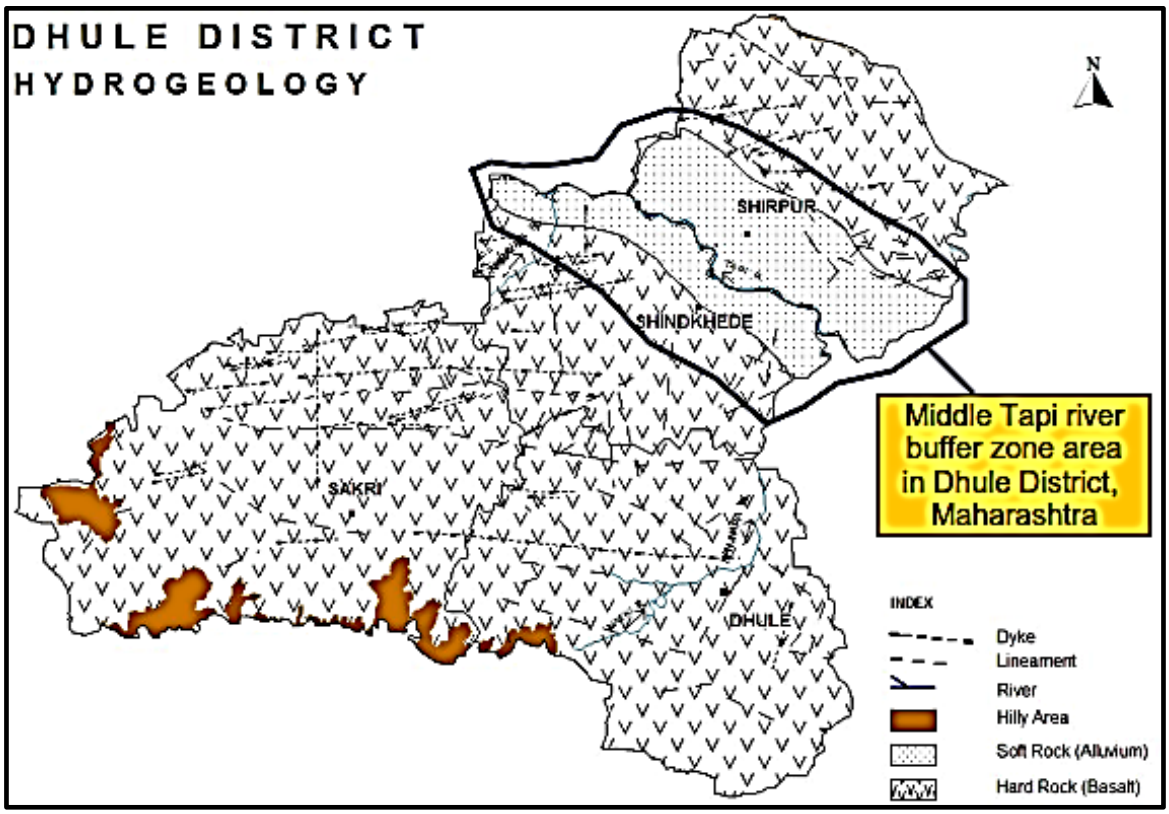


Fig. 7.7 Hydrogeology of Dhule district

(Source: http://www.cgwb.gov.in/District_Profile/Maharashtra/Dhule.pdf)

Alluvium is encountered down to 100 m depth. Ground water occurs under semi-confined and confined conditions in inter granular pore spaces of gravel and sand as observed from ground water exploration data. The yield of the dug wells varies between 150 and 200 m^3/day, whereas

that of exploratory wells varies from 1.50 to 6.00 lps as per exploration data. The yields of the tube wells drilled by State ground water department/agency ranges from 20 to 250 m^3/hr. The ground water occurs to the depth of 20 m under unconfined conditions in the weathered zone, vesicular/amygdaloidal basalt, jointed and fractured massive basalt. The water bearing strata occurring below 30 m depth, beneath the redbole and dense massive Basalt, exhibit semiconfined to confined conditions. On the elevated plateau tops, having good areal extent, local water table develops in top most layers and the wells in such areas show rapid decline in water levels in post monsoon season and go dry during peak summer. In the valleys and plains of river basin, the water table aquifer occurs at shallow depth and the wells in such areas do not go dry and sustain perennial yield except in extreme summer or drought conditions. The yield of the dug wells varies from 60 to 125 m^3/day, whereas those of bore wells varies from 2 m^3/hr to 20 m^3/hr (CWGB 2013e).

7.2.2.3 Nandurbar district

The Deccan Trap includes several flows of basalt which are supposed to have fissure volcanoes. The flows are mainly of two types, i.e., "Pahoehoe" and "aa" types, the former being very common. Alluvial deposits of Tapi river valley occurs in long narrow basin, which are probably caused by faulting. It consists of clays, silt, sand, gravels and boulders etc. The beds of sand and gravels are discontinuous and pinch out laterally inside small distance. They are mixed with large proportions of clayey material rendering delimiting of individuals granular horizons difficult. Fig. 7.8 shows hydrogeology of Nandurbar district of Maharashtra. As per ground water exploration data, alluvium is met up to 100 m depth. The ground water occurs under water table, semi-confined and confined conditions in inter granular pore spaces of gravel and sand. The yield of the dug wells varies between 150 and 200 m^3/day, whereas that of exploratory wells varies from 0.27 to 7.40 lps as per exploration. The yields of the tube wells drilled by State ground water department/agency ranges from 20 to 250 m^3/hr. Further, the ground water occurs under unconfined conditions to the depth of 20 m bgl in the weathered zone of the vesicular/amygdaloidal Basalt, jointed and fractured units of massive Basalt. Ground water occurs under semi-confined to confined conditions generally below 40 m depth beneath the red bole and dense massive Basalt in the fractured or jointed massive/vesicular/amygdaloidal Basalt. In the valleys and plains of river, the water table aquifer occurs at shallow depth, and the wells in such areas do not go dry and sustain perennial

yield except in extreme summer or drought conditions. The yield of the dug wells varies from 60 to 125 m^3/day, whereas that of bore wells varies from 2 to > 20 m^3/hr (CWGB 2013f).

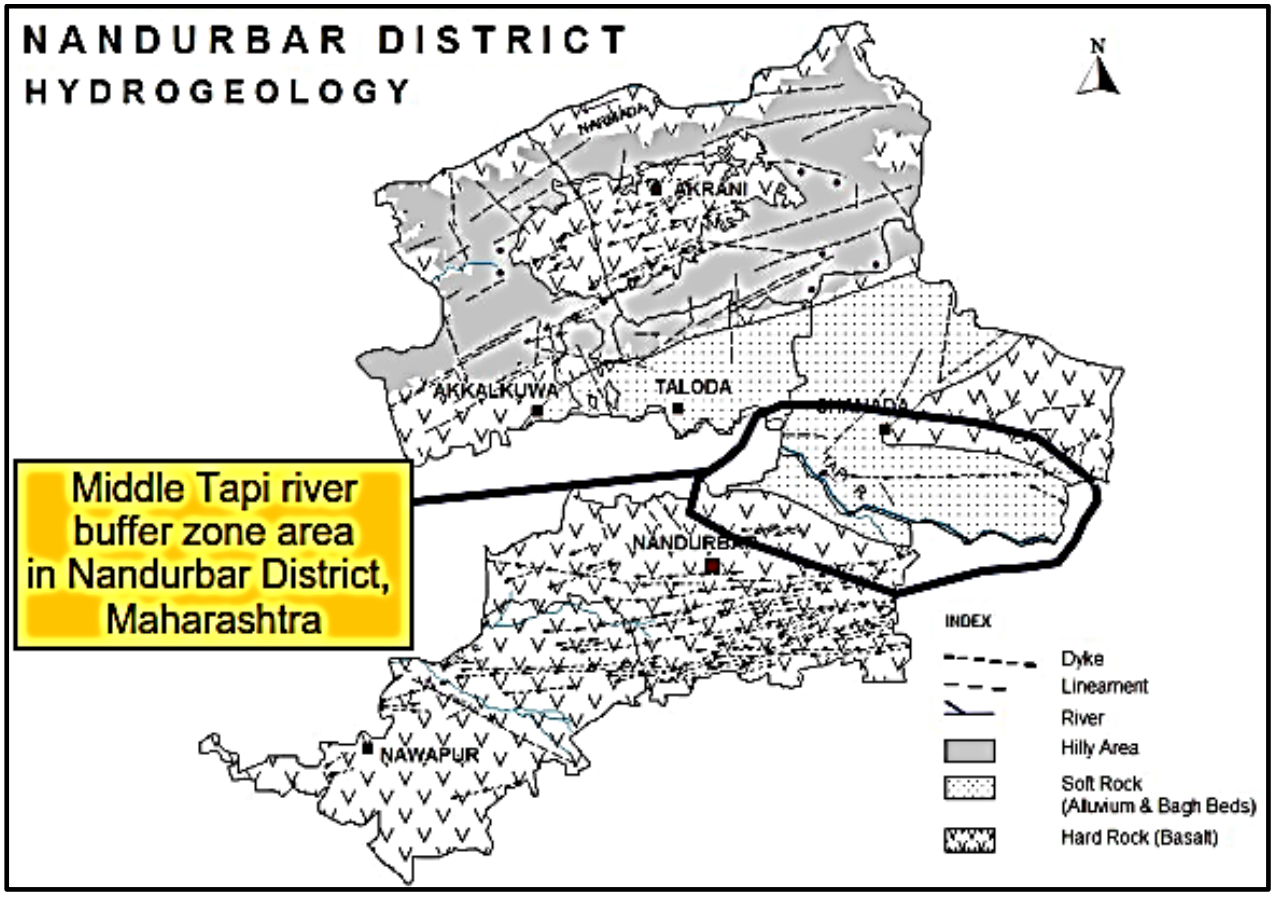


Fig. 7.8 Hydrogeology of Nandurbar district
(Source: http://www.cgwb.gov.in/District_Profile/Maharashtra/Nandurbar.pdf)

7.2.3 Lower Tapi basin

7.2.3.1 Tapi district

The oldest rocks, covering the Tapi alluvium flood plain deposits, are Deccan traps of lower Eocene age. These are present in the form of horizontal sheets at places showing gentle dips toward west. The ground water occurs in unconfined to semi-confined conditions. The occurrence and movement of ground water is governed by the thickness and extent of weathered zone and presence of fractures and joints. At places, dykes act as ground water barriers and restrict the flow of ground water. On the other hand, at places, the dykes themselves form good aquifers owing to deeper levels of weathering in them. Depths of dug wells in Deccan traps ranges from less than 2 m to 25 m with maximum number of wells, being 5 to 15 m deep. The depth to water levels in the dug wells ranges from 1 to 20m. However, in 90% of the wells, the water levels are less than 10 m bgl. Yields of the dug wells are moderate to low on the hill slopes. The dug wells generally sustain pumping for 4 to 5 hours with yields

of 50 to 150 m^3/day. Recuperation of water levels is generally slow. The alluvium occurs in the form of channel fill deposits and flood plain deposits (CWGB 2013g).

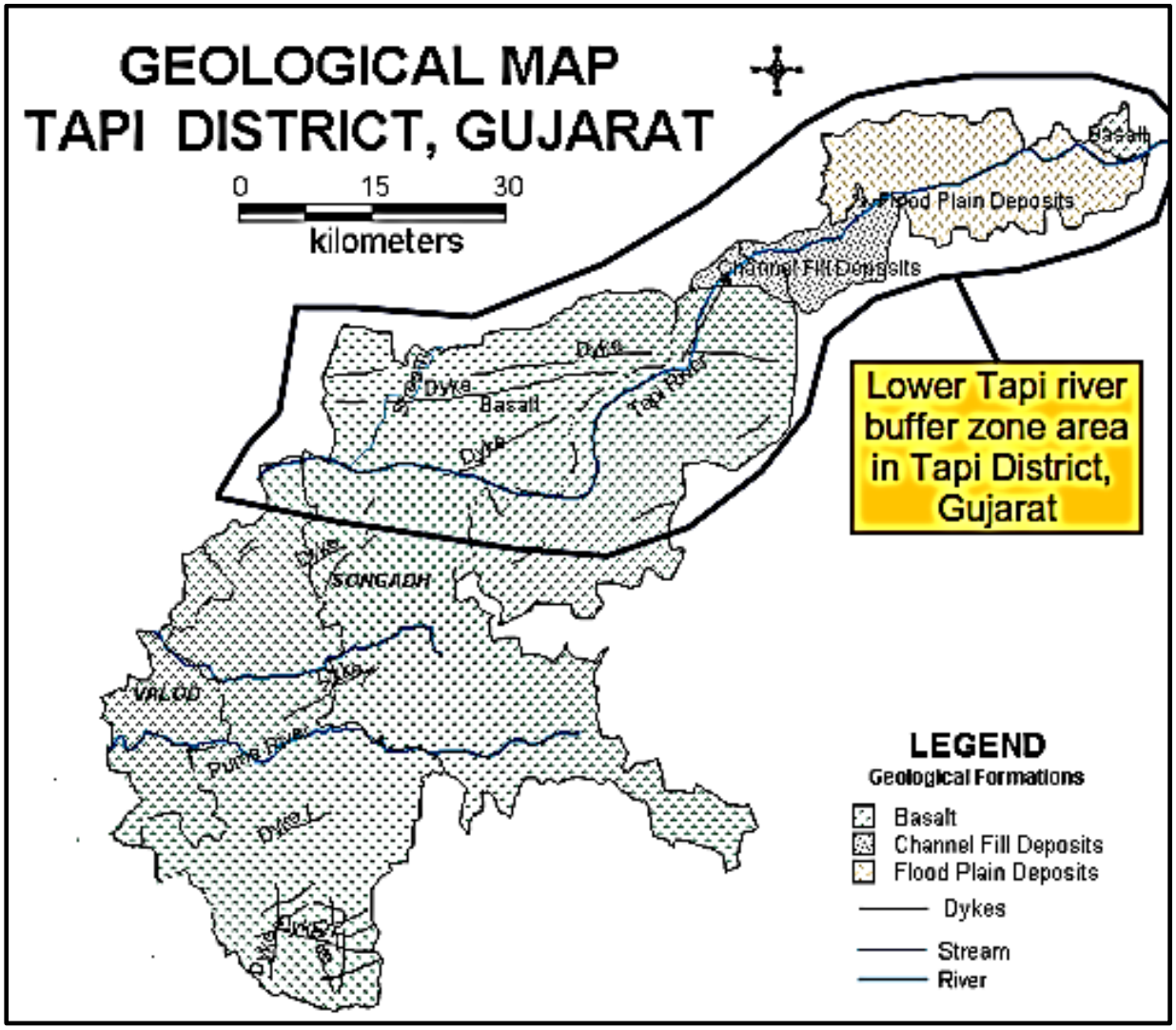


Fig. 7.9 Hydrogeology of Tapi district
(Source: http://www.cgwb.gov.in/District_Profile/Gujarat/Tapi.pdf)

7.2.3.2 Surat district

Major geological formations exposed in the district are Quaternary alluvium, Tertiary limestone and sandstones and Deccan Trap basalt. Fig. 7.10 shows the geology of the district and the succession of geological formations in the district.

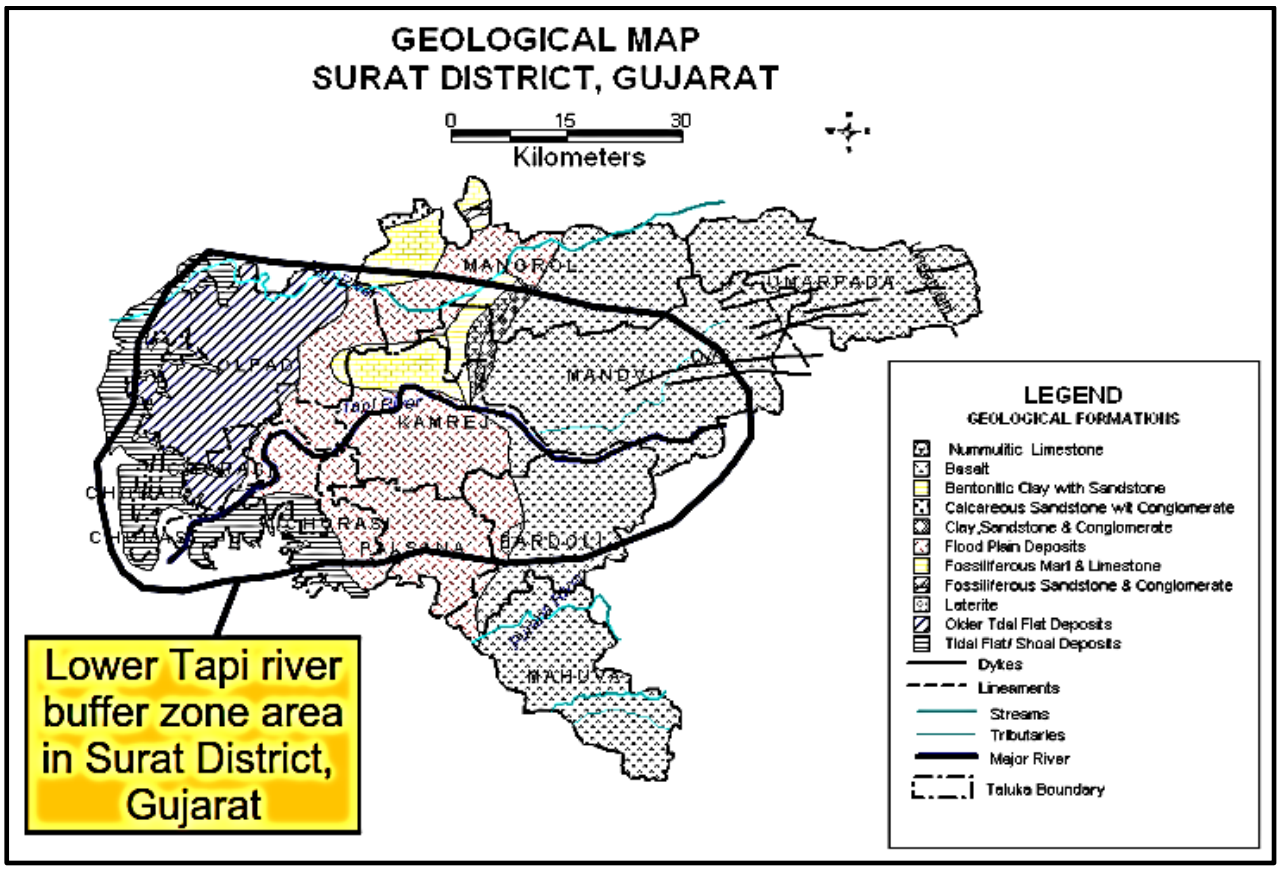


Fig. 7.10 Hydrogeology of Surat district
(Source: http://www.cgwb.gov.in/District_Profile/Gujarat/Surat.pdf)

The hydrogeological frame work of the area is essentially governed by geological setting, distribution of rainfall falls and facilities for circulation and movement of water through inter connected primary and secondary porosity of the geological units forming the aquifers. The major aquifers in the Surat district are formed by alluvium and Deccan Trap basalt with Tertiary formations occupying a small area. The alluvium occurs in the western part of the district and along the streams whereas in eastern parts weathered and fractured basalt form aquifer hydrogeological units. The Deccan Traps from the aquifers in north-eastern, eastern and south-eastern parts of the district comprising of Mangrol, Mandvi, Vyara, Valod Mahuva, Songadh, Uchchhal and Nizar talukas. The ground water occurs in unconfined to semi-confined conditions. The occurrence and movement of ground water is governed by the thickness and extent of weathered zone and presence of fractures and joints. At places, dykes act as ground water barriers and restrict the flow of ground water. On the other, at places, the dykes themselves from good aquifers owing to deeper levels of weathering in them. The western and north-western parts of the Surat district comprising of Choryasi, Olpad, Kamrej, Palsana and parts of Bardoli talukas is covered by Alluvium. This aquifer can broadly be demarcated into

two zones namely newer alluvium and older alluvium. The newer alluvium is present along the river courses and comprises fine to coarse grained sand trap wash with cay intercalations. The sand is unconsolidated but shows some degree of cohesion at places. Water levels are, in general, deeper in newer alluvium. Older alluvium is present in inter river plains and comprises sand, clay, kankar, grave and silt. The ground water occurs mostly under unconfined conditions but at places semi-confined conditions are also observed, probably due to presence of clay lenses. The depths of the wells in alluvium generally range from 3.0 to 30.0m with some of the wells having bores down to 50m below bottom of the wells. The maximum number of wells, about 80% are 5 to 20 m deep. Depths to water levels in the wells range from 0.5 to 15m bgl. Yields of the dug wells and dugcum-bored wells range between 100 to 450 m^3/day (CWGB 2013h).

CHAPTER 8
LAND-USE CHANGES

8.1 GENERAL

Information on the existing land-use practices and patterns are extremely important on formulating land-use in the river basin. To overcome the problems of haphazard, uncontrolled development, deteriorating environmental quality, loss of prime agricultural lands, destruction of important wetlands and wildlife habitats etc., it is necessary to have adequate knowledge about the land-use changes that have taken place over time. Analysing the changes in the land-use patterns also plays an important role from the perspective of studying global environmental changes and sustainable development highlighting the intensity and pattern of relationship between the human and earth (Liu et al., 2010). Apart from aforesaid factors, the land-use changes directly affect catchment hydrology as it causes changes in the climatic pattern that the catchment experiences. For example, a transition in land-cover from forest to agricultural land, not only causes a reduction in rainfall received, but also accelerates the erosion in the catchment.

Floodplains are valuable ecosystems performing important functions and providing space for habitats and food production (Hazarika et al., 2015). These are formed mainly of river sediments and face degradation by river regulation as well as changes in land-use practices that happens time to time in the river basin. Also, the lateral as well as vertical mobility of river instigates changes in land-use patterns along the floodplains, leading to seasonal and periodic modifications of the same.

Taking into consideration, the importance of Land-use land-cover (LULC) patterns in the basin, the present chapter deals with quantifying the changes in land-use patterns along the Tapi river. This study can be effectively used in flood plain management studies as well as throwing light on the aspect of riverine hazards occurring near the floodplain region as a result of fluvial dynamics of the river.

8.2 DATA AVAILABILITY AND ANALYSIS

Change detection of land-use and land-cover requires accurate and timely data of different land utilization categories of an area (Mohamed et al., 2014). Considering this, the remote sensing data has been used to acquire the required information. The details of the dataset used in this study are appended in Table 8.1.

Table 8.1 Dataset used in the present study

Data	Resolution/Scale	Year	Source
Landsat TM	30 m	1990	USGS[a]
IRS LISS-III	23.5 m	2000	NRSC[b]
IRS LISS-III	23.5 m	2010	NRSC

[a]USGS: United States Geological Survey
[b]NRSC: National Remote Sensing Centre

8.3 METHODOLOGY

To obtain the land-use land-cover changes in the catchment, LULC classification has been carried out for the years 1990, 2000 and 2010 at sub-basin level. The Purna sub-basin and the Girna sub-basin are excluded in this study because of the non-availability of satellite imagery scenes with similar colour scheme. In order to avoid the over-estimation of river expanse, the satellite imagery chosen are of non-monsoon period only. To carry out the classification, the False Colour Composite (FCC) of the satellite imagery are prepared by compositing the Near Infrared (NIR), Red (R), and Green (G) bands. Survey of India toposheets and Google Earth imagery for the study area are taken as the reference to identify different land-use patterns and assign classes to the satellite imagery.

The classification scheme used in present study is given in Table 8.2. A Level I classification has been adopted for the present study (Anderson, 1976), employing the classification strategy given by the United States Geographical Survey (USGS) classification of land-use land-cover system (Table 8.2). A maximum likelihood supervised classification algorithm is used to independently classify the images of different years into six land-use classes with the help of ArcGIS 10.4©.

Table 8.2 Description of the land-use/ land-cover classes

Sr. No	Land-cover Class	Description of the class
1	Agriculture	Agricultural plantations like orchards, tea gardens with significant patterns, areas under cultivation etc.
2	Built-up	Areas under urban and rural built-up including homestead area
3	Water	Rivers/ waterbodies, streams, lakes, reservoirs
4	Forest	Deciduous forest, open forest and scrub forest
5	Fallow	Areas which are ready for cultivation
6	Scrub land	Land with or without scrub, sandy area, stony waste, salt affected land

8.4 LAND-USE CHANGES, RESULTS AND DISCUSSIONS

Once the classification was completed, the areas and the corresponding percentage area covered by various land-use/land-cover classes were computed for different sub-basins. The observations and deductions made are explained separately for each sub-basins in the succeeding sub-sections.

8.4.1 Burhanpur sub-basin

The land-use land-cover maps for the Burhanpur sub-basin, along with the table showing areas and the corresponding percentage area occupied by each land-use class, are given in Fig. 8.1 (a)-(c) and Table 8.3 for years 1990, 2000 and 2010. It can be seen that more than half of the total area of the sub-basin is covered with dense forest, located predominantly at its northern side. The forest cover is part of the Satpura hill ranges, which separates Tapi Basin and Narmada Basin. The second and third predominant land-use classes are Fallow land and Agricultural land respectively. Rest of the classes occupy relatively lesser areas in the sub-basin.

The decadal variations in percentage of the total areas, under each land-use class over a period of 1990-2010 are as shown in Fig 8.2 (a)-(f). It can be observed that the forest cover in the Burhanpur sub-basin has reduced from 59.40% to 49.56%, thus showing a decline of 9.84% during 1900-2010. In contrast to this observation, the agricultural land has been observed to increase by 13.64% from 15.79% in 1990 to 29.43% in 2010. From the figures, it is evident that this increase has occurred at the expense of the forest cover and fallow land in the sub-basin. The increase in built-up area (1.28%) is not observed to be significant when compared with the rest of the classes. The water bodies are observed to be expanding, may be due to upcoming minor storage structures in the basin.

Table 8.3 Percentage areas falling under different land-use classes

LULC Classes	Land-use area in % (Area in km^2) for different years		
	1990	2000	2010
Agriculture	15.79 (1675.63)	25.31 (2685.90)	29.43 (3123.11)
Built-up	0.41 (43.51)	0.90 (95.51)	1.69 (179.34)
Water	0.24 (25.47)	0.27 (28.65)	0.59 (62.61)
Forest	59.40 (6303.53)	51.99 (5517.18)	49.56 (5259.31)
Fallow	22.35 (2371.78)	20.42 (2166.97)	17.72 (1880.45)
Scrub land	1.81 (192.08)	1.11 (117.79)	1.01 (107.18)

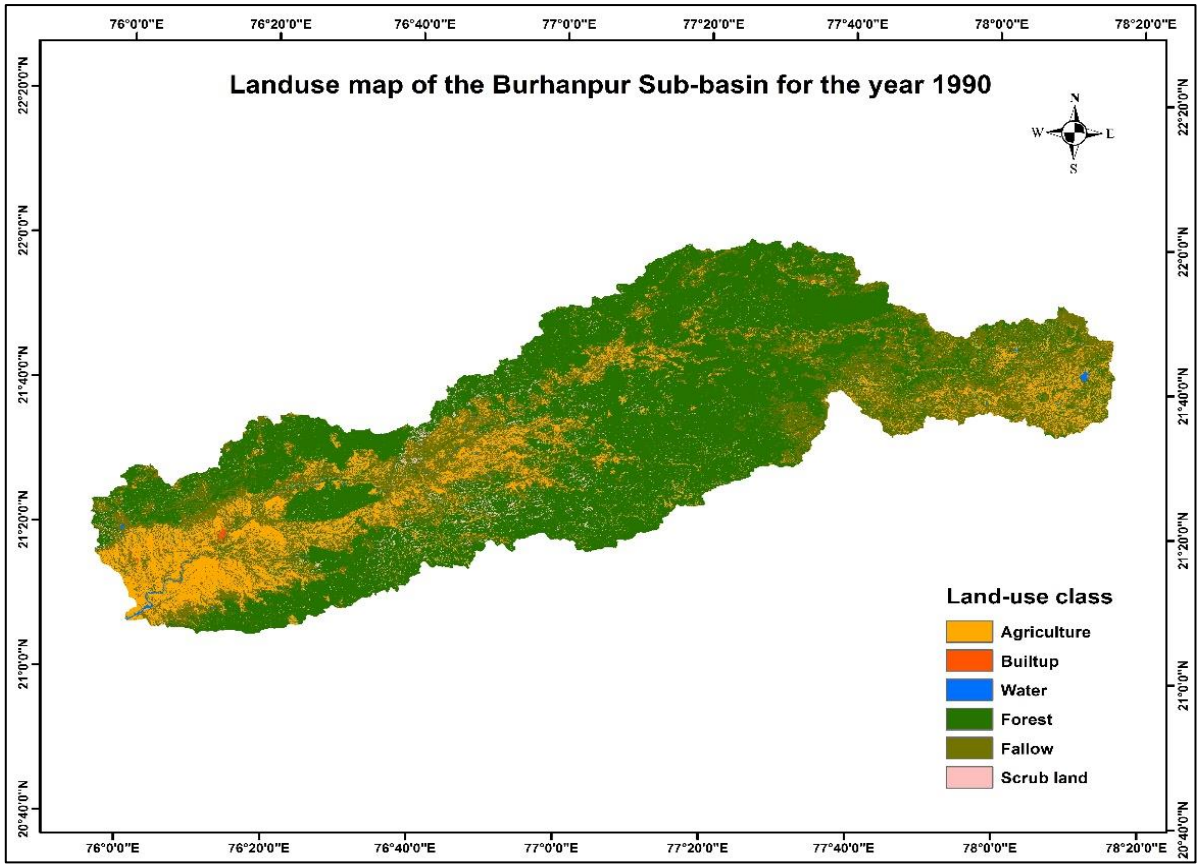


Fig 8.1 (a) Land-use land-cover classification for the year 1990 for Burhanpur sub-basin

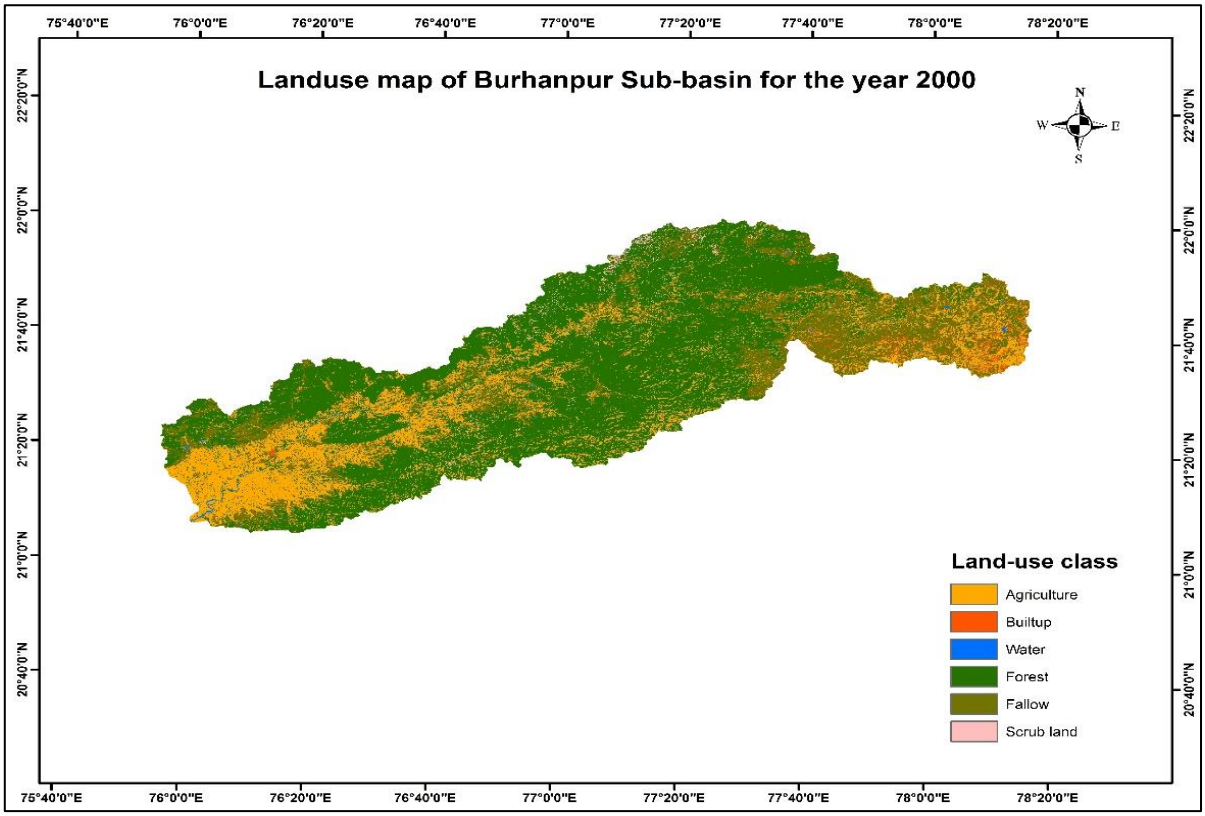


Fig 8.1 (b) Land-use land-cover classification for the year 2000 for Burhanpur sub-basin

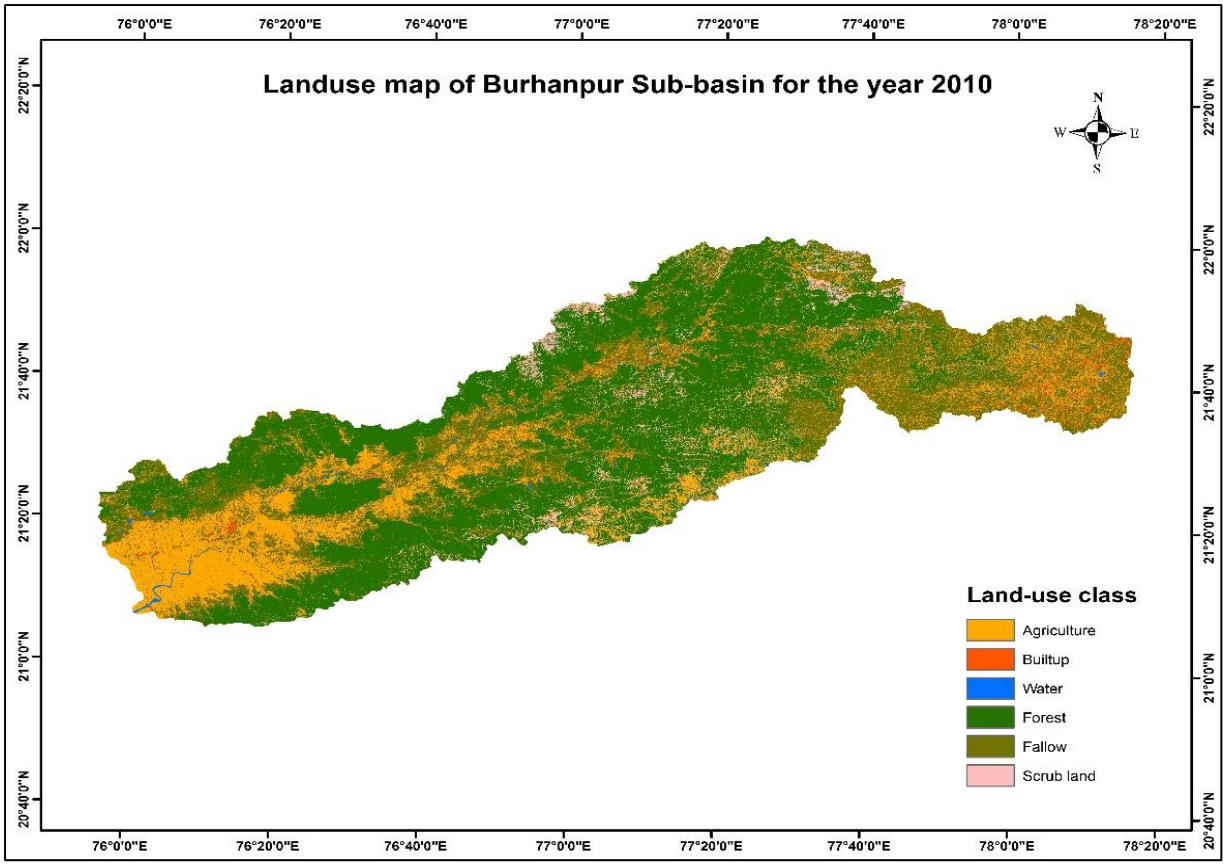


Fig 8.1 (c) Land-use land-cover classification for the year 2010 for Burhanpur sub-basin

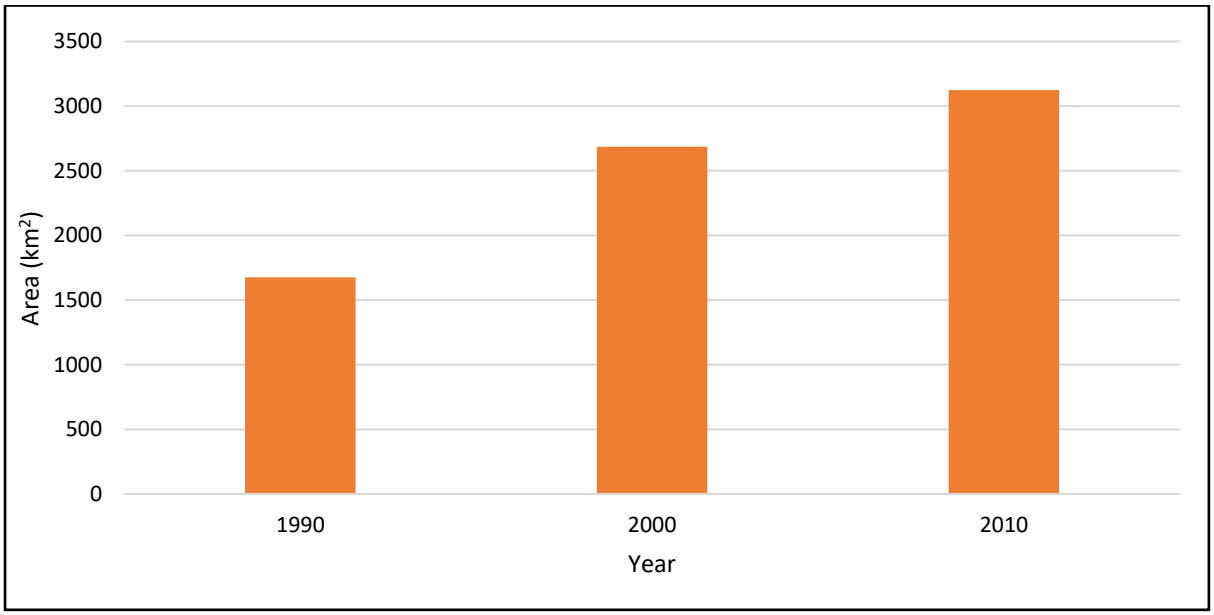


Fig 8.2 (a) Decadal variations in area (agriculture) for Burhanpur sub-basin

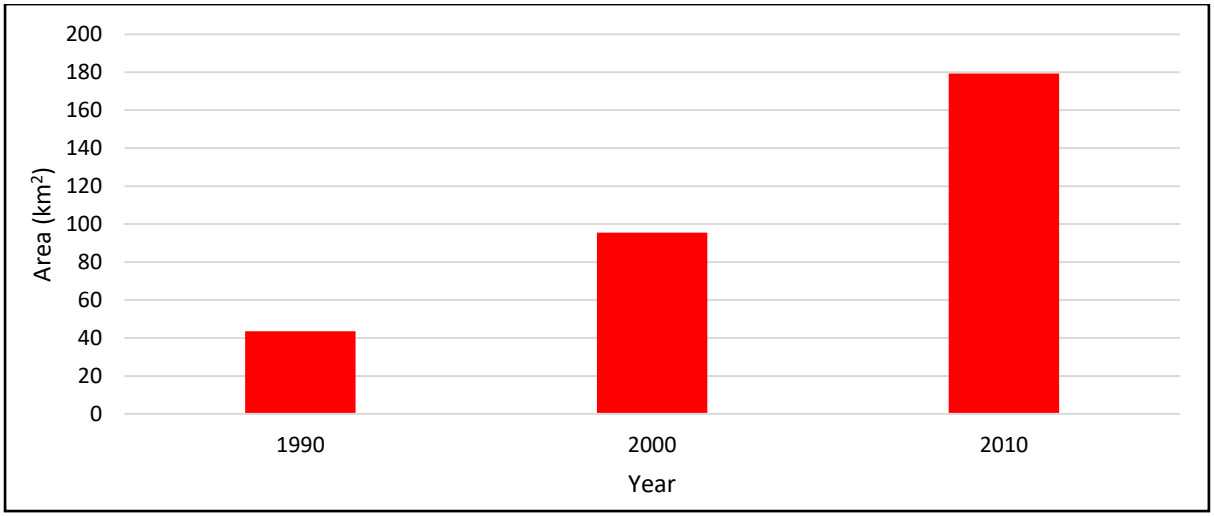


Fig 8.2 (b) Decadal variations in area (built-up) for Burhanpur sub-basin

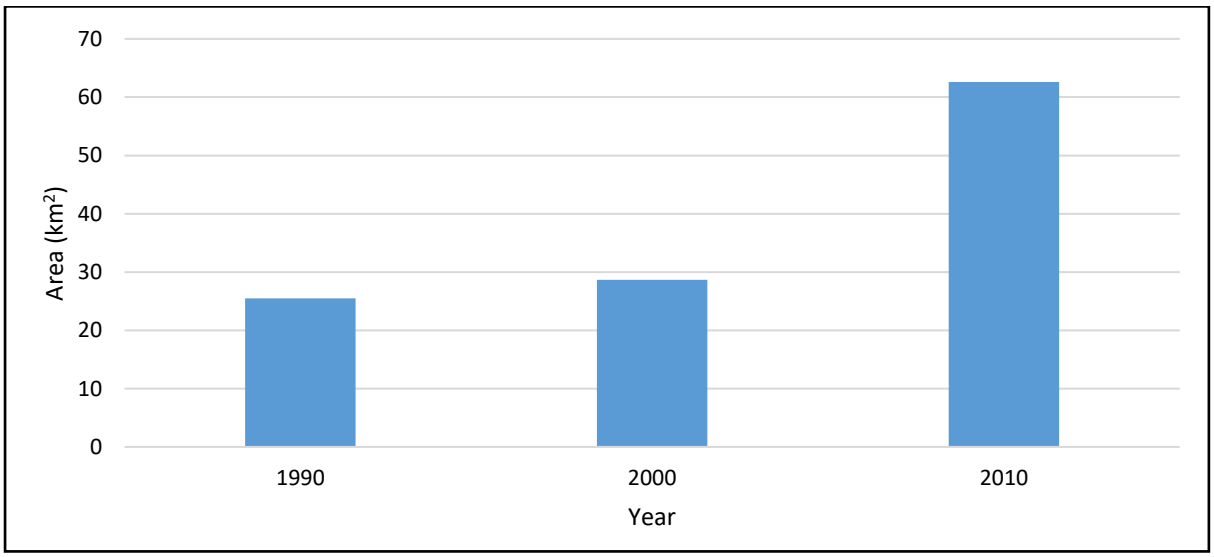


Fig 8.2 (c) Decadal variations in area (water) for Burhanpur sub-basin

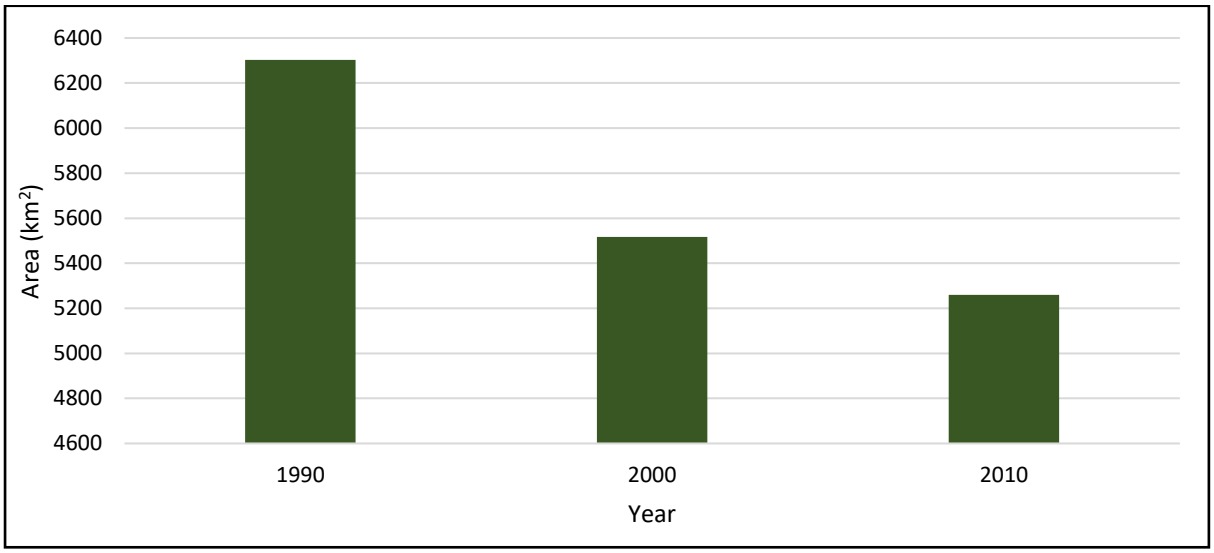


Fig 8.2 (d) Decadal variations in area (forest) for Burhanpur sub-basin

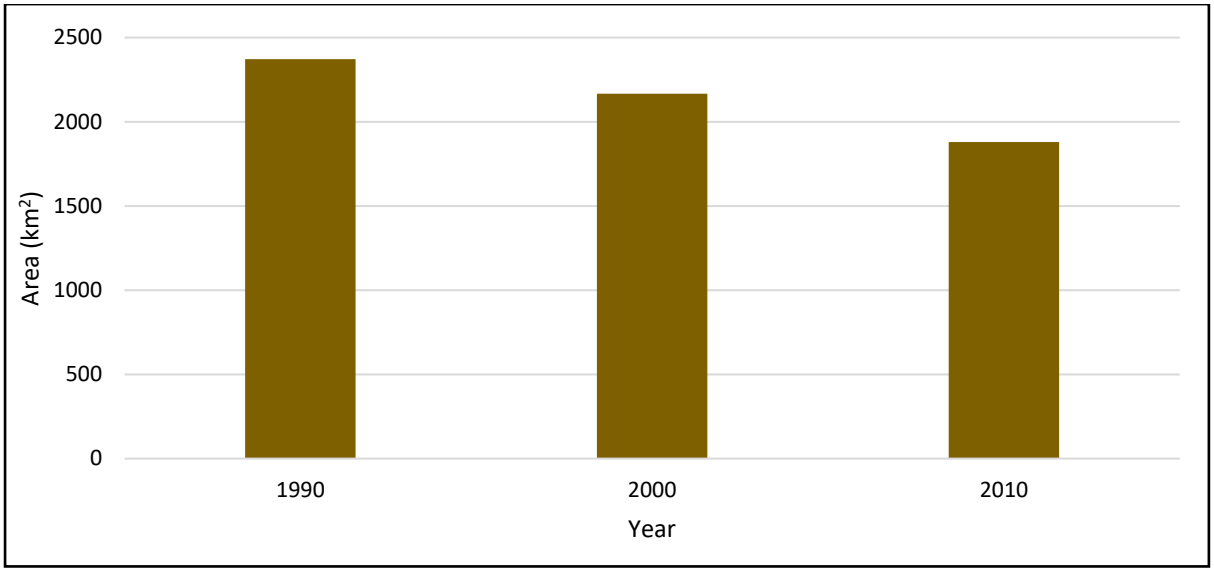


Fig 8.2 (e) Decadal variations in area (fallow) for Burhanpur sub-basin

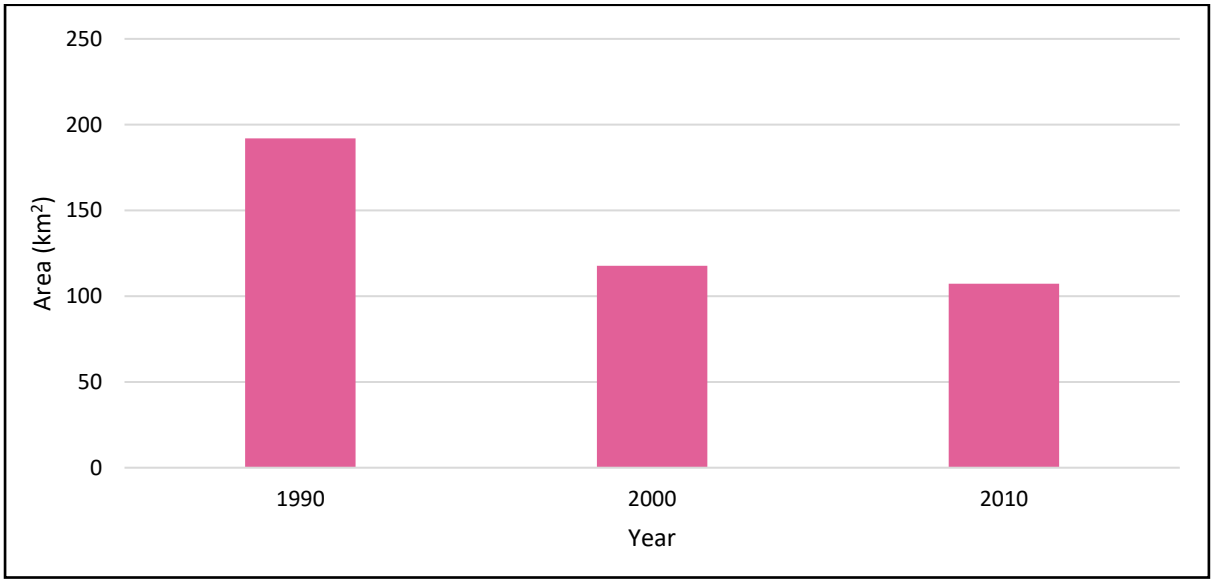


Fig 8.2 (f) Decadal variations in percentage area (scrub land) for Burhanpur sub-basin

8.4.2 Middle Tapi river sub-basin excluding Girna sub-basin

The land-use land-cover maps for the Middle Tapi river sub-basin, excluding the Girna River basin, along with the table showing percentage areas occupied by each land-use class are given in Figs. 8.3 (a)-(c) and Table 8.4 respectively. It is observed that agricultural land and fallow land together occupy more than 60% of the total area in the sub-basin. This can be attributed to the abundancy of alluvial soil in the sub-basin, which makes it suitable for cultivation and human occupancy. The second predominant land-use class is the forest cover, which can be seen on the northern as well as north-western part of the sub-basin. The land-use classes like

built-up area, water and scrub land occupy comparatively less percentage area in the sub-basin, as observed in the Burhanpur sub-basin.

Similar trend is observed in the change in land-use land-cover classes in the Middle Tapi river sub-basin as observed in Burhanpur (Upper Tapi) sub-basin. However, since the sub-basin is less hilly and situated on fertile plains, the agricultural area has been observed to increase by 21.62% during the recent decade (2000-2010). This can be attributed to a decrease in fallow land and forest cover by 16.89% and 3.56% respectively, during the same time period. During 1990-2010, the forest cover in the area has been observed to reduce by 6.13%. The built-up area has also been found to be increased during the recent decades. From the land-use maps, it can be observed that built-up lands are expanding, in between the agricultural and fallow land. The decadal variations in percentage of the total areas, under each land-use class over a period of 1990-2010 are as shown in Figs 8.4 (a)-(f).

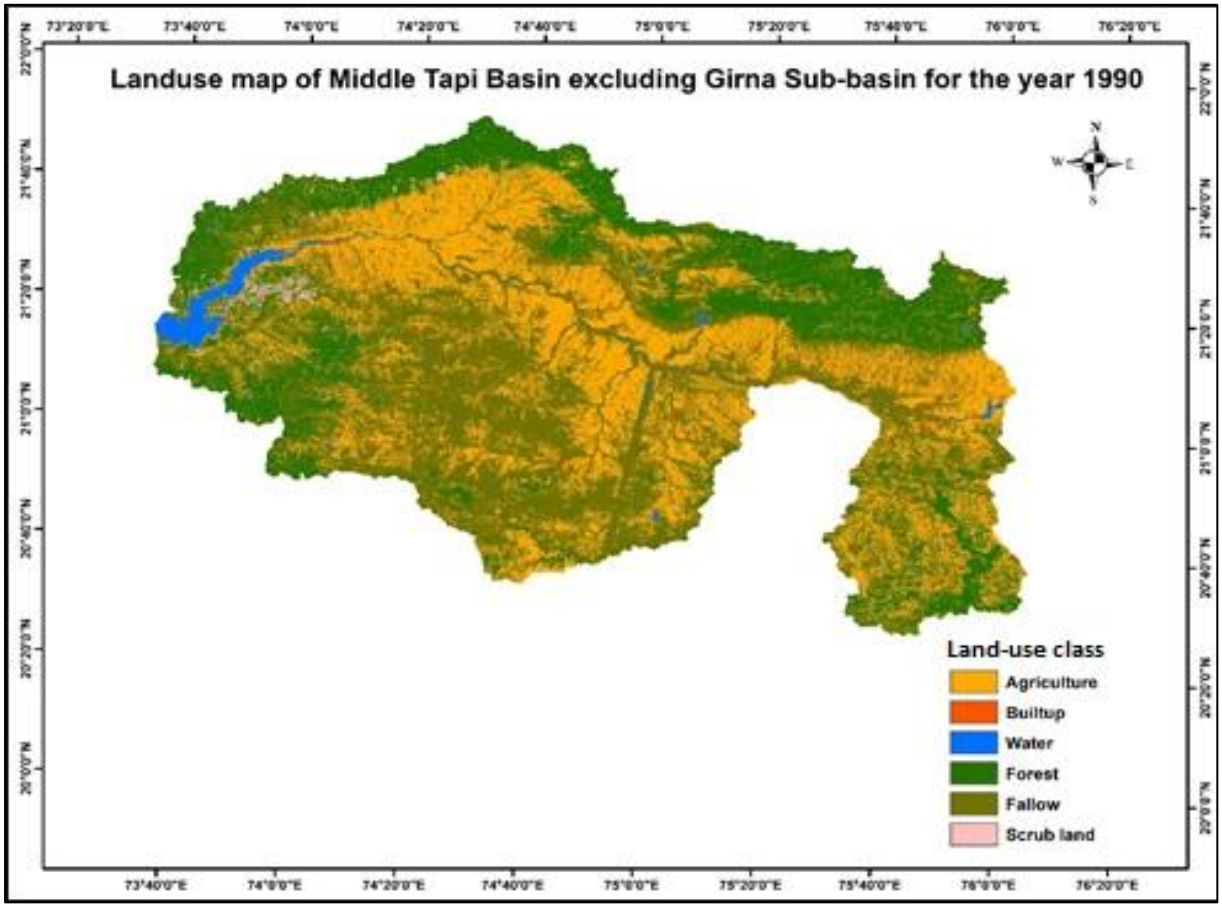


Fig 8.3 (a) Land-use land-cover classification for the year 1990 for Middle Tapi sub-basin

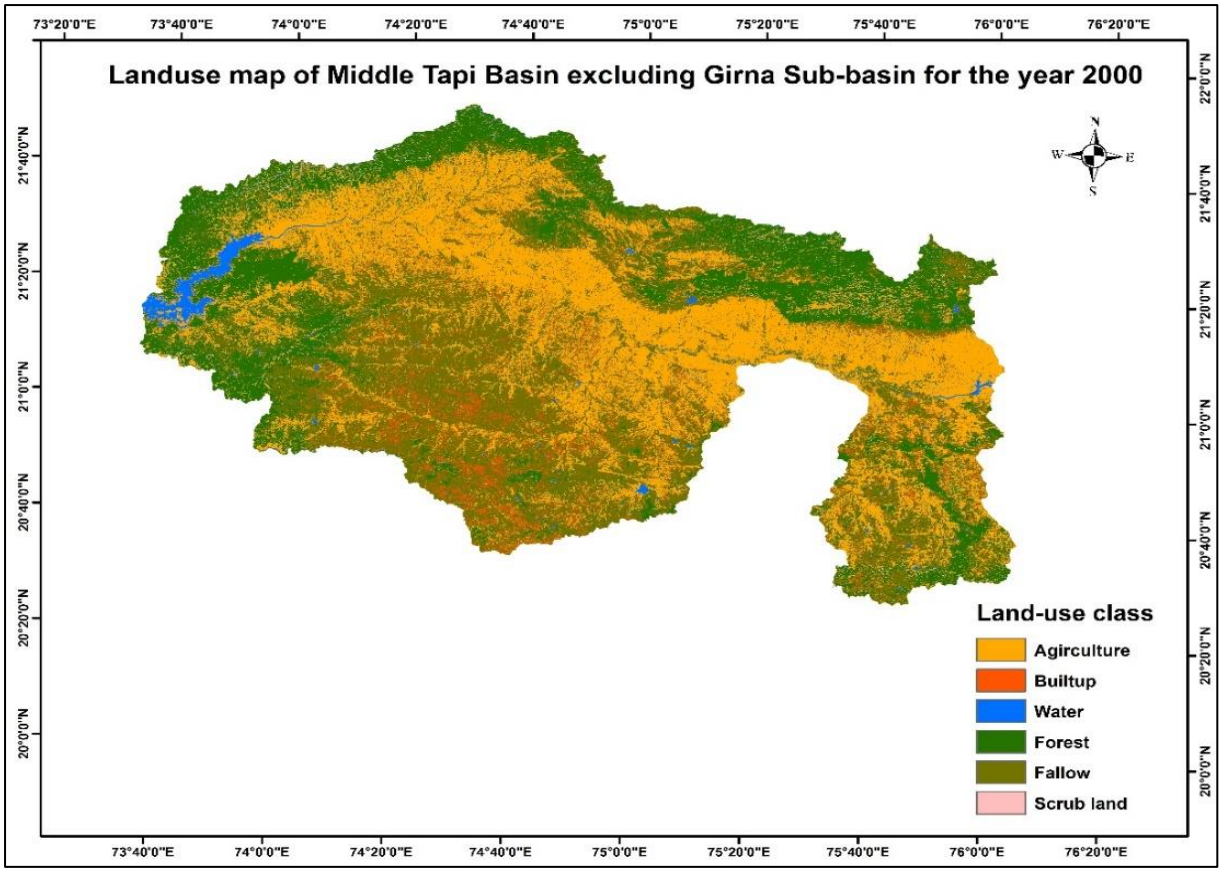


Fig 8.3 (b) Land-use land-cover classification for the year 2000 for Middle Tapi sub-basin

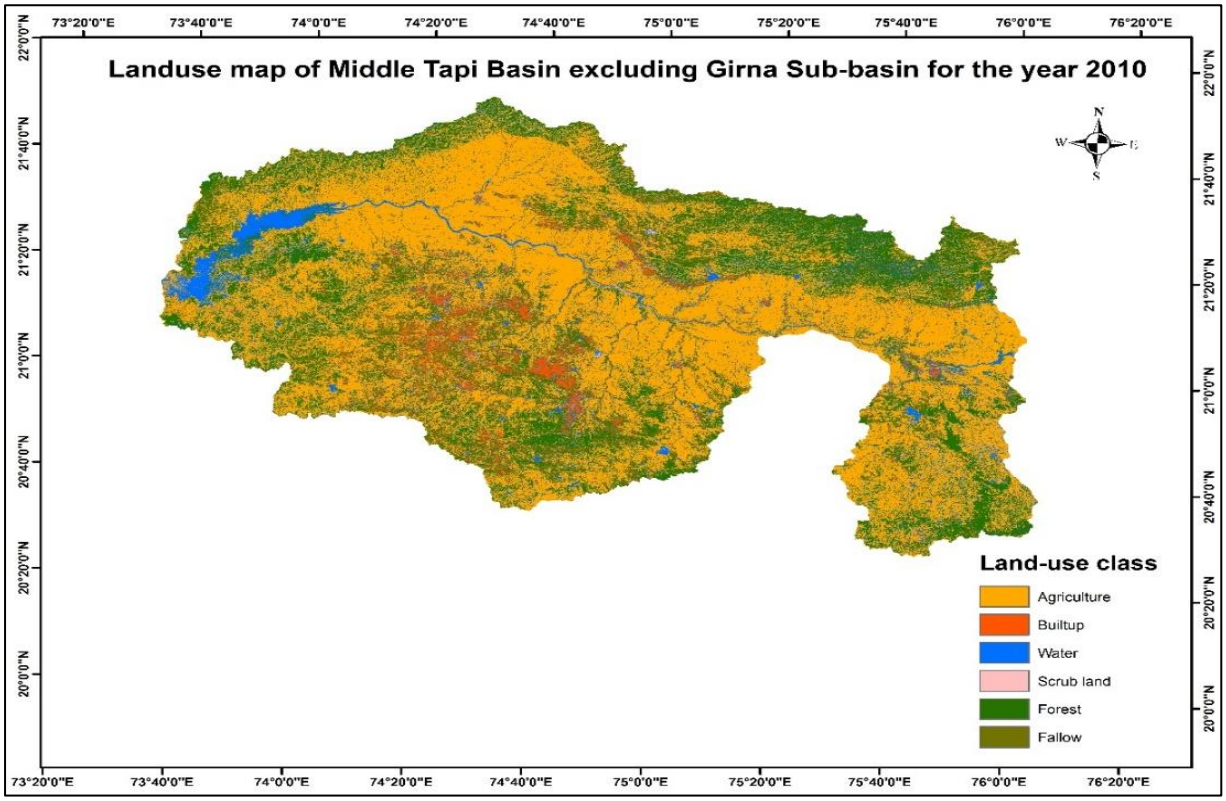


Fig 8.3 (c) Land-use land-cover classification for the year 2010 for Middle Tapi sub-basin

Table 8.4 Percentage areas falling under different land-use classes

LULC Classes	Land-use area in % (Area in km^2) for different years		
	1990	**2000**	**2010**
Agriculture	33.08 (7563.74)	35.92 (8213.11)	56.18 (9288.56)
Built-up	0.63 (144.05)	4.14 (946.61)	8.35 (998.63)
Water	1.80 (411.57)	1.95 (445.87)	2.31 (528.18)
Forest	25.47 (5823.46)	22.90 (5235.86)	19.34 (4421.90)
Fallow	38.24 (8743.19)	38.44 (7878.36)	17.55 (4012.63)
Scrub land	0.78 (178.34)	0.67 (153.19)	0.27 (61.73)

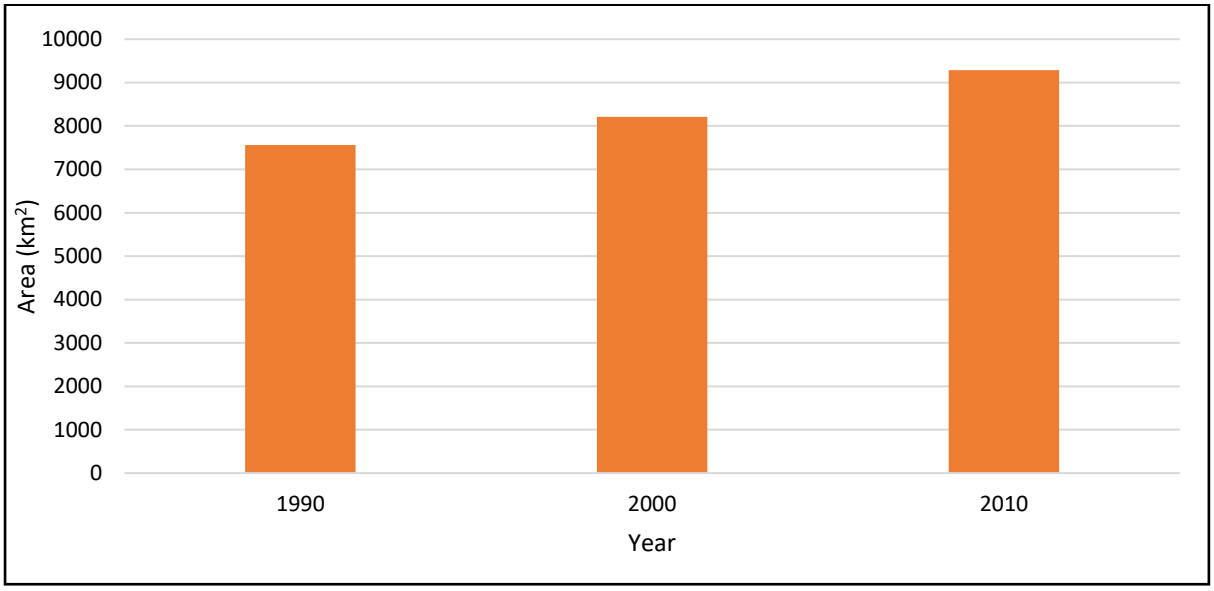


Fig 8.4 (a) Decadal variations in area (agriculture) for Middle Tapi sub-basin

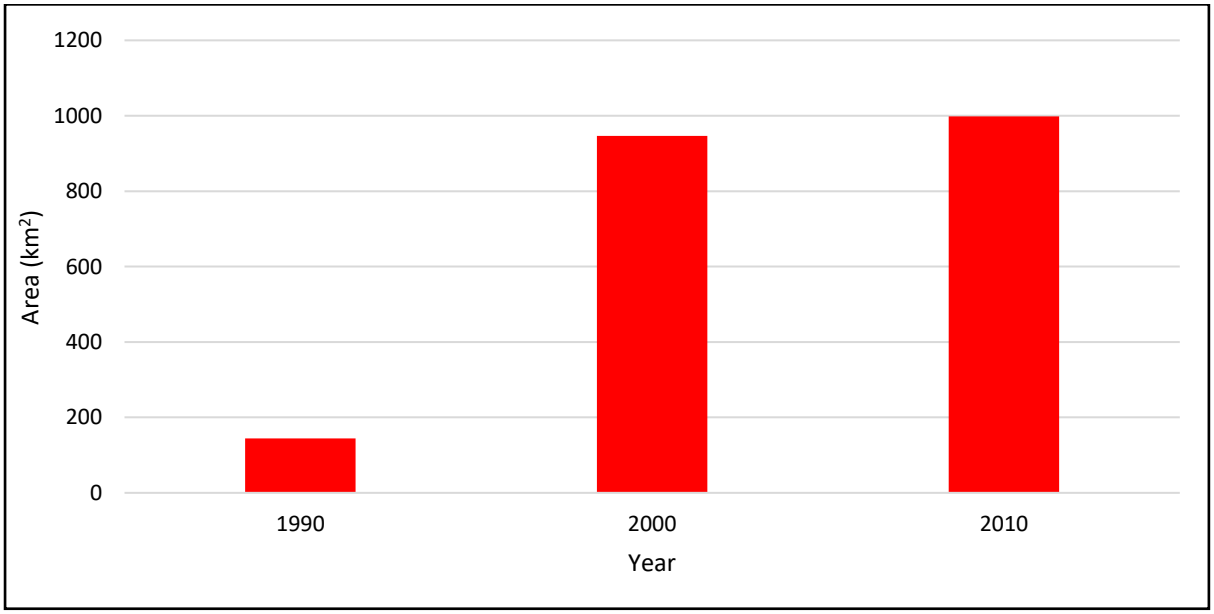


Fig 8.4 (b) Decadal variations in area (built-up) for Middle Tapi sub-basin

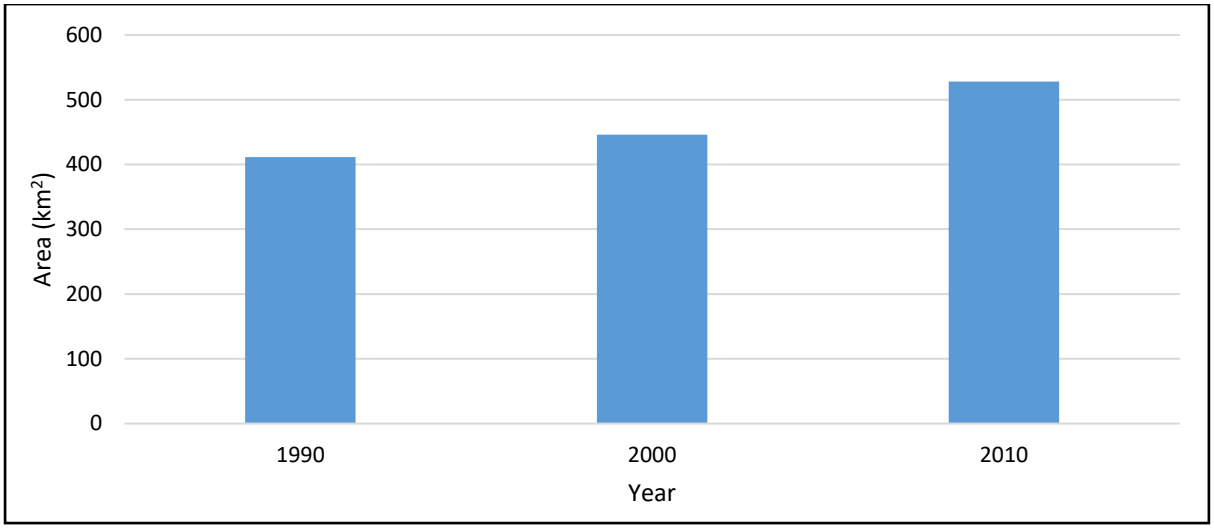


Fig 8.4 (c) Decadal variations in area (water) for Middle Tapi sub-basin

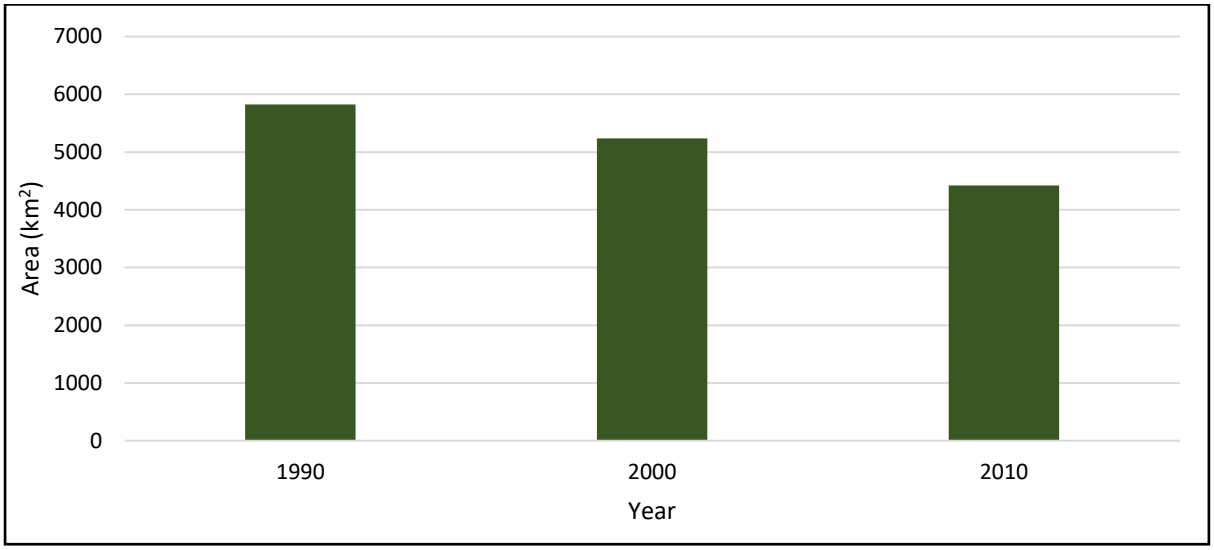


Fig 8.4 (d) Decadal variations in area (forest) for Middle Tapi sub-basin

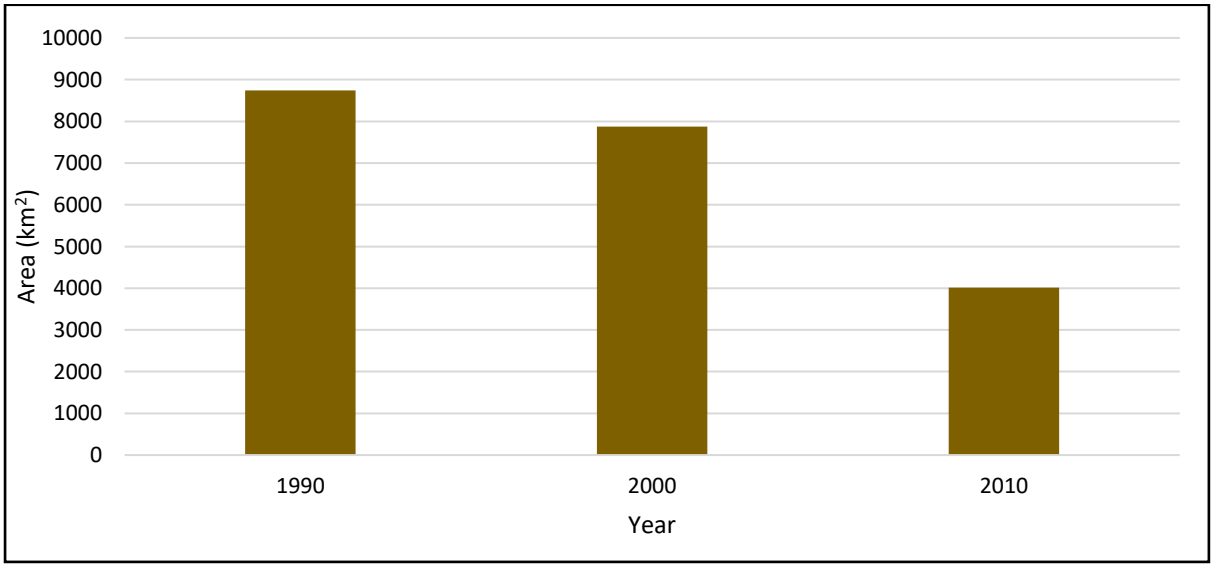


Fig 8.4 (e) Decadal variations in area (fallow) for Middle Tapi sub-basin

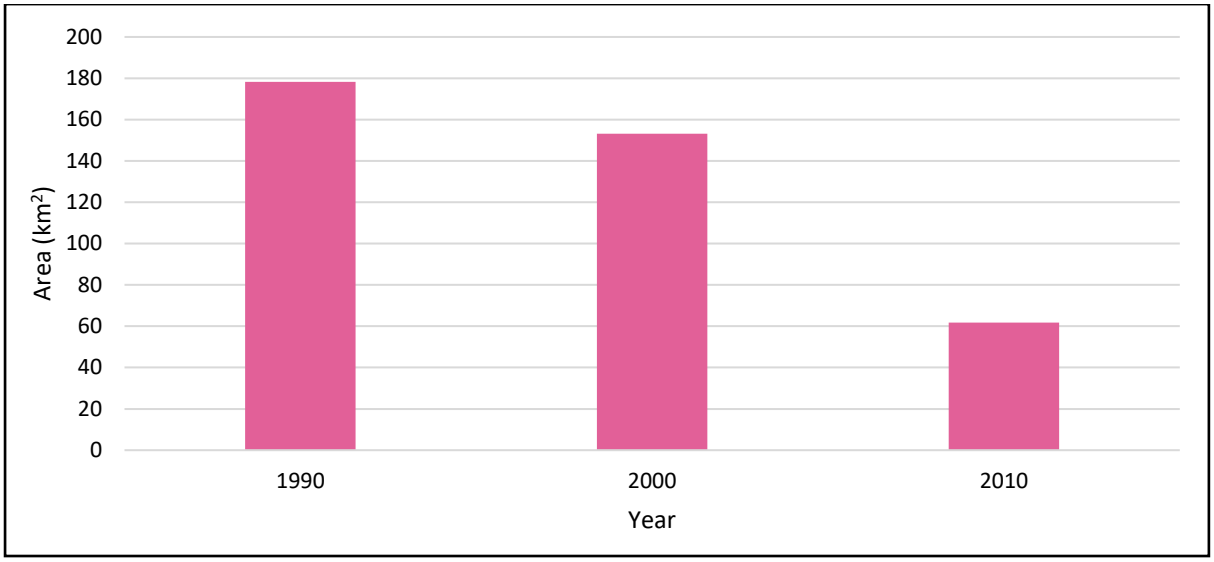


Fig 8.4 (f) Decadal variations in area (scrub land) for Middle Tapi sub-basin

8.4.3 Lower Tapi Basin

The land-use land-cover maps for the Lower Tapi Basin, along with the table showing percentage areas occupied by each land-use class are given in Figs. 8.5 (a)-(c) and Table 8.5 respectively. More than half of the sub-basin is occupied by agricultural lands. The highly fertile alluvial plains of the sub-basin and the availability of water through different irrigation schemes, facilitates the same. The next abundant land-use land-cover class is fallow land, which can be observed to undergo gradual transition to agricultural land. The sub-basin has a forest cover of more than 10%. Other land-use classes like water bodies, scrub lands and built-up areas are observed in less percentages in the sub-basin.

It can be observed from Table 5 that, the agricultural land has increased by 8.74% during 1990-2010. The forest areas are observed to be declining while agricultural and built-up land are increasing during the aforementioned duration. There has been a decrease of 6.09% in forest area in the sub-basin during 1990-2010. As observed in the previous two sub-basins a transition is observed from fallow land to cultivable agricultural land. During the recent decades, i.e., 2000 and 2010, the built-up areas are observed to appear in between the agricultural land. The waterbodies are observed to be expanding and the scrub lands are observed to be declining. The decadal variations in percentage of the total areas, under each land-use class over a period of 1990-2010 are as shown in Figs 8.6 (a)-(f).

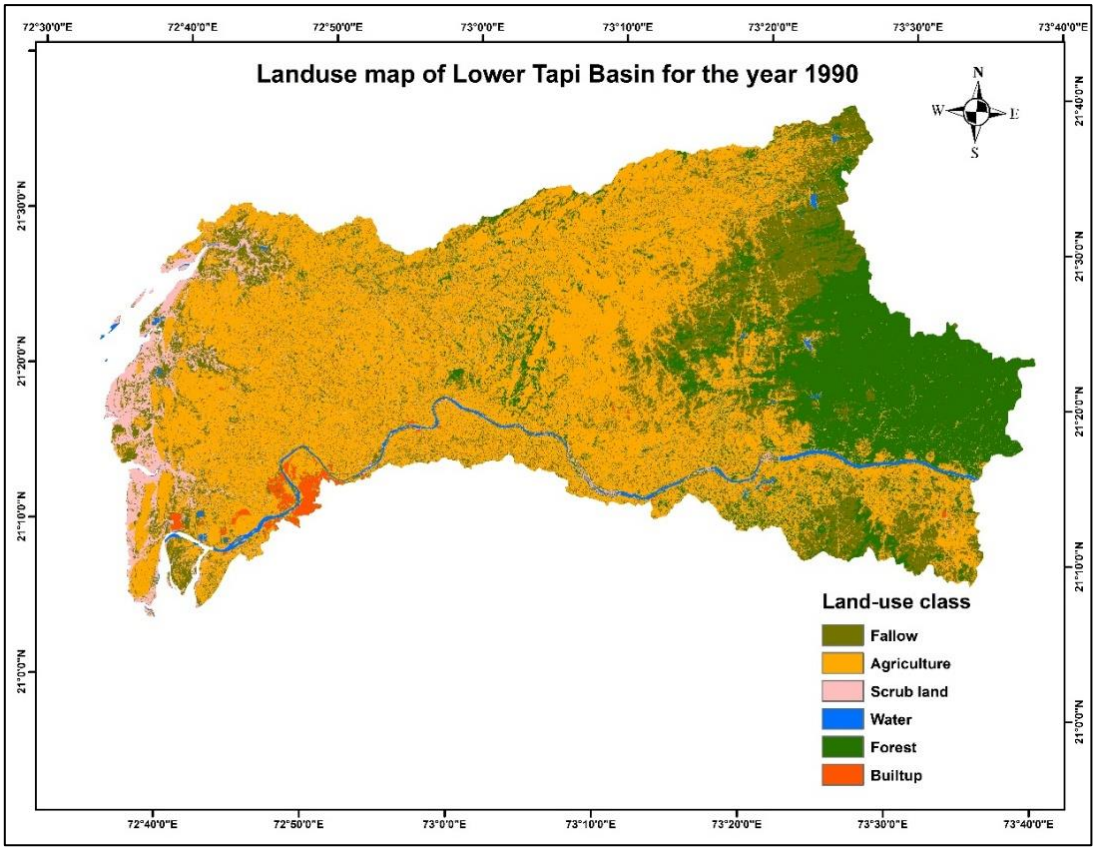


Fig 8.5 (a) Land-use land-cover classification for the year 1990 for Lower Tapi sub-basin

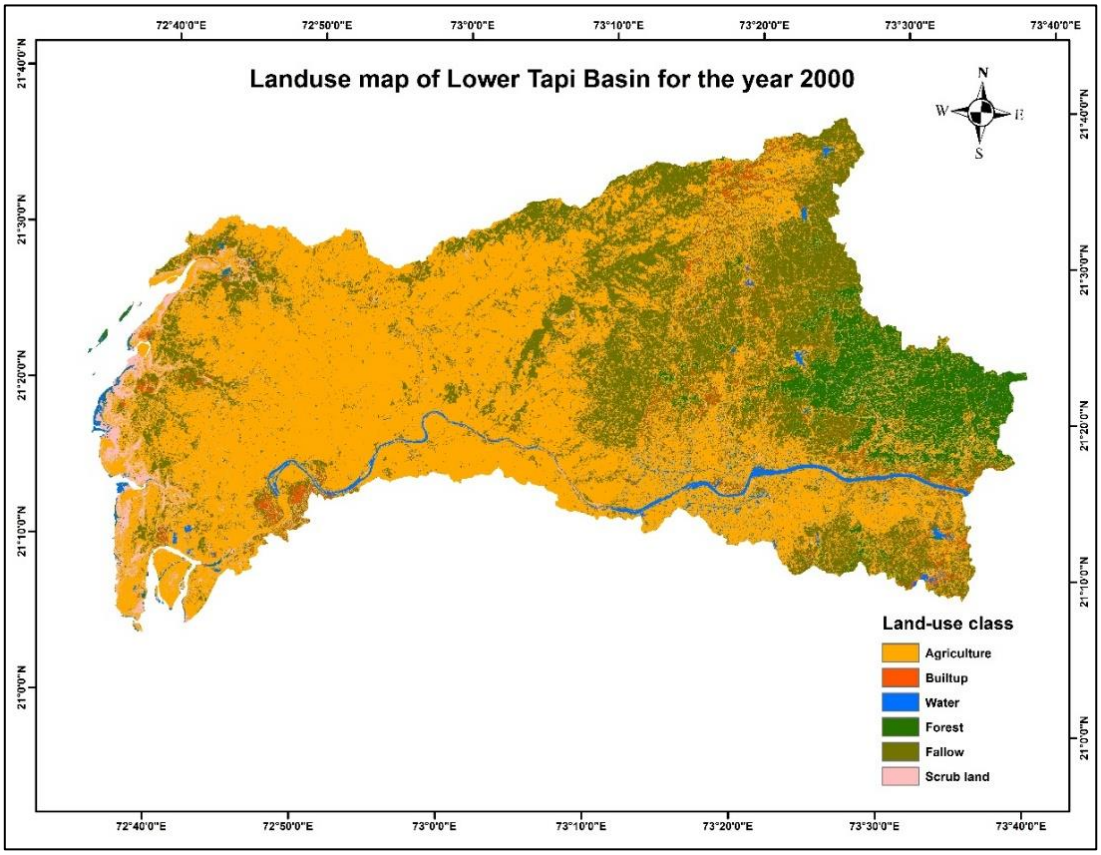


Fig 8.5 (b) Land-use land-cover classification for the year 2000 for Lower Tapi sub-basin

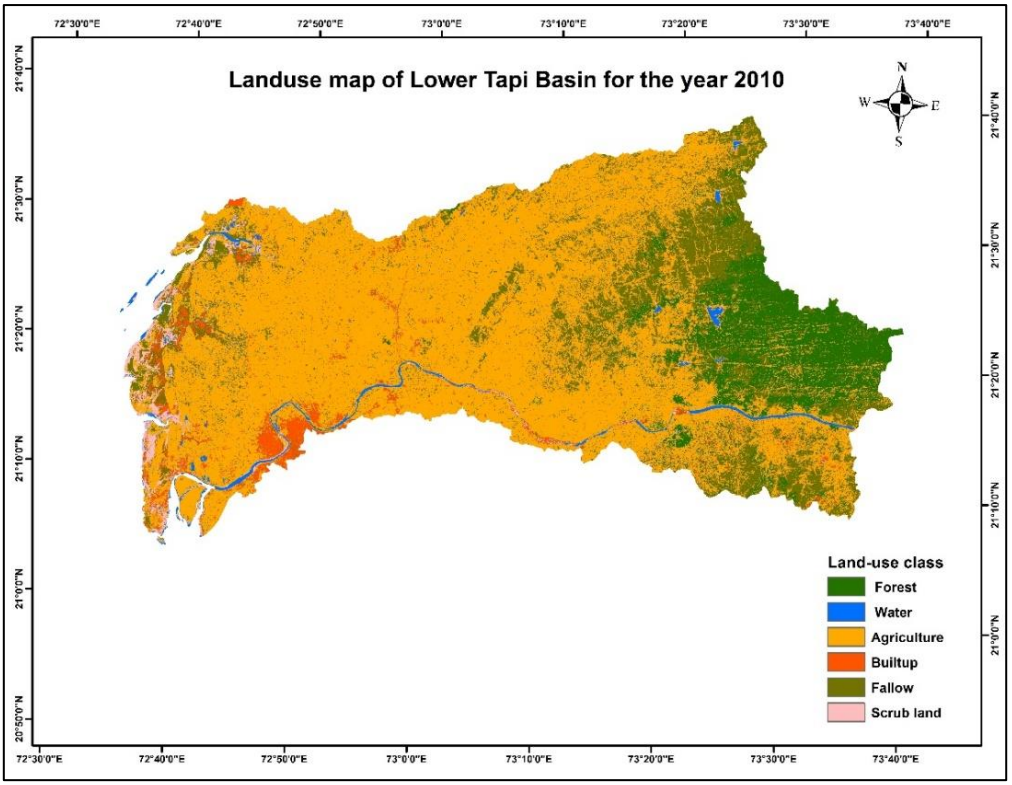


Fig 8.5 (c) Land-use land-cover classification for the year 2010 for Lower Tapi sub-basin

Table 8.5 Percentage areas falling under different land-use classes

LULC Classes	Land-use area in % (Area in km^2) for different years		
	1990	**2000**	**2010**
Agriculture	55.58 (1994.76)	60.04 (2154.84)	68.32 (2308.44)
Built-up	0.78 (27.99)	1.45 (52.04)	3.73 (133.87)
Water	1.01 (36.25)	1.94 (69.63)	2.39 (85.78)
Forest	17.18 (616.59)	15.85 (568.86)	11.09 (398.02)
Fallow	20.09 (721.03)	16.31 (585.37)	15.54 (557.73)
Scrub land	5.36 (192.37)	4.41 (158.27)	2.93 (105.16)

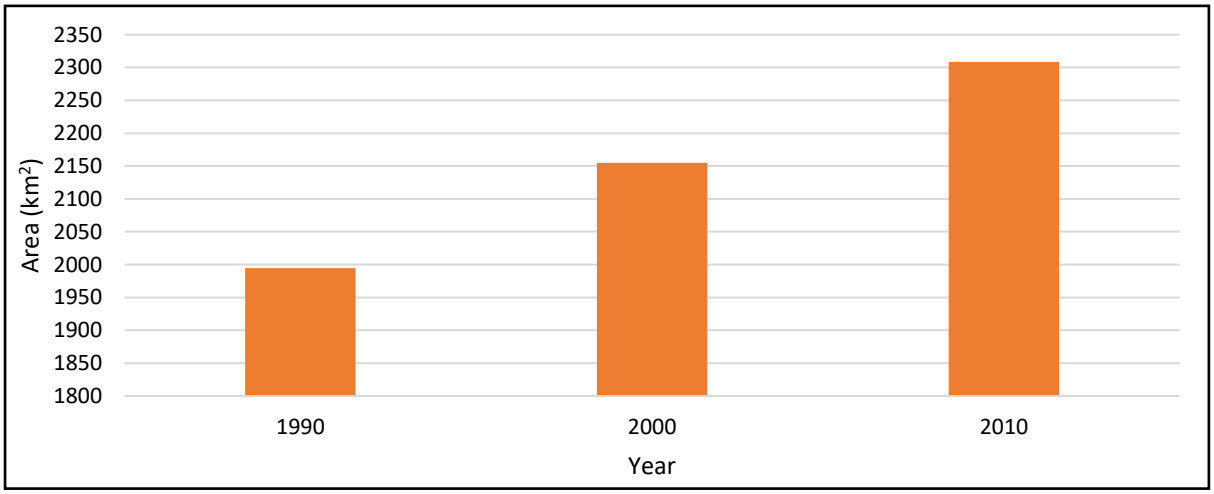


Fig 8.6 (a) Decadal variations in area (agriculture) for Lower Tapi sub-basin

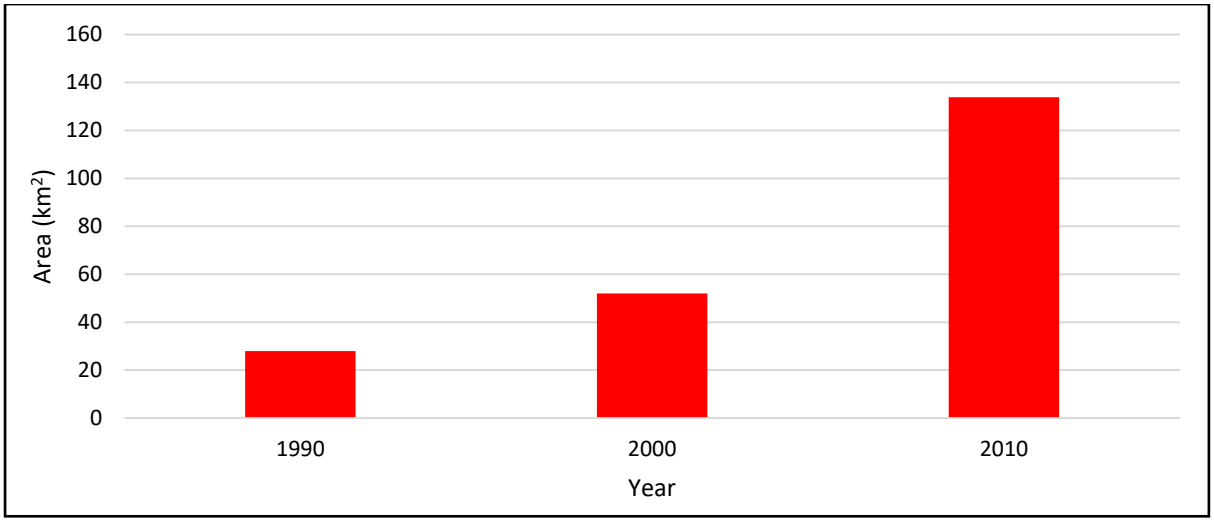


Fig 8.6 (b) Decadal variations in area (built-up) for Lower Tapi sub-basin

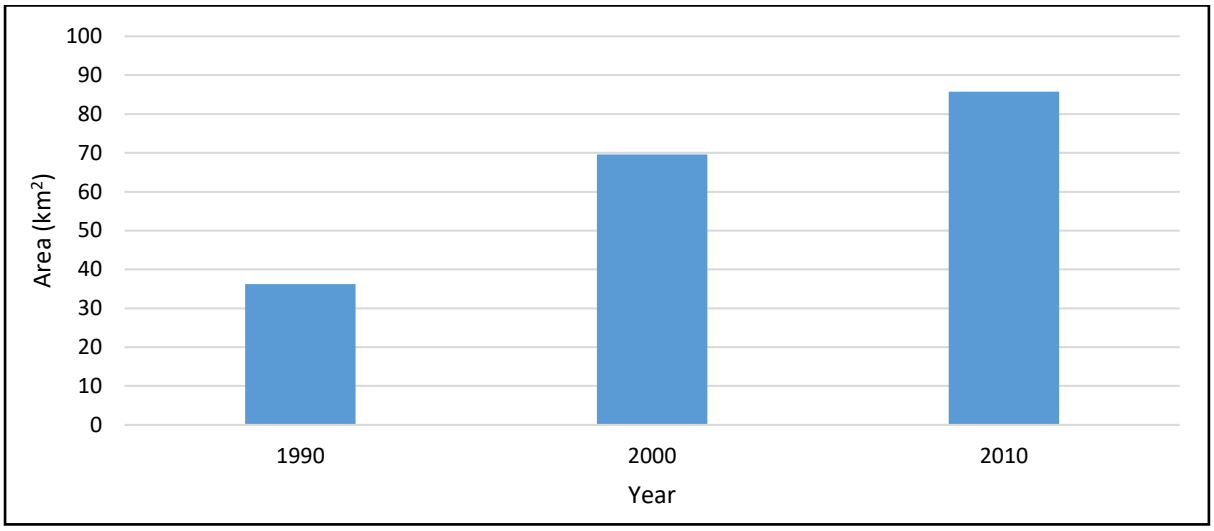


Fig 8.6 (c) Decadal variations in area (water) for Lower Tapi sub-basin

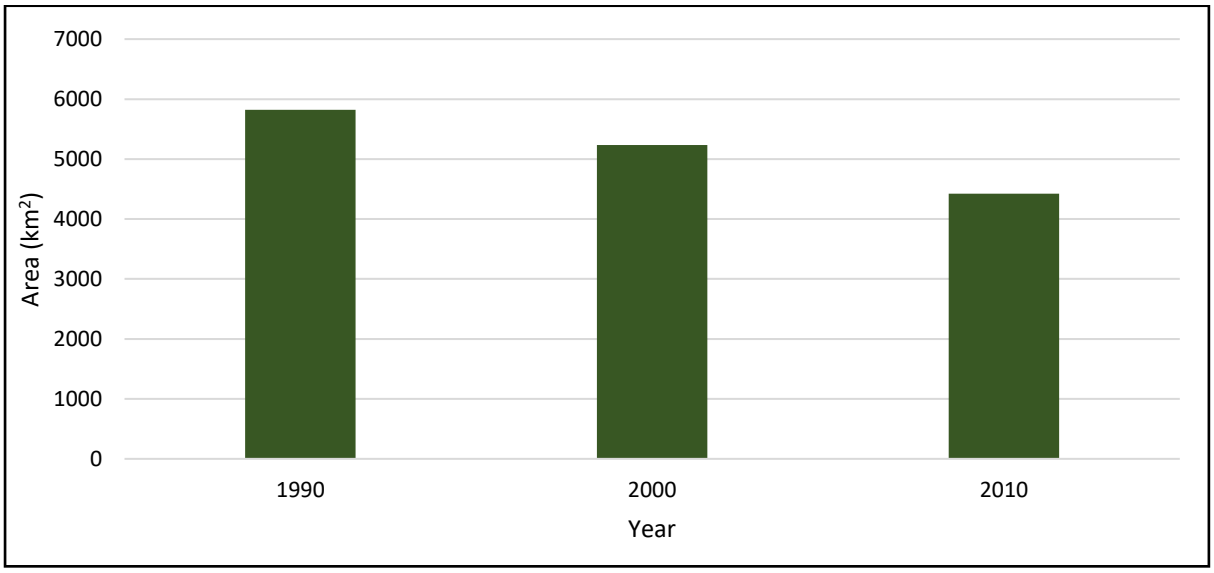


Fig 8.6 (d) Decadal variations in area (forest) for Lower Tapi sub-basin

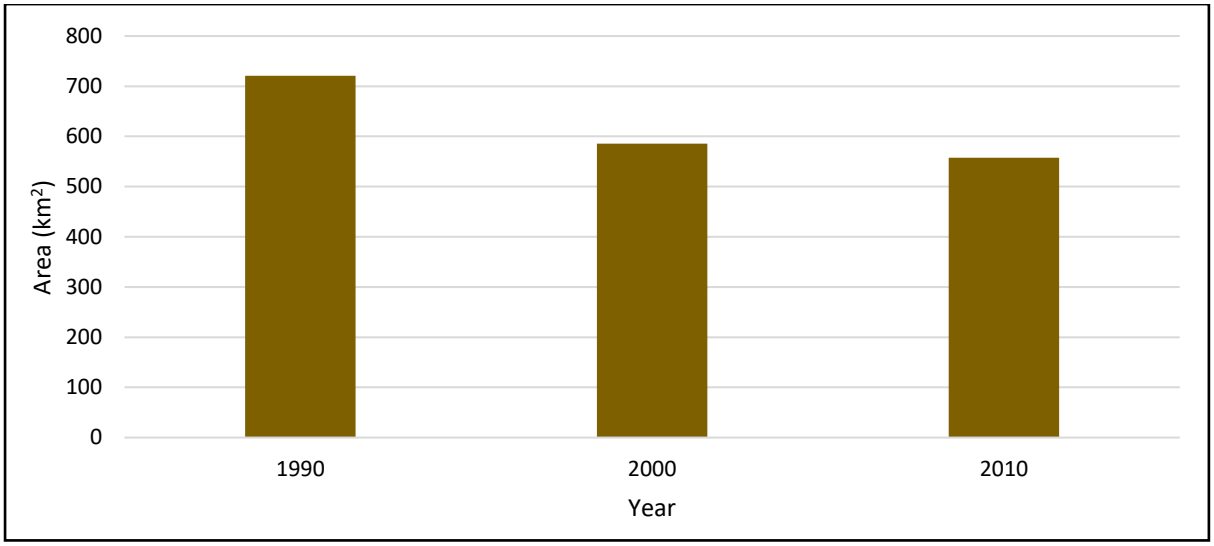


Fig 8.6 (e) Decadal variations in area (fallow) for Lower Tapi sub-basin

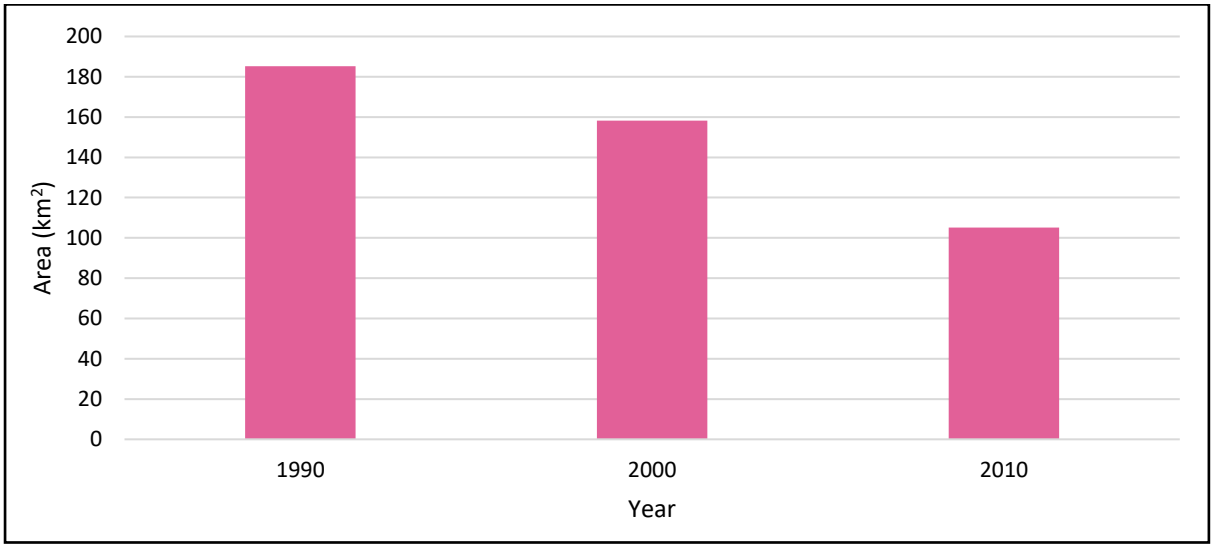


Fig 8.6 (f) Decadal variations in area (scrub land) for Lower Tapi sub-basin

8.5 IMPACT OF LAND-USE CHANGES ON RIVER MORPHOLOGY

Human land-use activities fundamentally change the hydrogeomorphology of rivers (James and Lecce, 2013). Changes in land-use can have significant impact on the runoff, sediment delivery, water quality, aquatic habitat and channel and flood plain morphology. Human impacts on rivers can be classified as 'direct changes', which occur within channels and the riparian vegetation and 'indirect changes', which occur in the form of agricultural expansion, urbanization, mining and changes in vegetation in the basin. The succeeding sub sections explain the effect on land-use changes that have occurred in Tapi Basin during 1990-2010, and their effects morphological behavior of the river, taking into consideration, the sediment yield, water quality and increasing braiding pattern in Lower Tapi river reaches.

It has been observed from the decadal variation in sediment rating curves (Section 6.7, Table 6.17) for Burhanpur (Upper Tapi river) and Sarangkheda (Middle Tapi river) stream gauging stations that there has been a decrease in the suspended sediment transport rates during the monsoon months (June-October) in the decade 2001-2010, vis-a-vis the decade 1980-1990. It has also been observed from the land-use land cover statistics for Upper Tapi Basin and Middle Tapi Basin that, there has been an increase in agricultural land at the expense of forest cover in the basin (Table 8.3 and Table 8.4). Naturally, due to the conversion of land from less erodible to more erodible status, the top soil will get eroded and ultimately more sediment will reach the river. But contrasting observations are revealed from the sediment rating curves. The possible reason can be explained by the increase in area of waterbodies in Upper (Fig.8.2c) and Middle Tapi Basins (Fig.8.4 c). This increase in the area of waterbodies is caused by the artificial storage of water created within the basin, due to the construction of hydraulic structures. Along with the storage of water, these structures trap sediments upstream, thereby restricting the sediments from entering the main river.

The water quality of the river is affected both by the increase in agricultural areas as well as built-up areas, in the form of urbanization. The Lower Tapi river gets affected to the maximum extent by deterioration in the quality of water due to the presence of large number of industries as well as remarkable increase in the population and urban growth. The Central Pollution Control Board (CPCB) has assigned different levels to the quality of water ranging from A (fit for drinking without any need of conventional treatment) - E (not fit for drinking; fit for irrigation, industrial cooling, and controlled disposal). The water quality of Tapi river falls under Grade C. However, the water quality in the river at Surat city (stations Varachha, Rander, Weir Cum Causeway) is relatively impaired compared to stations in the upstream. Within the city limits of Surat, water quality of the Tapi river has deteriorated to D and E grades. The detailed analysis have been presented in Chapter 10, Section 10.1. Excessive nutrient loadings into the river from agricultural chemicals can lead to eutrophication. Excessive floral growth has been reported in the Lower Tapi river at locations like Bodhan Village, Savjibhai-Korat bridge Site and Variav and Amroli Villages. The detailed description with photographs is presented in Chapter 9 (Sections 9.2.4 to 9.2.7).

Flood plain encroachment in the form of urban settlements and industries have flourished in the Lower Tapi river in the recent period. It has been observed that the flood carrying capacity of Tapi river in Surat has been reduced by almost 70%, due to heavy deposition of silt (Melvyn

Thomas, Times of India, 2016). The silt deposition has resulted in an increase of rise of water level during floods. Also, due to the absence of environmental flows during the lean period, the Tapi river flow is not able to transport the excess sediments deposited during the tidal currents at downstream of Singanpore weir. Analysis of planform of Lower Tapi river was carried out for Lower Tapi river, and the Plan Form Index (PFI), which represents the degree of braiding in the river, has been computed for all the decades during 1981-2010 (Chapter 11, Table 11.8). An increase in the degree of braiding has been observed for all the reaches in the Lower Tapi river during 1981-2010. This is an indication of river undergoing transition to multiple channels, with increased sediment deliveries and reduced lean period flows.

CHAPTER 9
RECONNAISSANCE

9.1 GENERAL

To assess the present condition of critical reaches of the Tapi river, field trips were conducted to the relevant reaches. The trips were carried out separately for Lower, Middle and Upper Tapi river reaches, starting from downstream and progressed towards upstream during different periods of the project. Based on the erosion-deposition analysis carried out during the project, the reaches which have undergone maximum changes regarding migration of bank lines and the resulting loss of land were identified. The major observations and conclusions derived out of the visits are discussed in the following sections.

9.2 VISIT TO LOWER TAPI RIVER REACHES

To verify the identified critical erosion prone areas, a site visit was conducted along the lower reaches of Tapi river, starting from Hazira which falls at the mouth of the river near the Arabian Sea till the Mandvi bridge location, which falls in the upstream side of the Lower Tapi river. The first visit was conducted on 25/06/2016, and covered the locations specified in Section 9.2.1 - 9.2.6 and discussed in the succeeding sections. The second visit was held on 02/07/2016, which covered locations specified in sections 9.2.7 - 9.2.9.

9.2.1 Tapi Estuary System, Suvali Gam, Hazira

The Tapi estuary system forms a part of the Gulf of Khambat and is in Hazira town of Surat District, Gujarat and falls approximately at CH: 787 km from the origin of Tapi river. The Hazira is one of the most important elements of Surat Metropolitan Region which is six kilometers from the Arabian Sea. The location serves as the industrial belt of Surat, where major industrial and shipping companies like Essar, KRIBHCO, Shell, Larsen & Toubro, NTPC, ONGC, GAIL, Gujarat State Petroleum Corporation, Ultra-Tech Cement and Reliance Industries are situated. Also, the industrial firms like Essar makes use of the multiple channels of Tapi for navigational purpose. The area is located at the confluence of the Tapi river with Arabian Sea. It was observed that, over the time the estuary has been lined by mud and has silted up significantly. The field observations have proven that the right bank of the channel is undergoing migration as well as silting up at the same time. It was observed that bank protection works have been provided in this region to arrest bank migration and subsequent erosion; however, the protection works are getting degraded due to river action and owing to

the high erosion at the right bank (Photos 9.1 - 9.3). The distance between the right bank line and the road (NH 6) was around 4 m at the time of the visit. The bed material was observed to be fine sand with low amounts of silt and clay, having muddy river water (Photo 9.3).



Fig 9.1 Location map of Tapi estuary system, Suvali Gam, Hazira



Photo 9.1 The alarming proximity of right bank to the NH 6 road



Photo 9.2 The right bank getting eroded at Suvali Gam, Hazira



Photo 9.3 Protection provided at the right bank getting degraded

The two islands formed due to three river channels, are valuable reserves for the mangrove vegetation (Fig 9.1). These islands also shield the inland areas during sea surges and minimize

the damage. Due to gradual outward migration of the river at this location and the action of tides, the mangrove cover is required to be protected in near future.

9.2.2 Bhatpor village, Surat

The Bhatpor village is situated in Choryasi Taluka of Surat District at chainage CH: 772 km from the origin of Tapi river. The location falls approximately 1.6 km to the right of ONGC bridge Road. As observed from Fig 9.2, the Tapi river forms a small channel at this particular location. During the time of the visit the channel was fully dry (Photo 9.4), however in a small portion, still water was observed. It was verified through discussion with local residents that during non-monsoon period, the Tapi river does not carry any water in this channel. A retaining wall has been constructed along the periphery of the right bank (Photo 9.5) and protection works in the form of rip rap has been provided in view to protect the structure at the time of monsoonal floods (Photo 9.6).



Fig 9.2 Location map of Bhatpor village, Surat



Photo 9.4 Dry channel observed in Bhatpor, Surat (view from right bank)



Photo 9.5 Retaining wall constructed along the periphery of right bank

9.2.3 Nehru bridge site, Surat

The Nehru bridge site is located in Surat District at Chainage CH: 765 km from the origin of Tapi river. Nehru bridge along with the Hope bridge, is one of the oldest bridges that has been built across Tapi river by the British. Another Road bridge, Makkai Pool Road runs parallel to Nehru bridge about 380 m downstream of the bridge. During the visit, both the right bank and left bank were found to be well protected. During the analysis using satellite imagery, the right bank was observed to undergo an outward migration, which resulted in erosion in this particular

location. The authorities have already taken protective measures to arrest the migration right bank (Photo 9.7). The left bank is seen to be well protected by the provision of levees (Photo 9.8). Both the right bank side and left bank side are thickly populated and urbanized.



Photo 9.6 Rip-rap stones provided at the right bank in view to protect the retaining wall



Fig 9.3 Location map of Nehru bridge site in Surat city



Photo 9.7 View of Nehru bridge and Makkai Pool bridge from right bank of Tapi river



Photo 9.8 Levee constructed in order to protect left bank near Nehru bridge, Surat

9.2.4 Variav and Amroli villages, Surat

The Variav and Amroli villages, situated in Surat District, Gujarat, falls at chainages CH: 755 km and CH: 757 km respectively from the origin of the Tapi river (Fig 9.4). These villages are located on the right bank of the Tapi river, where the river forms a prominent meander belt. It was observed during the analysis that the outer right bank of the Tapi river has undergone erosion due to the bank getting cut, due to the increased velocity of flow. During the site visit, it has been observed that in Variav village, flood gates are constructed to control the flow of water, at times of flood (Photo 9.9). To protect the flood gates and to guide the river flow past

the flood gates without causing damage to it, guide bunds have been provided at the upstream of the flood gates on its right flank (Photo 9.9). The right bank of the river has been well protected by the construction of embankments (Photo 9.10). In Amroli village a new flood gate has been constructed in the recent past in view to protect the village from flooding due to Tapi river (Photo 9.11).

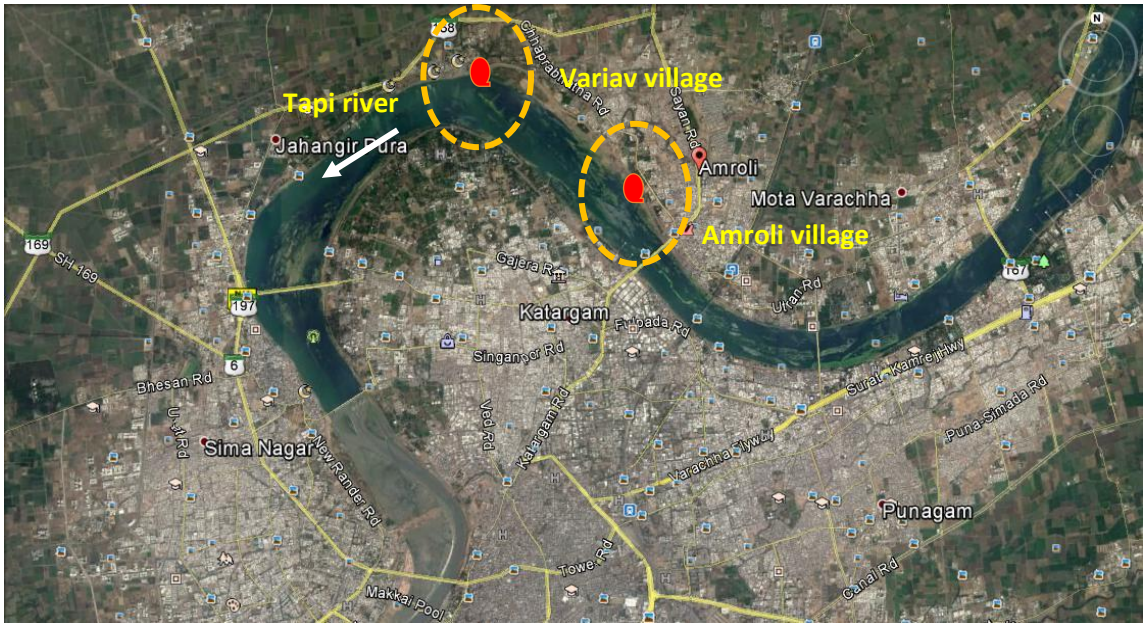


Fig 9.4 Location map of Variav village and Amroli village in Surat



Photo 9.9 Flood gate constructed across the river in Variav village



Photo 9.10 Embankment constructed to protect the right bank of Tapi river



Photo 9.11 Newly constructed flood gate across Tapi river in Amroli village

9.2.5 Utran-Kapodra bridge site

The Utran-Kapodra bridge, situated near Utran village in Surat District, Gujarat is a 1013 m long bridge located at CH: 750 km from the origin of the Tapi river (Fig 9.5). The width of the Tapi river at this location is approximately 530 m. The bridge which connects Kapodra and Utran areas was constructed under the supervision of Surat Muncipal Corporation (SMC) and was made open to public on 25th May 2012. During the analysis, it was observed that the right bank of the Tapi river, especially downstream of the bridge site, was subjected to erosion

(Photo 9.12). During the field visit, we could see that the flood plain at the left bank Tapi river is getting encroached by new buildings getting constructed (Photo 9.13). According to a local resident, the right bank of the river has been migrating outward resulting in erosion of its right bank, over the last few years. No proper protection works are provided to arrest the migration of right bank and the resulting erosion. The banks must be protected against both the flood plain encroachment as well as erosion in the right bank in this location.



Fig 9.5 Location map of Utran-Kapodara bridge site



Photo 9.12 Erosion on the right bank of the river at Utran-Kapodra bridge site



Photo 9.13 Flood plain getting encroached on the left bank of Tapi river

9.2.6 Savjibhai-Korat bridge site

The Savjibhai-Korat bridge, which was constructed across Tapi river in May-2001 connecting Nana-Varachha and Mota Varachha in Surat District, Gujarat, is located at CH: 748 km from the source of Tapi river (Fig 9.6). The bridge, which was built under the supervision of Surat Municipal Corporation has a length of 544.6 m, with 13 spans. The Tapi river has a width of about 490 m at this location. The right bank of Tapi river was observed to be getting eroded at a minor rate at this site (Photo 9.15).



Fig 9.6 Location map of Savjibhai-Korat bridge site



Photo 9.14 Construction of intake well in progress on left bank of Tapi river



Photo 9.15 Intake wells already constructed on the left bank of Tapi river

Three intake wells exists near the left bank of the river (Photo 9.14) and one intake well is under construction (Photo 9.15). The major observation at this site was the excessive eutrophication in the form of floral growth in Tapi river (Photo 9.16). The river needs to be immediately cleaned, or otherwise over the long run, it might cause major issues related with quality of water.

9.2.7 Bodhan village, Mandvi

The Bodhan is a village situated on the right bank of Tapi river in Mandvi Taluka of Surat District, Gujarat and falls at a chainage of CH: 721 km from the origin of the river (Fig 9.7).

The bank width of the Tapi river at this location is around 390 m. The location falls around 900 m upstream of Bodhan Flyover. No critical erosion was observed at this particular site and the banks were observed to be not under threat. During the time of the visit, sand mining activities were observed to be taking place near the left bank of the Tapi river (Photo 9.17). The parent bed material at this reach is composed of sand. The rocky left overs, which have got transported from upstream could be seen on the river bed (Photo 9.18). On left bank, bunds are constructed using sand bags to provide protection to the agricultural lands (Photo 9.19).



Photo 9.16 Excessive floral growth observed in Tapi river at Savjibhai-Korat bridge site



Fig 9.7 Location map of Bodhan village near Mandvi Taluka, Surat



Photo 9.17 Sand mining activities taking place near the left bank



Photo 9.18 Rocky particles transported from upstream lying on the river bed

9.2.8 Umarsadi Haripura bridge site, Mandvi

The Umarsadi Haripura bridge constructed across Tapi river is situated in Mandvi Taluka of Surat District at a chainage CH: 705 km from the origin of Tapi river (Fig 9.8). The bridge is located approximately 42.7 km downstream of Ukai Dam and connects two villages, Umarsadi and Haripura. The bank width of the Tapi river at this location is around 520 m. However, the active river channel width is found to be very low in this site due to the formation of sand bars

in the river (Photo 9.20). The bed strata was found to comprise of rocky material, which was exposed due to low flow in the river at the time of the visit (Photo 9.21). As per the analysis carried out using satellite imagery, the right bank of Tapi river was observed to be eroding with migration of the bank line towards the northern side. Justifying the findings of our analysis, the right bank of the river was found to undergo cutting (Photo 9.20), which would be the effect of high flow in river during the monsoon period. The right bank hasn't been provided with any protection. Also, excessive sand mining activities were taking place near both the right bank and left bank during the visit (Photo 9.20).



Photo 9.19 Bund constructed using sand bags on left bank to protect the agricultural lands



Fig 9.8 Location map of Umarsadi Haripura bridge site, Mandvi



Photo 9.20 Sand mining activities taking place in the river, view from the right bank (the eroded right bank and sand bars formed in the river can also be seen)



Photo 9.21 View of Umarsadi Haripura bridge towards the left bank of the Tapi river

9.2.9 Mandvi bridge site

The Mandvi bridge constructed across Tapi river is situated in Mandvi Taluka of Surat District at a chainage CH: 696 km from the origin of Tapi river. The bridge is located approximately 33.8 km downstream of Ukai Dam and the Tapi river has a width of approximately 540 m here

(Fig 9.9). The bridge forms part of the Gujarat State Highway (SH-88). The Tapi river was observed to flow in multiple channels at this site due to the presence of rocky bed stratum and the vegetation that has grown within the active channel of the river (Photo 9.22). As per the analysis, the right bank of the Tapi river has undergone an outward migration resulting in the erosion of the right bank. Field observations also reveal similar trend where, cutting has been observed on the right bank, where no proper protection works have been provided to arrest the same (Photo 9.23).



Fig 9.9 Location map of Mandvi bridge site



Photo 9.22 Rocky bed stratum and growth of vegetation upstream of Mandvi bridge site



Photo 9.23 View of the eroded right bank downstream of Mandvi bridge site

9.3 VISIT TO MIDDLE TAPI RIVER REACHES

To verify the critical erosion prone areas in the Middle Tapi river reaches, a site visit was conducted during 20/08/2016 and 21/08/2016, starting from Velda village in Gujarat which falls in the downstream reaches of Middle Tapi river to Awer, Maharashtra, which falls in the upstream reaches of the river. The locations mentioned in Sections 9.3.1-9.3.5 were covered on the first day and locations 9.3.6-9.3.10 were covered on the second day of the visit. The major observations that were made during the visit along with the information about the sites are mentioned in the succeeding sections.

9.3.1 Kavithe-Kukarmunda bridge site

The Kavithe-Kukarmunda bridge which connects Kavithe village and Kukarmunda village via SH-198 is located in Nizar Taluka of Surat District, Gujarat, and falls at chainage CH: 589 km from the origin of the Tapi river (Fig 9.10 and Photo 9.24). Tapi river has a width of about 380 m at this location. A lift irrigation plan, 'Velda 3', which irrigates 130 Ha of the surrounding area exits on left bank of the river under Narmada Water Resources Water Supply and Kalpsar Department, Govt. of Gujarat (Photo 9.25) just upstream of the bridge. The left bank of Kavithe-Kukarmunda bridge is protected in order to safeguard the lift irrigation scheme (Photo 9.26 and Photo 9.27). Upstream and downstream of the irrigation scheme, the vertical left banks were observed to get cut due to erosion (Photo 9.27 and Photo 9.28). The visited site falls in Ukai reservoir area and upstream of aforesaid bridge. The vertical cuts in the left bank,

may be due to cave in of banks while filling the reservoir and bridge afflux between the river banks. However, the left banks seem to be stabilized nearby the intake well. No major erosion pattern seen from satellite imagery 1990 to 2010.

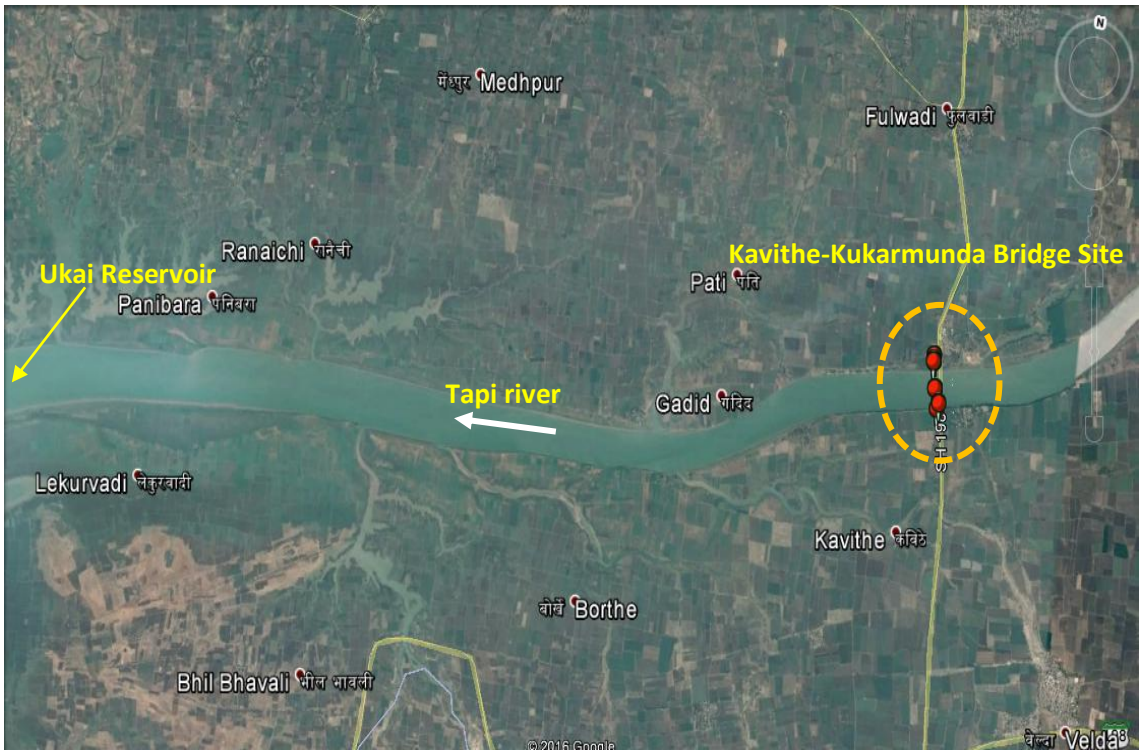


Fig 9.10 Location map of Kavithe-Kukarmunda bridge site



Photo 9.24 Kavithe-Kukarmunda bridge, Nizar Taluka, Gujarat



Photo 9.25 Details of the Velda 3 lift irrigation scheme



Photo 9.26 Velda 3 lift irrigation scheme on the left bank of Tapi river



Photo 9.27 Protection at left bank for the lift irrigation scheme and cutting of the left bank



Photo 9.28 Unprotected left bank downstream of the lift irrigation scheme under the threat of erosion

9.3.2 Prakasha barrage, Nandurbar, Maharashtra

The Prakasha barrage across Tapi river is located in Nandurbar district of Maharashtra state at a chainage CH: 561 km from the origin of the Tapi river (Fig 9.11). A bridge is constructed 400 m downstream of the barrage which is a part of Maharashtra State Highway MH SH-17 (Photo 9.29). The width of river just upstream of the barrage is around 550 m. The Prakasha barrage was constructed in 1999 and is maintained by Water Resources Department (WRD) of Government of Maharashtra (GoM) with the purpose of providing water for irrigation and municipal needs in the region, serving a culturable command area of 9840 ha. The barrage has a length of 503 m, height up to crest as 19.1 m (102.000 m RL) with 27 spillway gates and design discharge of 50,517 m^3/s. Approximately 1.5 km upstream of the barrage, a river named Gomai joins Tapi at its right bank (Fig 9.11 and Photo 9.30). Prakasha village is situated in the deltaic region at the confluence of both the rivers. The Gomai river was dry during the visit (Photo 9.30). Rocky bed material was observed in the Tapi river downstream of the barrage (Photo 9.31), while the bank material was observed to be silty (Photo 9.32). The bed slope was found to be very high; the right bank was seen to have minor erosion, without any threat to the structure (Photo 9.32).



Fig 9.11 Location map of Prakasha barrage site

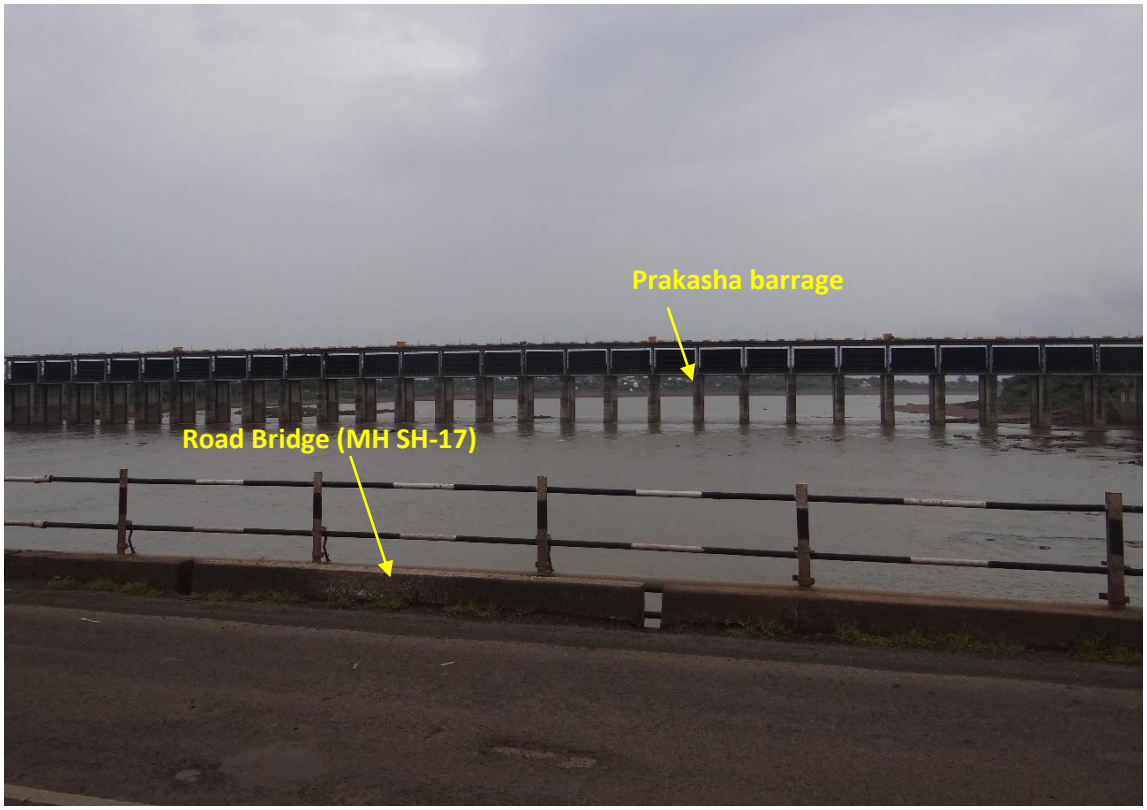


Photo 9.29 Location of road bridge (MH SH-17) and Prakasha barrage



Photo 9.30 View of Gomai river, right bank tributary of the Tapi river



Photo 9.31 Rocky bed strata downstream of Prakasha barrage

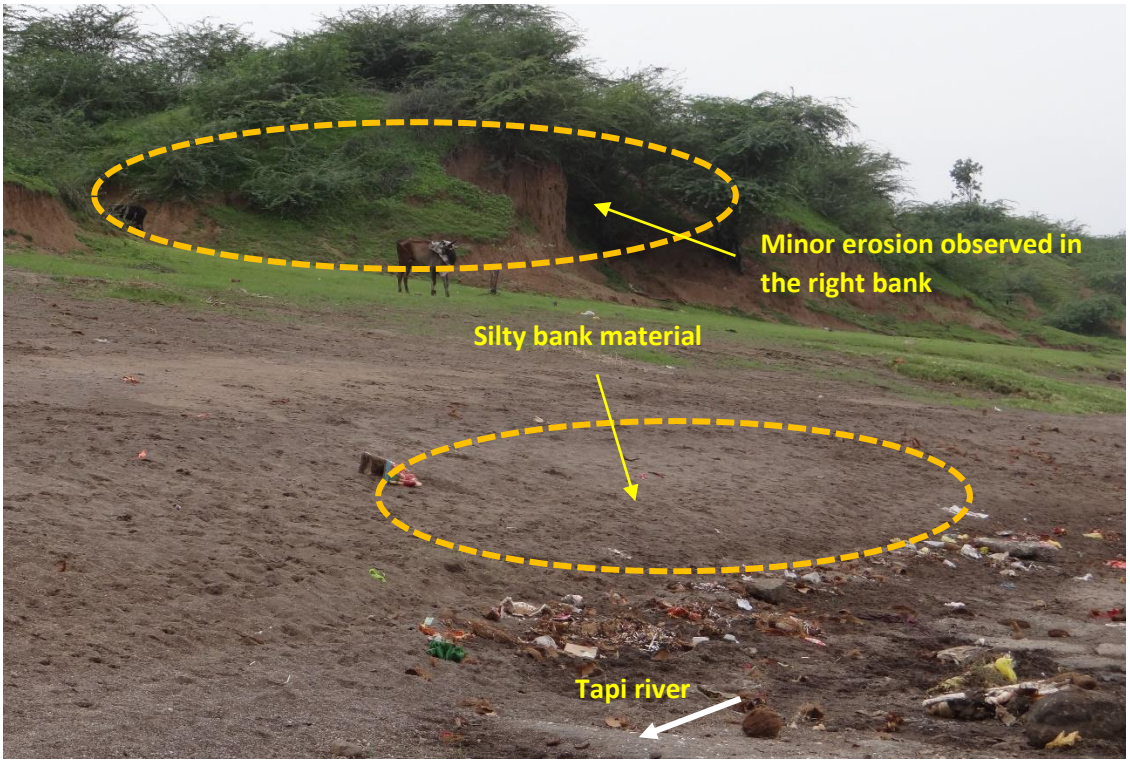


Photo 9.32 Silty bank material found at the Prakasha barrage site

9.3.3 Sasde village, Maharashtra

The Sasde village is situated on the right bank of the Tapi river in Nandurbar district of Maharashtra state at a chainage CH: 548 km from the origin of the Tapi river (Fig 9.12). A

village named Amaltha is situated on the left bank of the Tapi river exactly opposite to Sasde village. The width of the Tapi river is approximately 490 m at this site. Agricultural land is found in prominence on both right bank and left bank. The findings as per the analyses using satellite image were in agreement with what was observed at site.

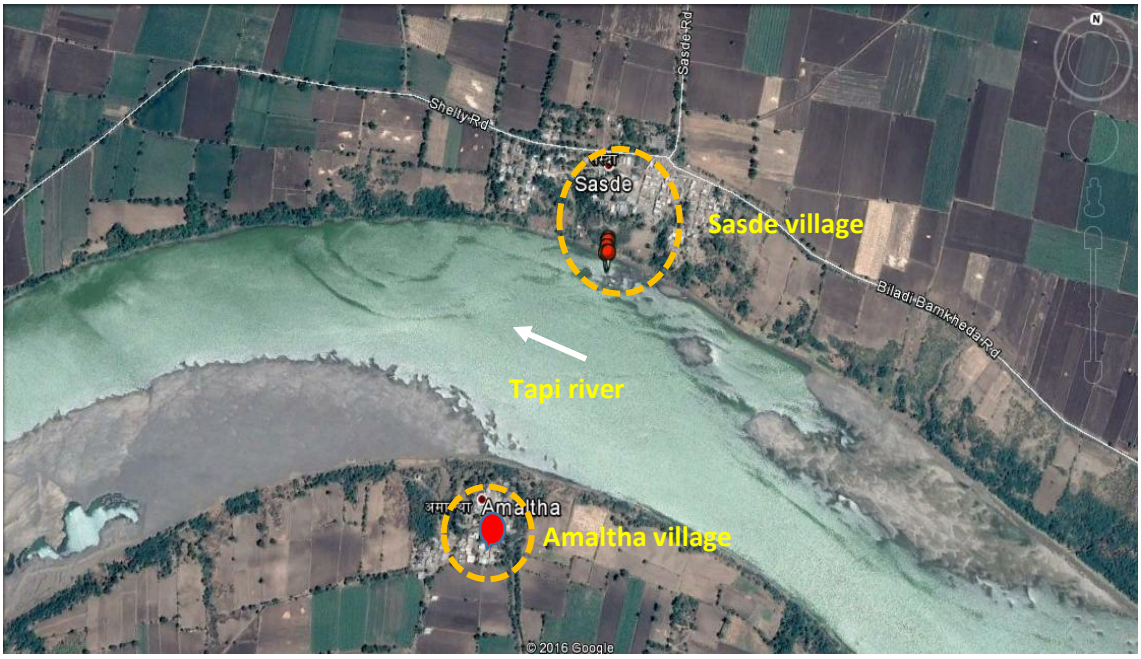


Fig 9.12 Location map of Sasde village, Nandurbar, Maharashtra



Photo 9.33 Erosion on right bank; banks are observed to get cut

The river bend near the site is subjected to erosion in its outer bend at the right bank, and deposition in its inner bend at the left bank (Photo 9.33 and Photo 9.34). The right bank was getting cut by the river flow, and has become almost vertical (Photo 9.33). The said village is

situated about 10 m above the average water line. The water depth was shallow, and was observed to be flowing with high velocity. The erosion phenomena, if persists may pose threat to the village located along the banks. No bank protection works were seen on the right bank of the river in this location. The right bank needs to be protected with proper protection works, to arrest erosion.

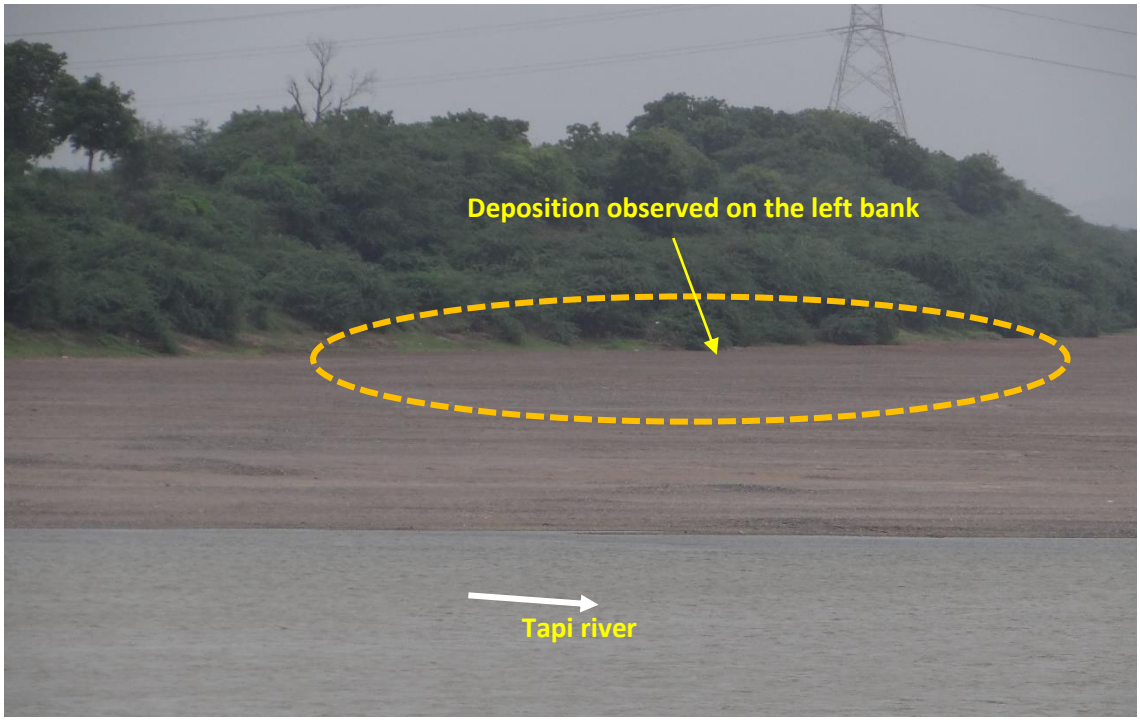


Photo 9.34 Deposition observed on the left bank at Sasde, Maharashtra

9.3.4 Biladi-Bamkheda village, Maharashtra

The location map of the site visited is presented in Fig 9.13. The Biladi-Bamkheda village is situated on the right bank of the Tapi river in Nandurbar district of Maharashtra state at a chainage CH: 544 km from the origin of the Tapi river. The agricultural fields are also seen in abundance nearby the right bank adjacent to the village. Pumping of water is carried out through the right bank and intake well was observed (Photo 9.35). As observed from the analysis part, erosion was observed in the right banks of the river (Photo 9.36) and deposition on the left bank (Photo 9.37). The village is situated at an altitude of almost 10 m above the mean water line in the river. The suitable bank protection works are to be carried out in order to protect the village, and agricultural lands. Sand mining activity was observed at the left bank at about 500 m upstream of the site (Photo 9.38). The intake well on the right bank seems to be in abandoned condition, may be due to excessive erosion in the surrounding.

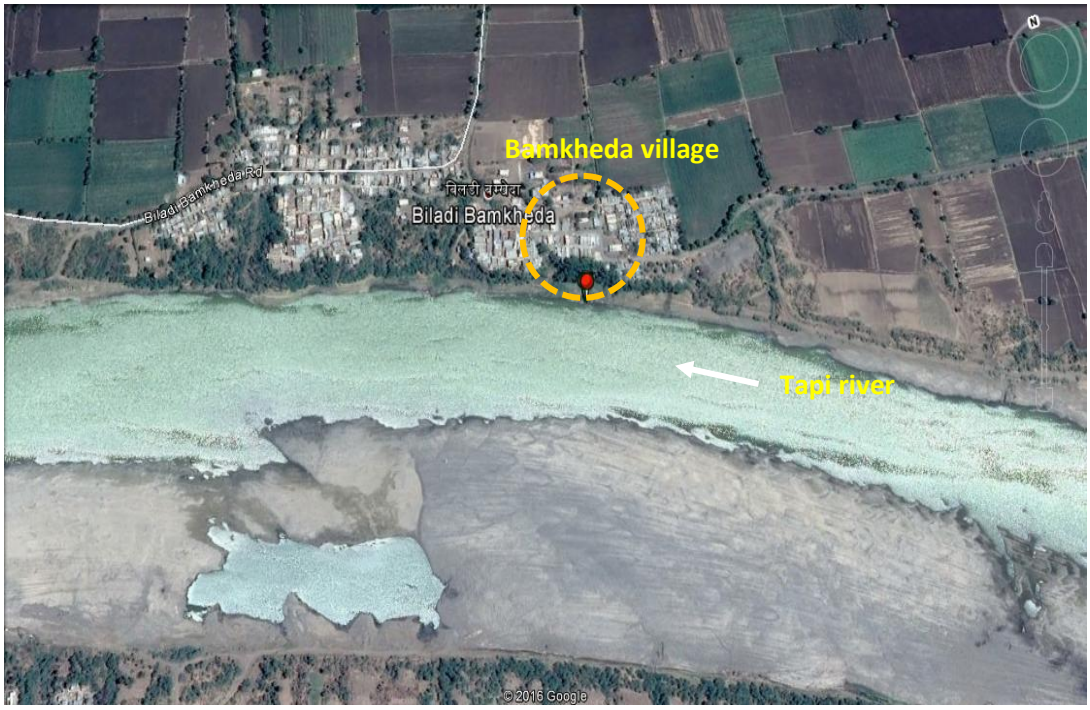


Fig 9.13 Location map of Bamkheda village, Nandurbar, Maharashtra



Photo 9.35 Pumping of water carried out at the right bank



Photo 9.36 Right banks which have got cut due to flowing water

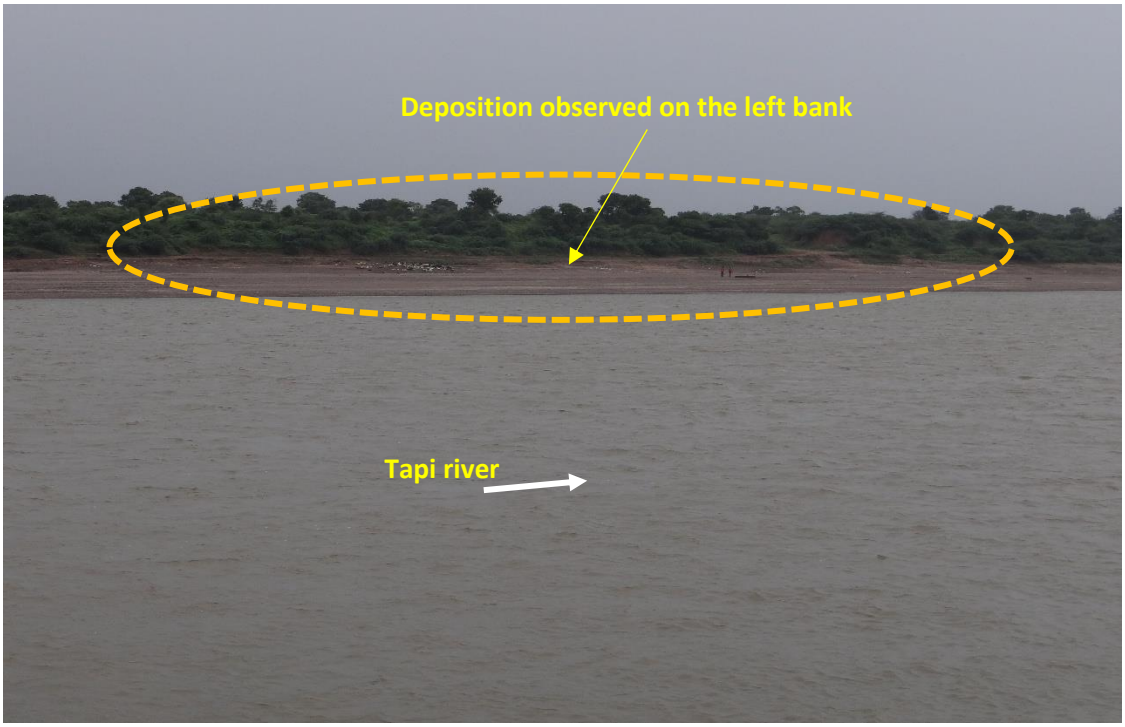


Photo 9.37 Deposition on the left bank of the river



Photo 9.38 Excessive sand mining observed at the upstream of the site

9.3.5 Sarangkheda Stream Gauging site/ Sarangkheda barrage, Maharashtra

The Sarangkheda barrage across Tapi river is located in Nandurbar district of Maharashtra state at a chainage CH: 537.9 km from the origin of the Tapi river. The location visited is the CWC stream gauging site, which is located approximately 20 m upstream of the Sarangkheda bridge (part of MH SH-1), and approximately 120 m downstream of Sarangkheda barrage (Fig 9.14). Two villages, Sarangkheda and Takarkheda are located on the right bank and left bank of Tapi river respectively at this location. The width of river just upstream of the barrage is around 480 m. The Sarangkheda barrage was constructed in 1999 and is maintained by Water Resources Department (WRD) of Government of Maharashtra (GoM) with the purpose of irrigation serving a culturable command area of 9742 ha. The barrage has a length of 484.5 m, height up to crest as 11 m with 26 spillway gates and design discharge of 50,529 m^3/s. The Water level in the barrage reached the crest level at the time of the visit. Also, rocky bed strata, boulders at the bank and transported sediment silt were observed at the site. The gauge readings were marked on the pillars of the bridge, just at downstream of the barrage having bed level between 109-110 m with respect to mean sea level.

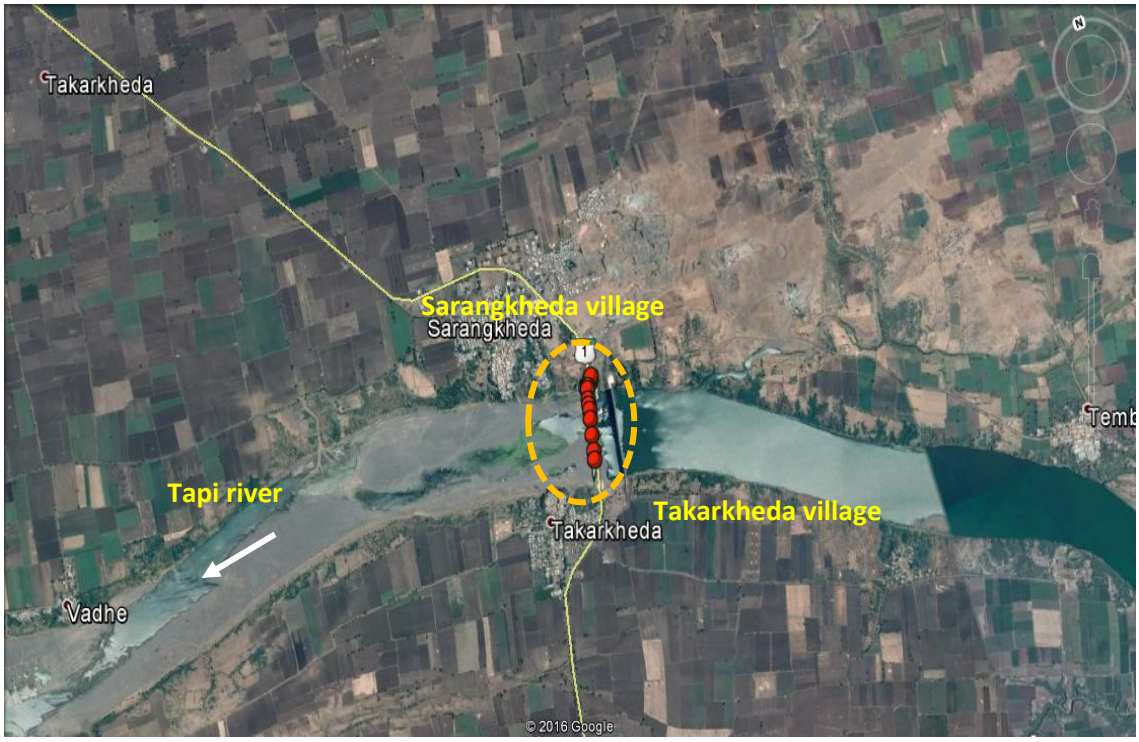


Fig 9.14 Location map of Sarangkheda CWC site, Nandurbar, Maharashtra



Photo 9.39 View of Sarangkheda barrage



Photo 9.40 The crest level of Sarangkheda barrage



Photo 9.41 Boulders seen on the banks of the river



Photo 9.42 Parent material of the river bed downstream of Sarangkheda barrage

During another site visit between 22/02/2017 to 27/02/2017, the same site was re-visited. It has been observed that considerable erosion has taken place on the left bank of the river, where the rip-rap protection below the bridge abutment has been found to be damaged (Photos 9.43 and 9.44). The prime reason for damaging of rip-rap protection is missing guide bunds between the barrage and the bridge. From Photo 9.45, it is seen that the portion between the barrage and bridge comprises of loose unstable banks and due to action of floods, the bank material gets washed away and this phenomenon further progressed downstream and thereby caused the erosion under the abutment. It is therefore recommended that if preventive measures are not taken at the earliest, a likely damage to the bridge structure is possible.



Photo 9.43 Erosion observed underneath the abutment of road bridge (MH SH1) on left bank



Photo 9.44 Rip-rap protection provided on left bank downstream of Sarangkheda barrage



Photo 9.45 Cutting of left bank in the immediate downstream of Sarangkheda barrage

9.3.6 Gidhade Stream Gauging site, Maharashtra

The Gidhade stream gauging site maintained by CWC on Tapi river is located in Nandurbar district of Maharashtra state at a chainage CH: 497 km from the origin of the Tapi river (Fig 9.15). Gidhade is a stream gauging site which is located approximately 1 km upstream of Sulwada barrage (Photo 9.46). The details of the site is given in Photo 9.47. During the visit, the velocity of flow was very less. As observed in the previous sites, the river here exhibited rocky bed stratum and transported silt on the banks as well. The banks are observed to be alluvial in nature. To measure the velocity of flow, suspension cable current meter is established at this site (Photo 9.48). The banks are comparatively stable here.

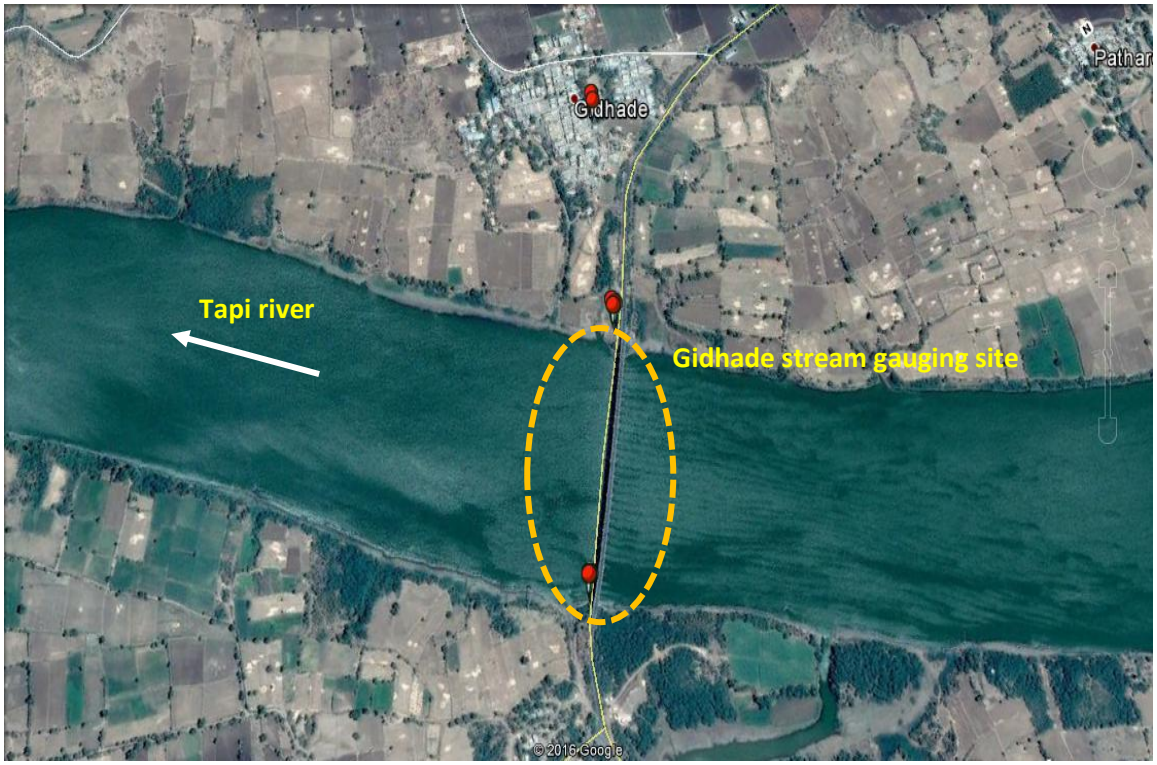


Fig 9.15 Location map of Gidhade CWC site, Maharashtra



Photo 9.46 Sulwada barrage; located 1 km downstream of Gidhade stream gauging site



Photo 9.47 Details of Gidhade stream gauging site



Photo 9.48 Suspension cable for current meter measurements at Gidhade

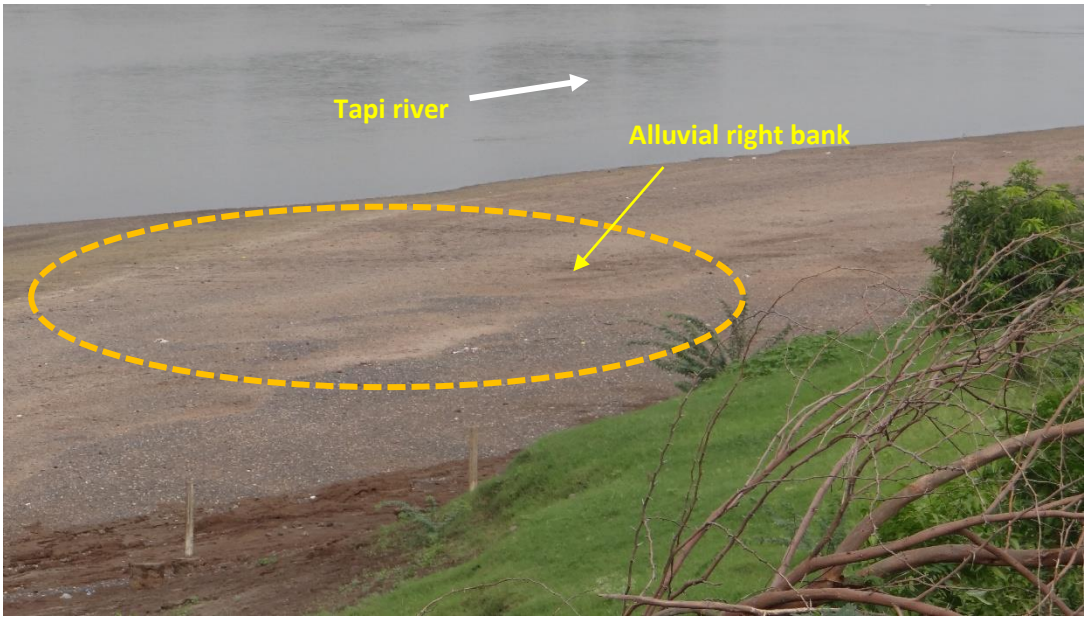


Photo 9.49 Alluvial right bank of the Tapi river at Gidhade

9.3.7 Babulde village, Maharashtra

The Babulde village on Tapi river is located in Dhule District of Maharashtra state at a chainage CH: 493 km from the origin of the Tapi river (Fig 9.16). Two bridges run parallel to each other across the river at this particular site, and is part of highway AH 47 (Photo 9.50). The channel width is observed to be very high here, almost 400 m with a very high slope. The bed was observed to be silty. The right banks were observed to get cut (Photo 9.51), and local scour was observed in the upstream bridge, and remarkable portion of the piles were exposed.

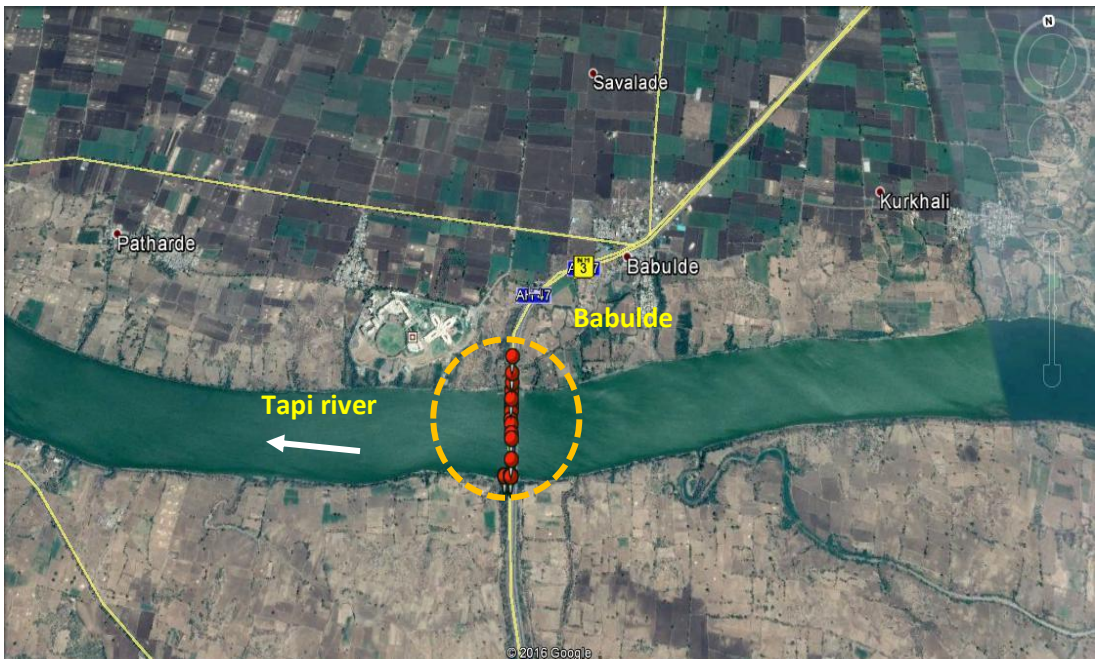


Fig 9.16 Location map of Babulde site, Maharashtra



Photo 9.50 bridges running parallel across the Tapi river near Babulde

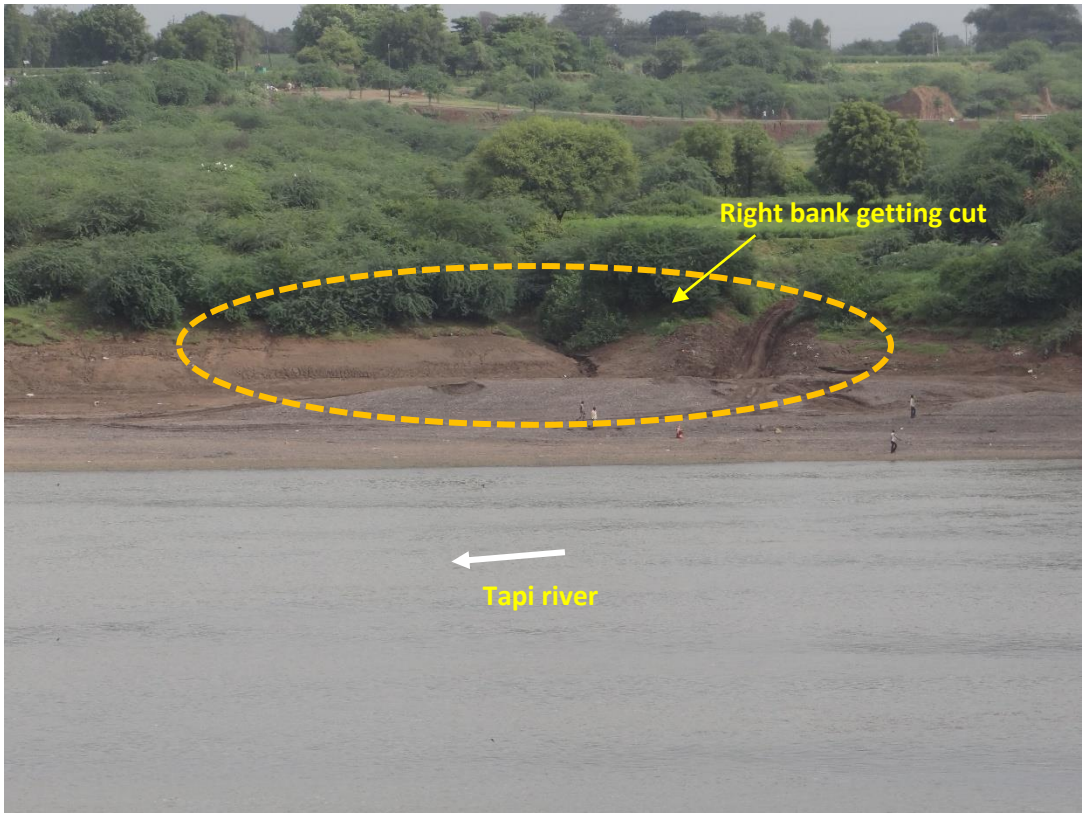


Photo 9.51 Cutting of right bank near Babulde

9.3.8 Mudawad village, Maharashtra

The Mudavad village is located in Sindhkheda tehsil of Dhule district in Maharashtra state at a chainage CH: 478 km from the origin of the Tapi river (Fig 9.17). The site visited is the confluence of Tapi and Panjara rivers (Photo 9.52). The Panjara river is the left bank tributary of the Tapi river which originates near a small town of Pimpalner in Dhule district. The width of Tapi river at this location is around 350-420 m, while that of Panjara river is about 100-150 m. The Tapi river is observed to carry fine sand and silt material while the Panjara river brings gravels and coarse sand along with it. Further, it has been observed that at the confluence of two rivers considerable damage to the staircase of Kapileshwar temple has taken place. This could be due to the turbulence created during the floods when the two rivers meet each other at the left bank (Photo 9.53), whereas right bank is subjected to huge amount of deposition forming a point bar (Photo 9.55). While, both the banks of Panjara river are subjected to erosion (Photo 9.54), and have high bed slope in comparison to the Middle Tapi river. Also, the velocity of the Panjara river was observed to be more in comparison with the Middle Tapi river. The bank materials of the Panjara river are coarser in size, whereas the Middle Tapi river have clayey particles on the bank as observed in Photo 9.56. The corrective measures to protect the temple at the confluence of both the rivers are urgently needed to protect the same due to erosive action of both the rivers.

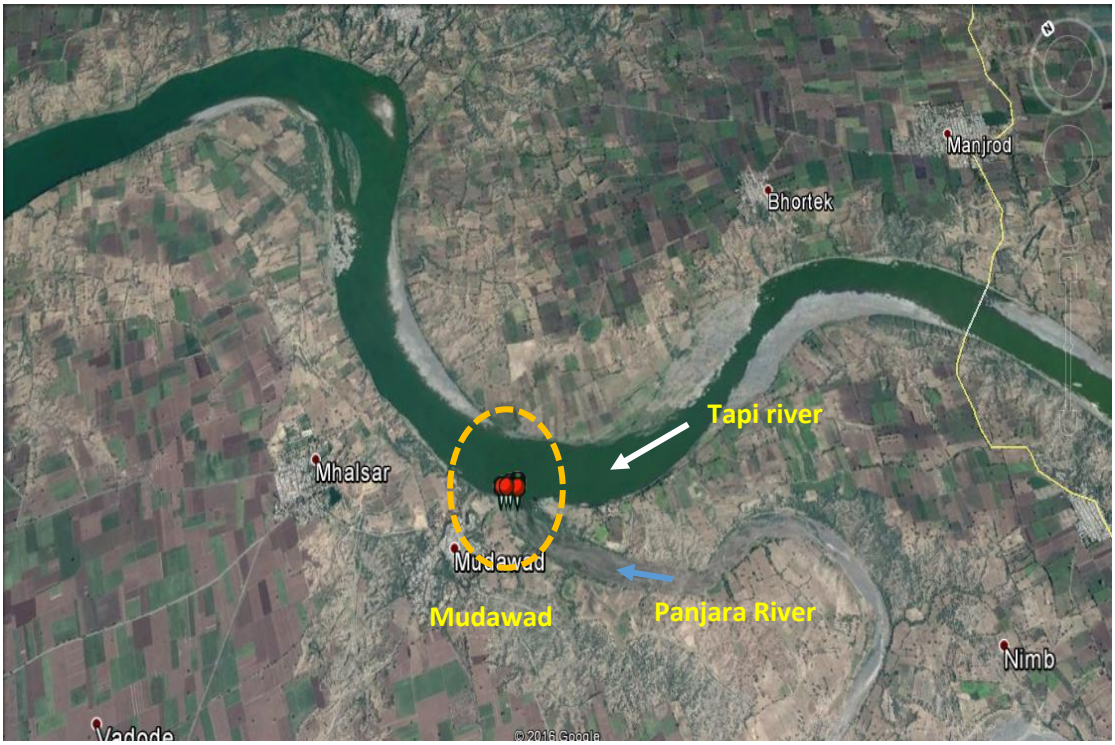


Fig 9.17 Location map of Mudawad site, Maharashtra



Photo 9.52 Confluence of Tapi and Panjara rivers



Photo 9.53 Eroded structure at the confluence of Tapi and Panjara rivers



Photo 9.54 Erosion at the outer (concave-left) bank

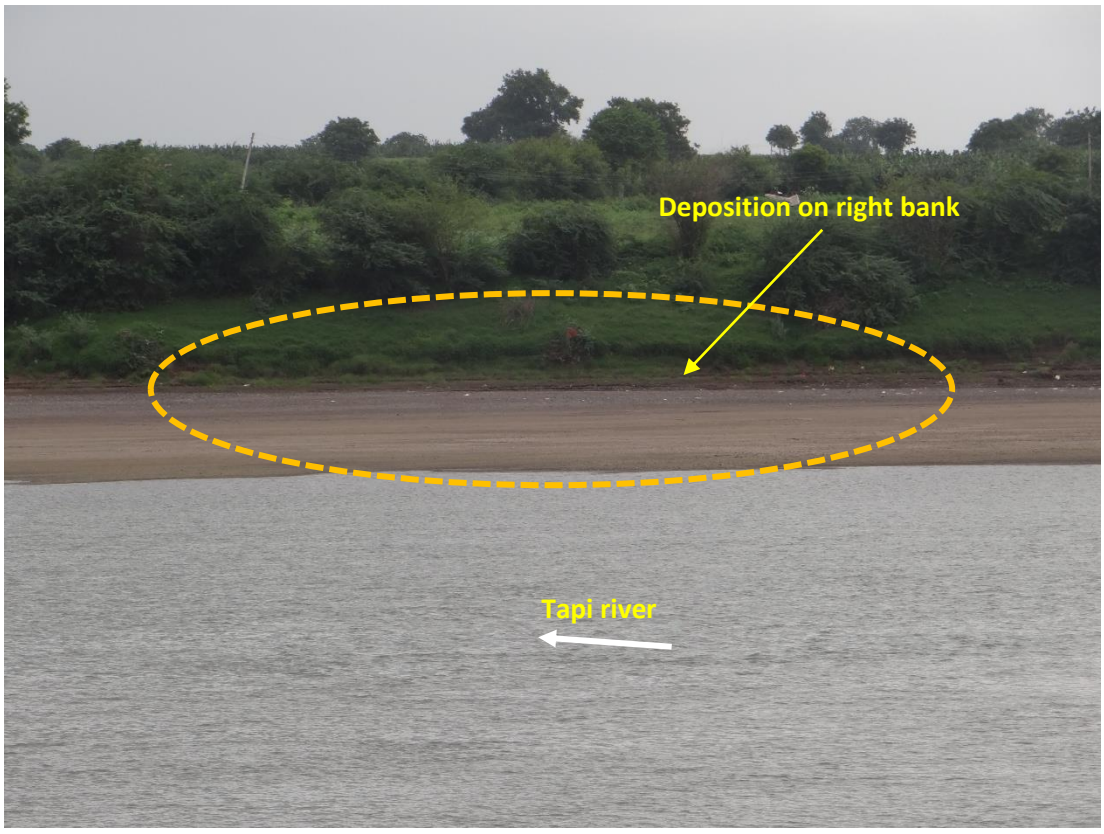


Photo 9.55 Deposition at the inner (convex-right) bank

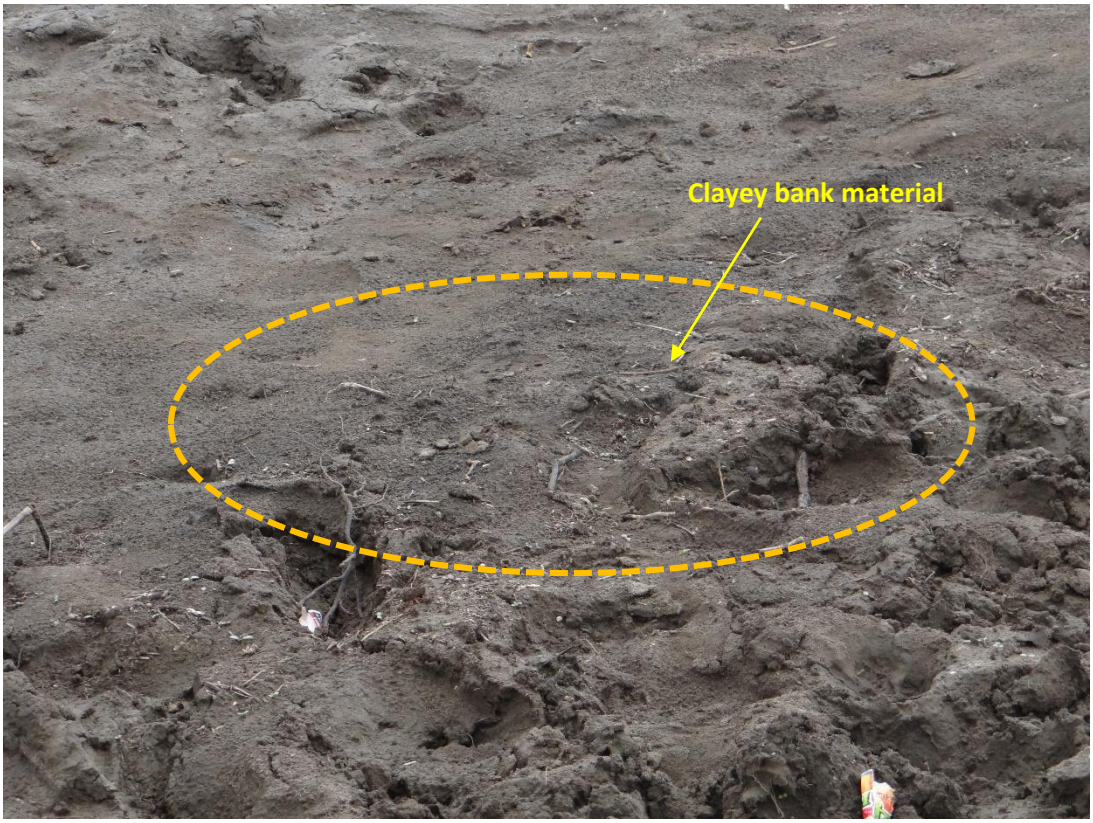


Photo 9.56 Clayey material at the bank of the river

9.3.9 Padalsare Dam, Maharashtra

The Padalsare Dam, also known as Lower Tapi Dam, is located downstream of the confluence of Aner, Bori and Tapi rivers near Amalner in Jalgaon district of Maharashtra state at a CH: 471 km from the origin of the Tapi river (Fig 9.18). The Padalsare Dam is under construction across Tapi river (Photo 9.57) and is located between Savkheda and Gidhade stream gauging sites of the Central Water Commission. The Aner river meets Tapi river from the right, 1200 m upstream of the Padalsare Dam (Photo 9.59), while the Bori river meets Tapi river from the left, 2500 m upstream of the Padalsre Dam. Further, the Panjhara river meets Tapi river from the left, 7600 m downstream of Padalsare Dam. The dam is under construction and the downstream Guide bunds are also under progress (Photo 9.59). The width of the Tapi river at this location was found to be around 530 m, while the width of Aner and Bori rivers were found to be around 100 – 140 m. The length of the proposed dam is 1876.5 m for a design flood of 50,881 m^3/s. It has been observed that the left bank of the Tapi river at this location is lower than the right bank of the river and the area is likely to go under submergence after the completion of dam (Photo 9.60). The validity of hydrologic measurement site (Photo 9.61) needs to be verified after construction of dam as the same may get affected due to submergence.

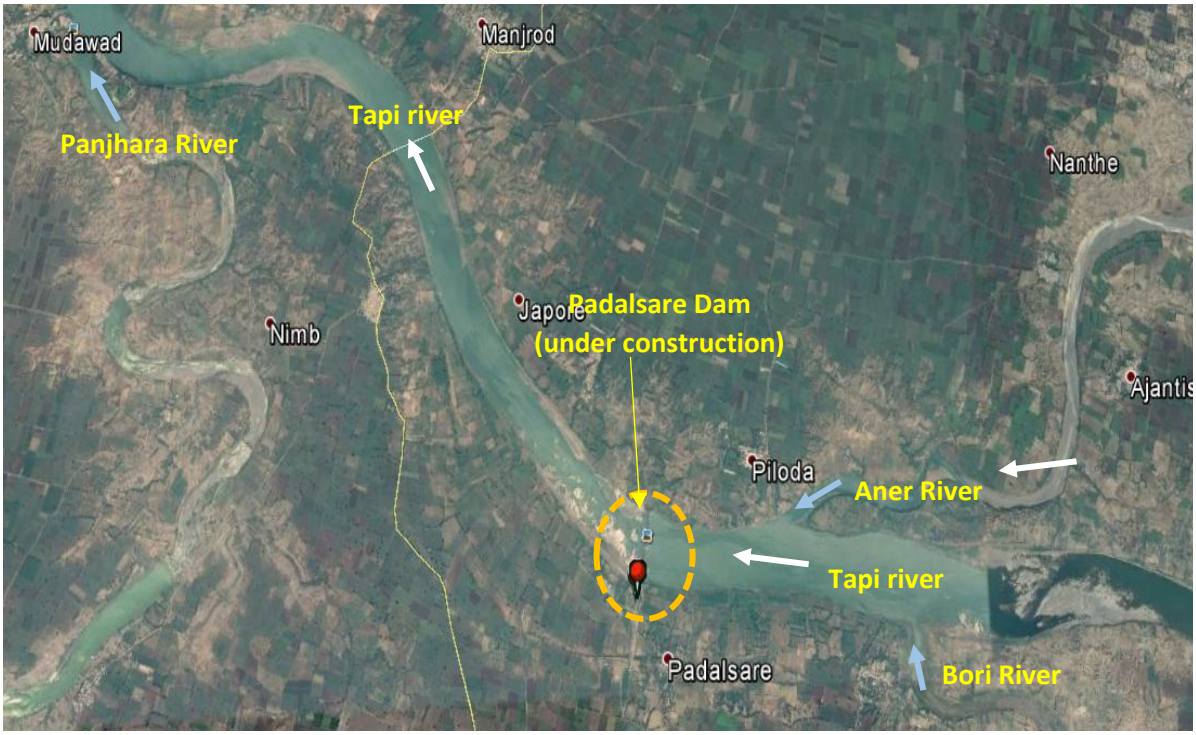


Fig 9.18 Location Map of Padalsare Dam



Photo 9.57 View of construction work in progress at Padalsare Dam



Photo 9.58 View of downstream guide wall at Padalsare Dam



Photo 9.59 View upstream of Padalsare Dam showing confluence of Aner and Tapi rivers



Photo 9.60 View upstream of Padalsare Dam



Photo 9.61 Hydrologic measurements carried out by HDUG at Padalse stream gauging site, upstream of Padalsare dam

9.3.10 Gangapuri, Jalod, Maharashtra

The location map of the bridge site is as per given in Fig 9.19. The Gangapuri village is located in Dhule district of Maharashtra state at a chainage CH: 454 km from the origin of the Tapi river. The bank width of Tapi river at this location is about 350 m. Silty bank material was found on the right bank whereas in left bank we could observe clayey deposits. On the left bank, i.e., outer bend, erosion was prominent and on the right bank, deposition was visible (Photos 9.62 and 9.63). Eroded structure was found near the left bank, and the intake wells are also observed to be under threat of erosion (Photo 9.64). Suitable bank protection works have to be carried out in the left bank to resist further bankline migration that results in the erosion. Also, the left bank line needs to be protected for safety of the bridge site near future (Photo 9.65). Sand mining activities were seen on the left bank in the downstream of the bridge (Photo 9.66). Such sand mining activities may aggravate the scouring of bridge/erosion of left bank further in future.

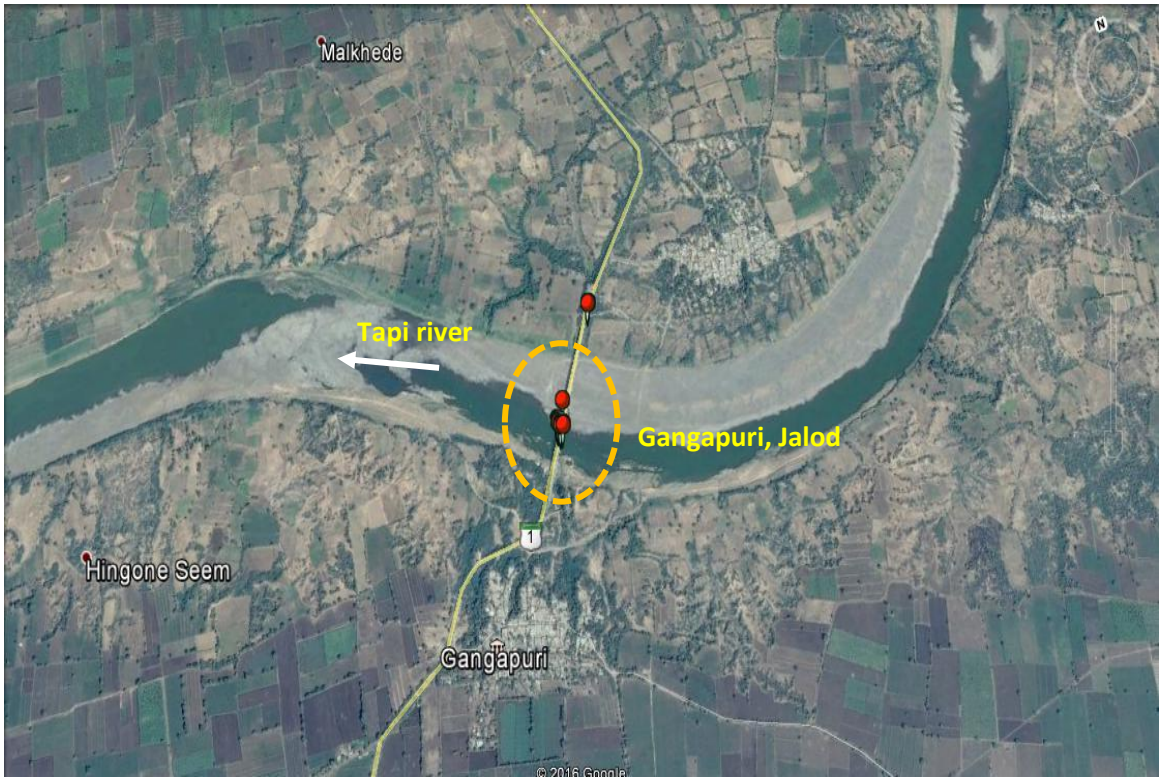


Fig 9.19 Location map of Gangapuri, Jalod, Maharashtra

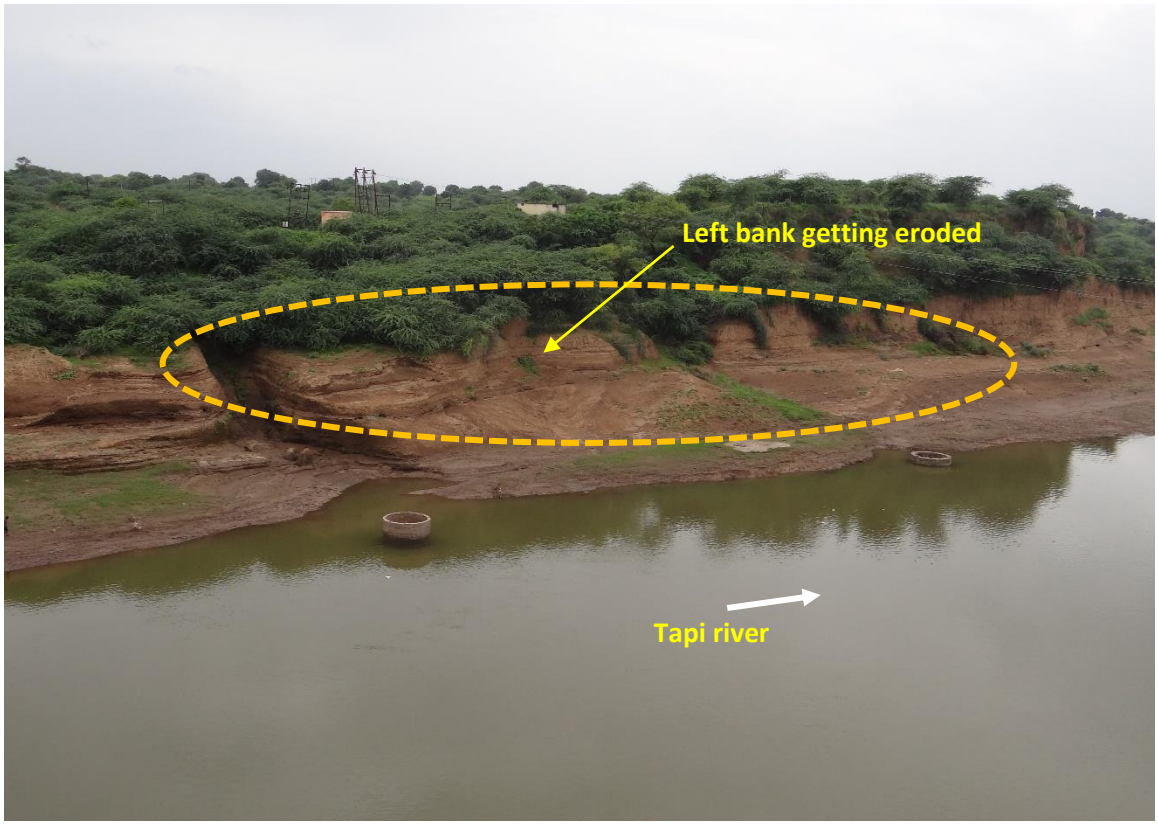


Photo 9.62 Erosion on left bank of the river

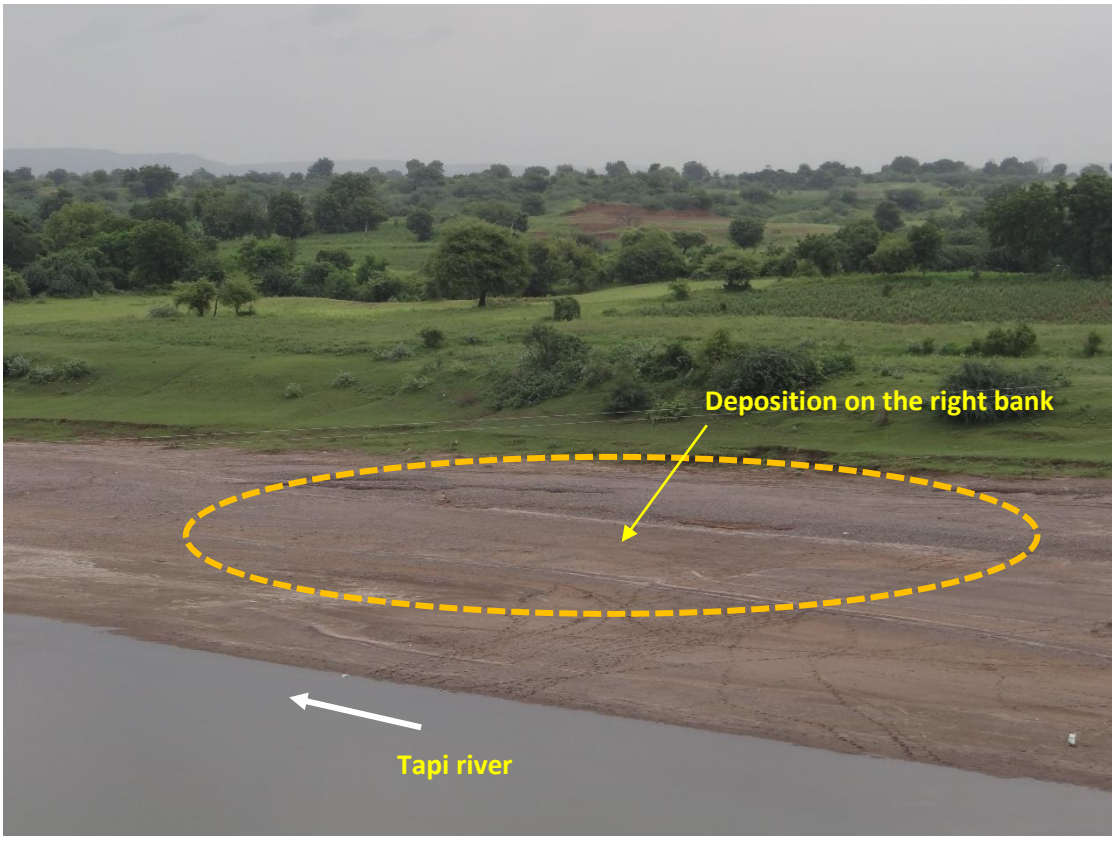


Photo 9.63 Deposition on right bank of the river



Photo 9.64 Intake well and eroded structure on the left bank at upstream of the bridge



Photo 9.65 bridge constructed across the Tapi river at Jalod, Maharashtra

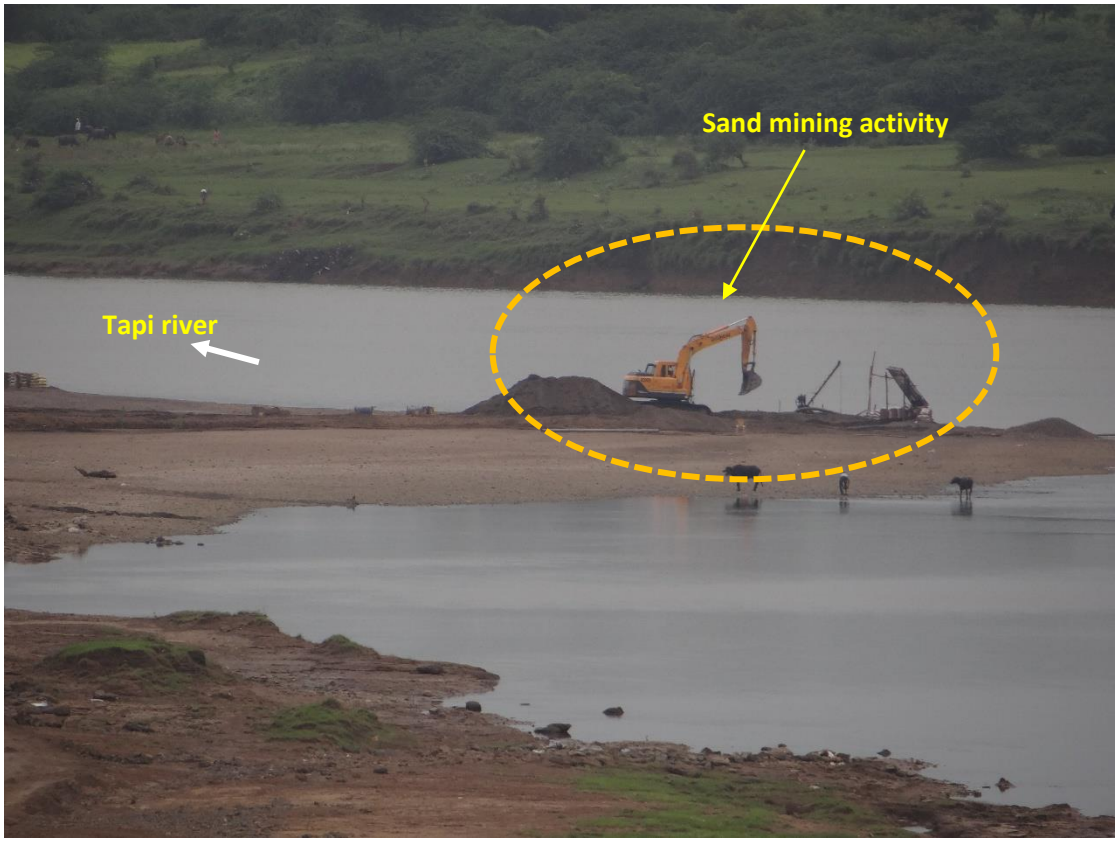


Photo 9.66 Sand mining activities taking place at the left bank

9.3.11 Awar, Maharashtra

The final site visited was a bridge location near Awar vilage in Maharashtra, at a chainage CH: 443 km from the origin of the Tapi river (Fig 9.20). The width of the river was very less and the depth of flow was high in this location. In agreement to the analysis carried out, the right bank was observed to be undergoing erosion in the form of cutting of banks (Photo 9.67). No major erosional or depositional phenomena were observed in the left bank. Bank protection works have to be constructed in this location to prevent cutting of right bank. Also, it was observed that scour protection works were carried out in order to safeguard the bridge piers (Photo 9.68). The protection work against bridge pier scouring seems to be in degraded condition, and requires urgent review to ensure the safety of the bridge.



Fig 9.20 Location map of Awar, Maharashtra

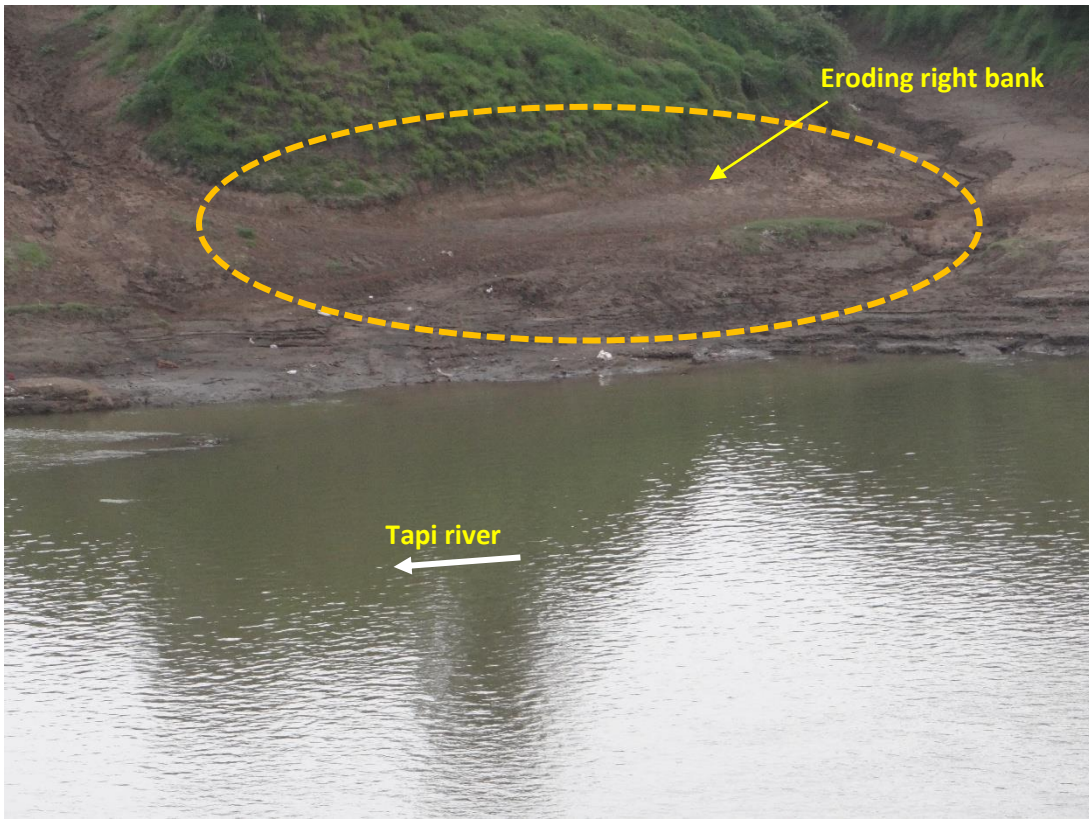


Photo 9.67 Erosion on right bank of the river



Photo 9.68 Scour protection works to safeguard bridge piers

9.3.12 Rameshwaram Temple, Palsod village, Maharashtra

The Rameshwaram Temple in located in Palsod village at the confluence of Anjani, Girna and Tapi rivers in Jalgaon district of Maharashtra state at a CH: 433.44 km from the origin of the Tapi river (Fig 9.21). The Girna is a left bank tributary of Tapi which meets it at Palsod village. The width of the Tapi river at this location is found to vary from 190 – 290 m, whereas the width of Girna river was observed to be around 80 – 130 m. It has been observed that upstream of the confluence, the Tapi river takes a sharp turn and significant deposition is reported on the right bank (Photo 9.73). Further, minor erosion is observed at the confluence of the rivers, however, no threat to the Temple is observed (Photo 9.70). The left bank of Tapi river, upstream of the confluence site is observed to have undergone erosion as the river strikes directly towards the outer portion of the bank (Photo 9.72). As a result, significant deposition is also observed at the inner end (on the right bank) of the Tapi river near Palsod village. The bed materials at the confluence site were observed to be pebbles and gravel in nature (Photo 9.71).



Fig 9.21 Location map of Rameshwaram Temple at confluence of Girna and Tapi rivers



Photo 9.69 Confluence of Girna and Tapi rivers



Photo 9.70 Minor bank cutting on right bank opposite to the confluence point of Tapi river



Photo 9.71 river bed material observed at the confluence site



Photo 9.72 Bank erosion observed on the left bank of Tapi river upstream of the confluence site

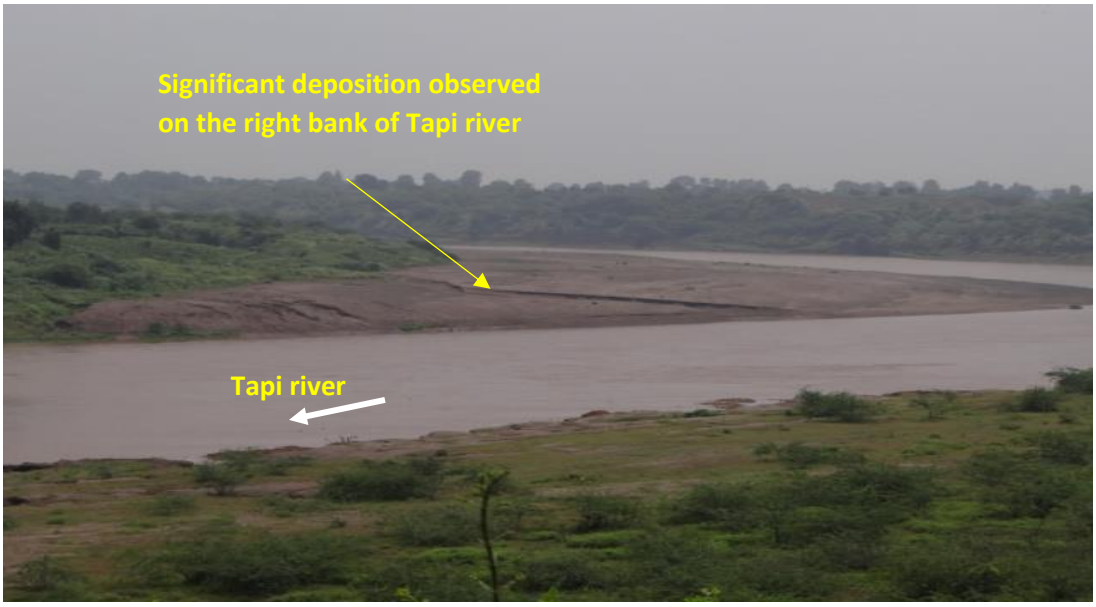


Photo 9.73 Significant deposition on the right bank of Tapi river upstream of the confluence site near Palsod village

9.3.13 Road bridge (MH SH 186) near Nhavi P Adawad, Maharashtra

The Nhavi P Adawad village is located in Jalgaon district in Maharashtra state at a CH: 410.14 km from the origin of the Tapi river (Fig 9.22). A bridge is constructed across the Tapi river as a part of Maharashtra State Highway MH SH 186, in 1995. The total length of

the bridge is 390 m. The width of the Tapi river at this location is around 220 m. At this location, no major morphological issue has been reported, however, minor deposition has been observed 600 m upstream of the bridge (Photo 9.74).

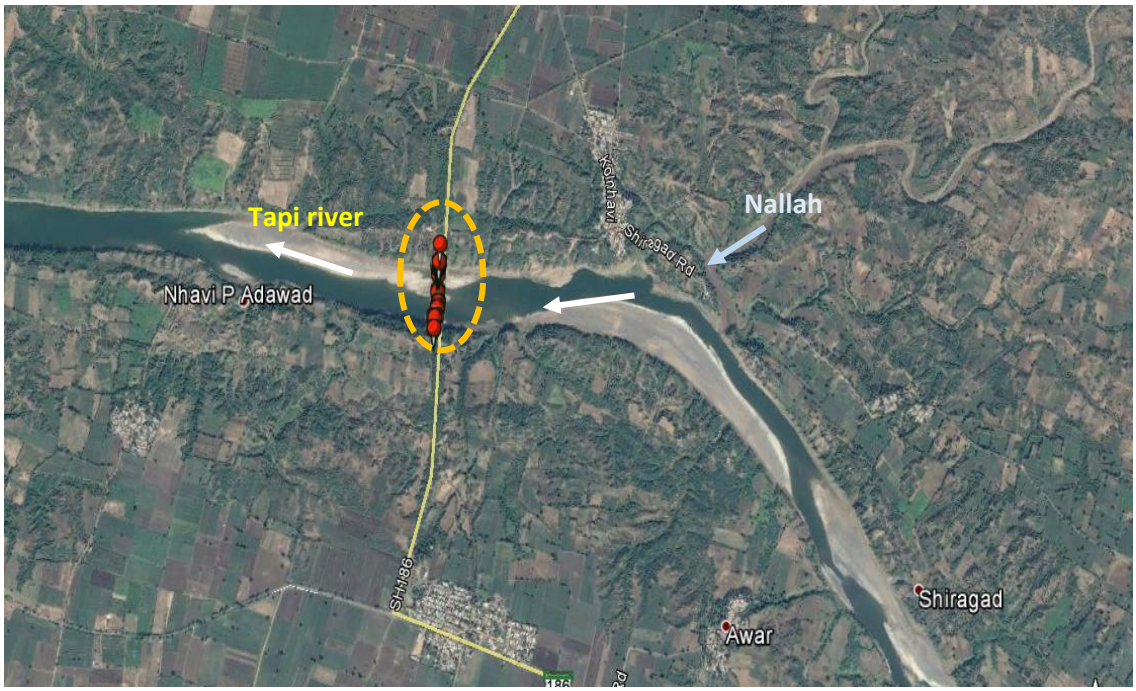


Fig 9.22 Location map of road bridge site (MH SH 186) near Nhavi P Adawad



Photo 9.74 Deposition on the left bank of Tapi river, upstream of the road bridge MH SH 186

9.3.14 Bhusaval CWC Gauging site, Maharashtra

The Bhusaval city is located in Jalgaon district of Maharashtra state at a CH: 376.39 km from the origin of the Tapi river (Fig 9.23). The CWC has established a gauging site in Bhusaval, located 18 km downstream of Hatnur dam, where the river gauge readings are observed (Photo 9.75). The width of the river at this location is found to be around 590 m. The CWC gauging site is located downstream of road bridge which is a part of Raver-Bhusaval highway (MH SH 187). A railway bridge, 5.3 km upstream of the road bridge, is constructed across the river (Fig 9.23). Upon investigation from the levels in Google Earth, it has been found there has been considerable change in stream slope between these two bridges, viz., a stream slope of 1 in 317 has been computed (difference of 55 ft in 5320 m). It has been further observed that the river stretch between these two bridges comprises of rocky strata and also seems to be braided (Photo 9.76 and Photo 9.77). This irregularity in the stream cross-section hinders the site engineers in developing a defined stage-discharge relationship for the site.

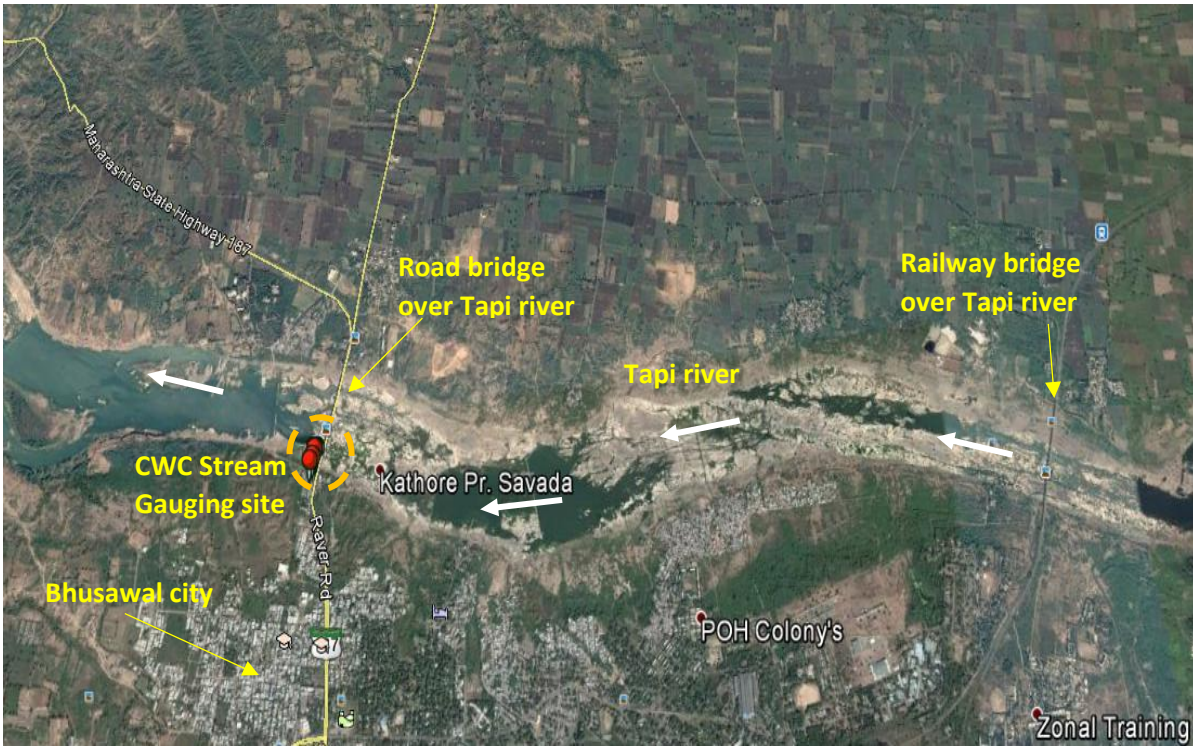


Fig 9.23 Location map of Bhusawal CWC stream gauging site



Photo 9.75 Stage measurements on bridge piers at Bhusawal CWC gauging site



Photo 9.76 View of Tapi river downstream of Bhusawal CWC stream gauging site



Photo 9.77 View of Tapi river upstream of Bhusawal CWC stream gauging site

9.4 VISIT TO UPPER TAPI RIVER REACHES

To verify the critical erosion prone areas in the Upper Tapi river reaches, a site visit was conducted during 22/02/2017 to 27/02/2017, starting from Velda village in Gujarat which falls in the downstream reaches of Middle Tapi river to Tapti Kund (origin of the Tapi river) in Multai, Madhya Pradseh. The major observations that were made during the visit along with the information about the sites are mentioned in the succeeding sections.

9.4.1 Hatnur Dam

The Hatnur dam also called Muktaisagar is located in Jalgaon district of Maharashtra state at a chainage CH: 360 km from the origin of the Tapi river (Fig 9.24). The Hatnur dam is an earthen dam with overflow section of length 604.75 m having Ogee spillway (Photos 9.78-9.80). The main purpose of the dam is irrigation in the region and providing drinking water in the vicinity and water for industries. The dam was constructed in 1982 and commissioned in 1985 and is managed by Tapi Irrigation Development Corporation (TIDC) Jalgaon. The dam is designed for a flood of 26415 m^3/s and provided with 41 radial spillway gates to pass the flood. The reservoir has its FRL at 214.00 m, MWL at 215.50 m and MDDL at 209.00 m with a Gross storage capacity of 388.0 MCM covering a catchment area of 29430 km^2. A canal originates from the dam from its right bank covering a culturable command area of 50450 ha. In

conversation with the authorities at Hatnur dam, it was highlighted that Purna river joins Tapi, just 8 km upstream of Hatnur dam. The main Tapi river along with Purna river which carry enormous amount of silt with it which eventually gets deposited in Tapi river. As a result of that the bed level of Tapi rises and thereby causing the river to migrate to its sides which eventually results in bank line migration. The bank line migration has been found to be more prominent on the right bank.

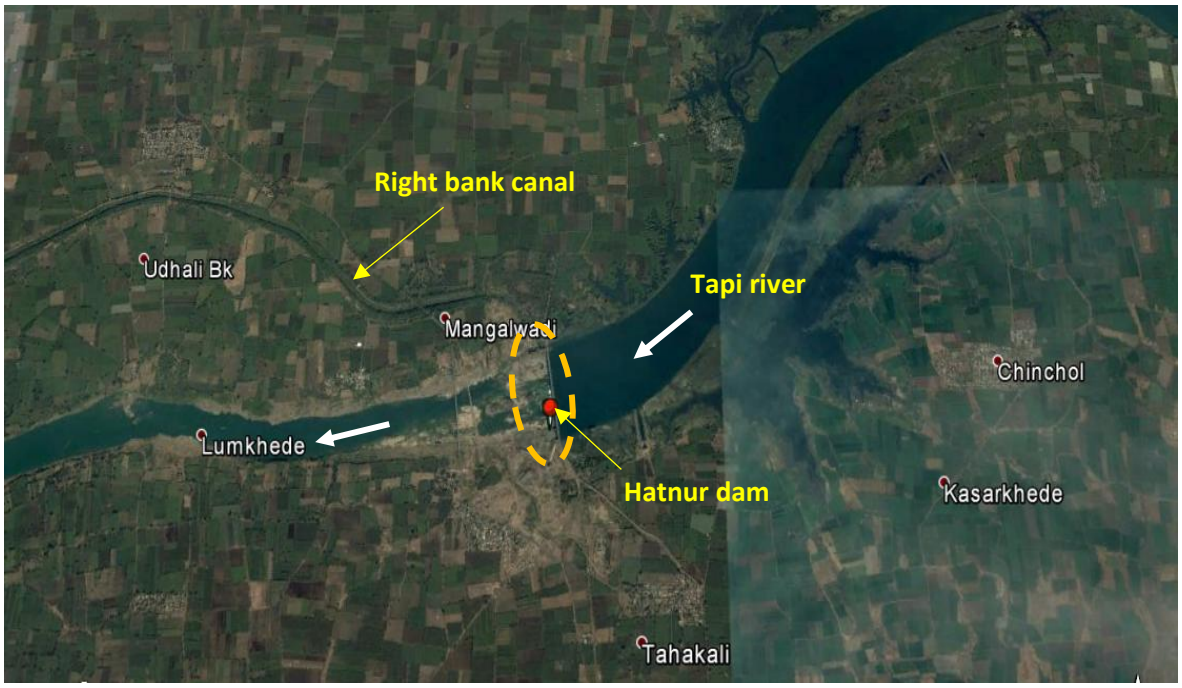


Fig 9.24 Location map of Hatnur dam

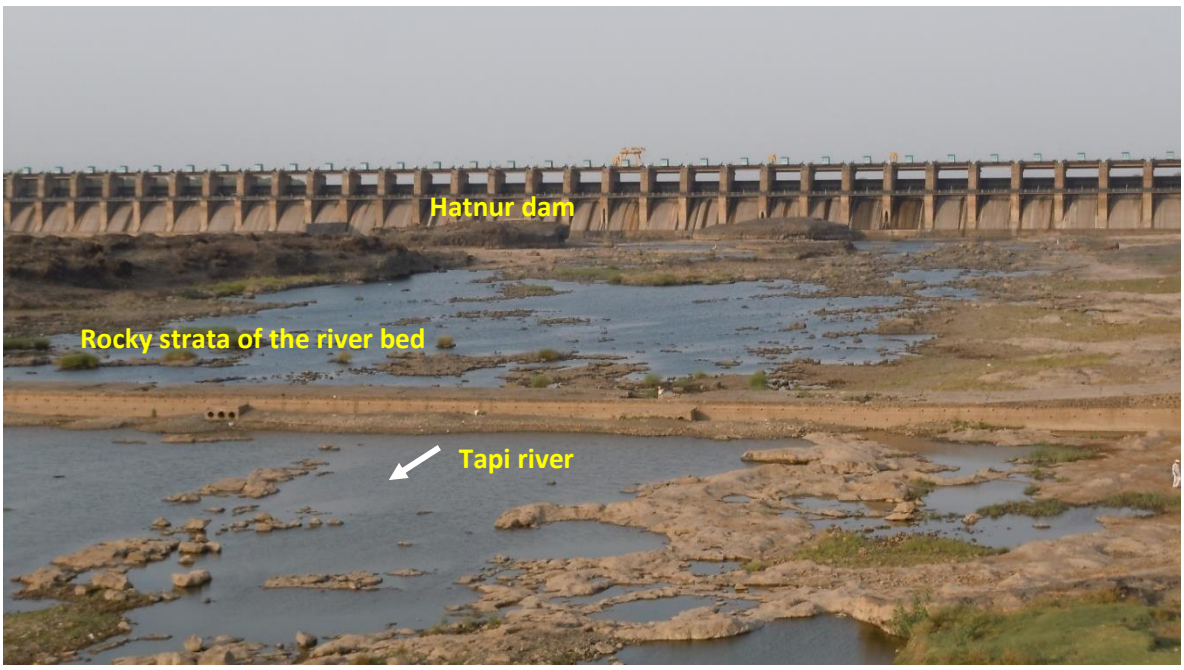


Photo 9.78 View of Hatnur dam from downstream



Photo 9.79 View of road bridge downstream of Hatnur dam



Photo 9.80 View of Hatnur dam and reservoir

9.4.2 Changdev village, Maharashtra

The Changdev village is located in Muktainagar tehsil of Jalgaon district in Maharashtra state at a chainage CH: 355.45 km from the origin of the Tapi river (Fig 9.25). It is situated on the confluence of the Tapi and Purna rivers (Photo 9.81). The Purna river is the left bank tributary of the Tapi river which originates in Pokharni village in Bhainsdehi tehsil of Betul district, Madhya Pradesh. The width of Tapi river at confluence location is around 300-330 m, while that of Purna river is about 270-290 m. The total length of Purna river is 334 km. The Hatnur

reservoir extends upstream for a length of 50 km. The banks were observed to be stable and s no major morphological issues were observed.

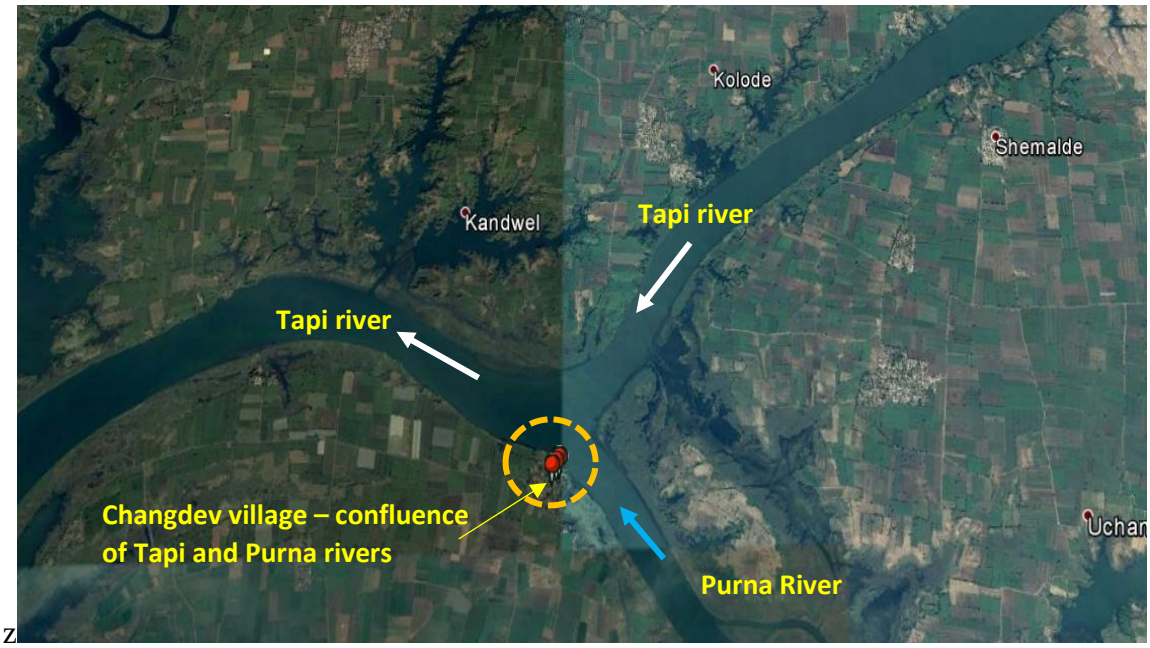


Fig 9.25 Location map of Changdev village



Photo 9.81 Confluence of Tapi and Purna rivers at Changdev village

9.4.3 Rajghat and Najirighat, Burhanpur, Madhya Pradesh

The Burhanpur city is located in Burhanpur district in Madhya Pradesh state at a chainage CH: 308 km from the origin of the Tapi river (Fig 9.26). The Rajghat is situated on a meander bend, and the width of the river at this location varies from 150-250 m. The river forms a meander bend here (Fig 9.26) and at the outer bend, i.e., the right bank has been eroded (Photo 9.84 a). It is further observed that soil underneath the walls of the Fort near Rajghat in Burhanpur has also eroded and in longer run likely to get damaged if protection measures are not provided

(Photo 9.84 a & b). Further, it was also observed that, at the inner bend, significant deposition of sediments and point bars have been formed (Photo 9.86).

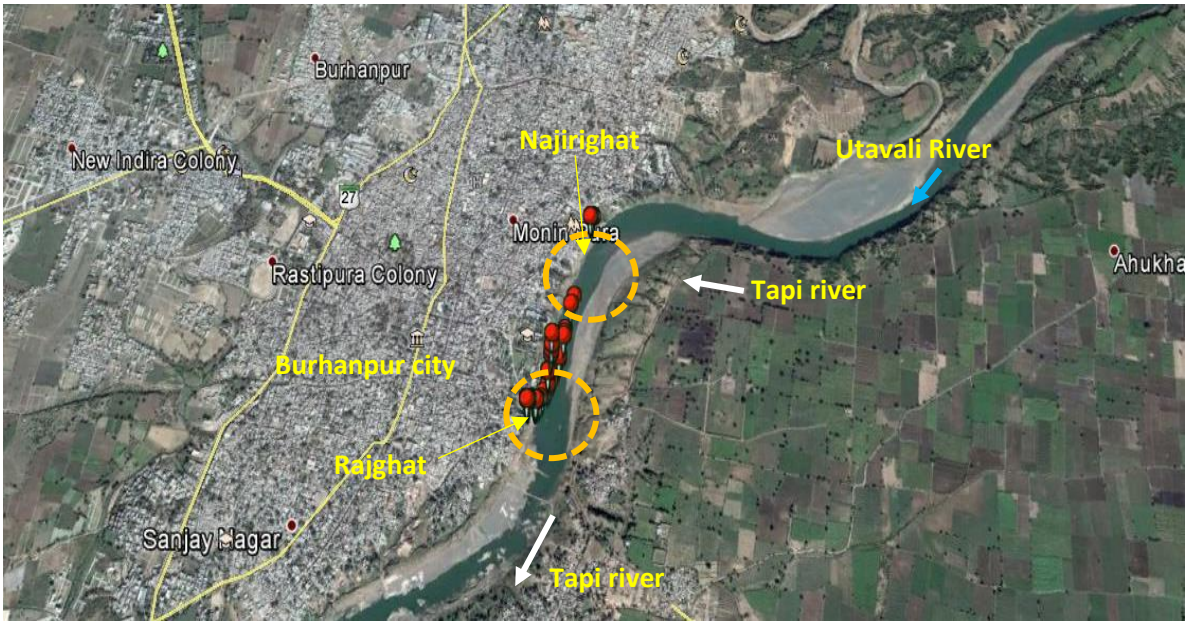


Fig 9.26 Location map of Rajghat and Najirighat in Burhanpur



Photo 9.82 Rajghat on right bank of Tapi river in Burhanpur



Photo 9.83 Considerable deposition on the left bank just upstream of Rajghat in Burhanpur



Photo 9.84 a) Damaged portion of Fort wall near Rajghat in Burhanpur

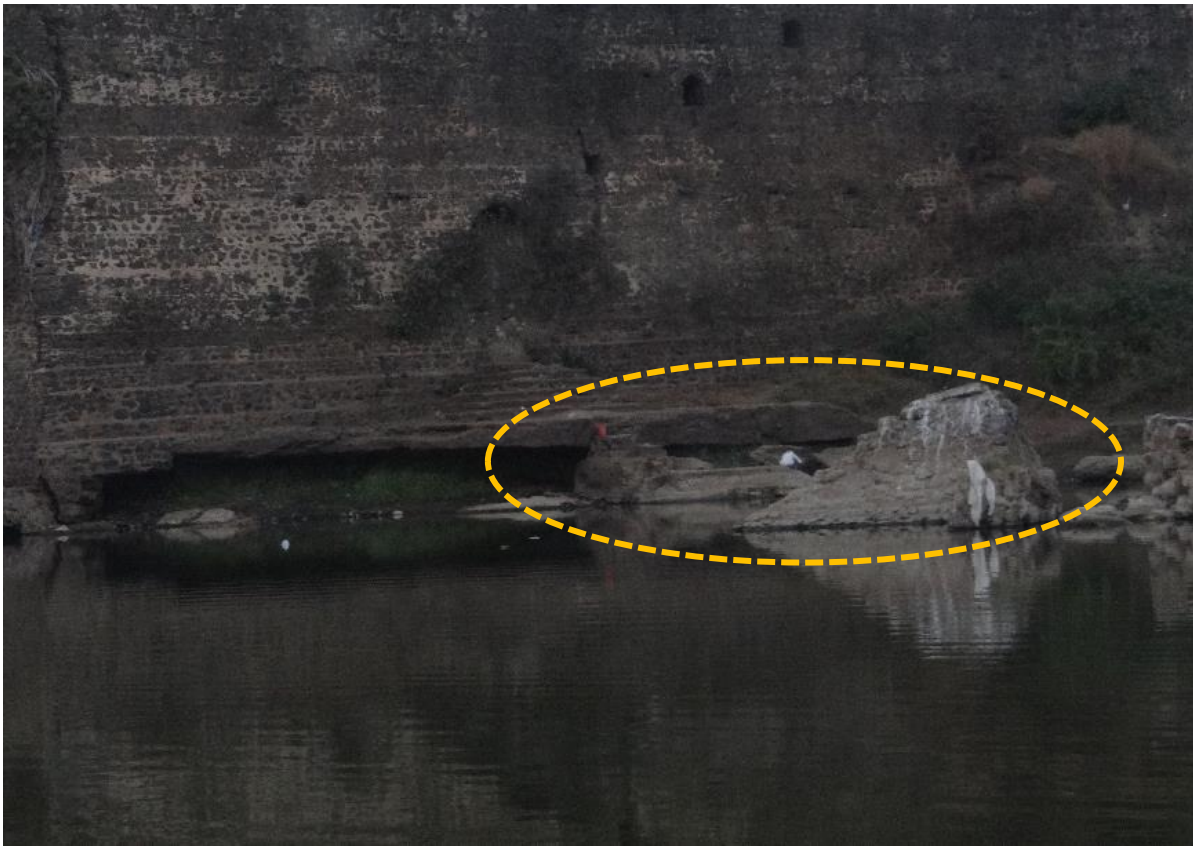


Photo 9.84 b) Damaged portion of Fort wall near Rajghat in Burhanpur



Photo 9.85 High flood level during 2006 floods at Rajghat in Burhanpur



Photo 9.86 View of Tapi river from Nagjirighat in Burhanpur

9.4.4 Mohana Nadi Sangam, Burhanpur, Madhya Pradesh

The Mohana Nadi Sangam is located in Burhanpur city at a chainage CH: 312.47 km from the origin of the Tapi river (Fig 9.27). The Mohana river, which is a left bank tributary of the Tapi river, meets with Tapi at this location (2.5-3 km away from Burhanpur city) (Photo 9.88).

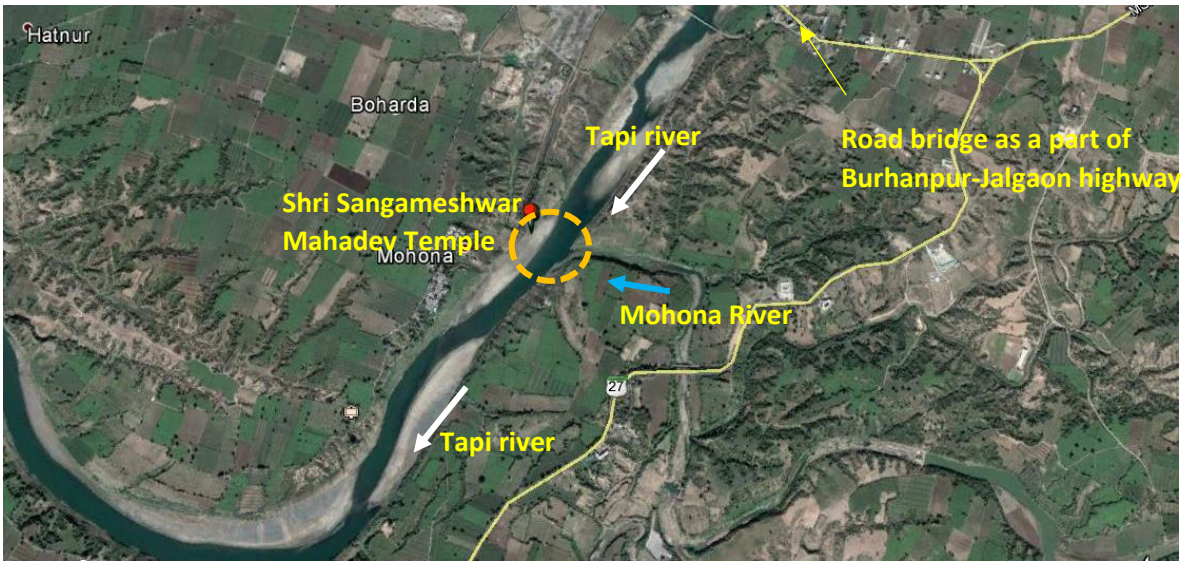


Fig 9.27 Location map of Mohona Nadi Sangam in Burhanpur

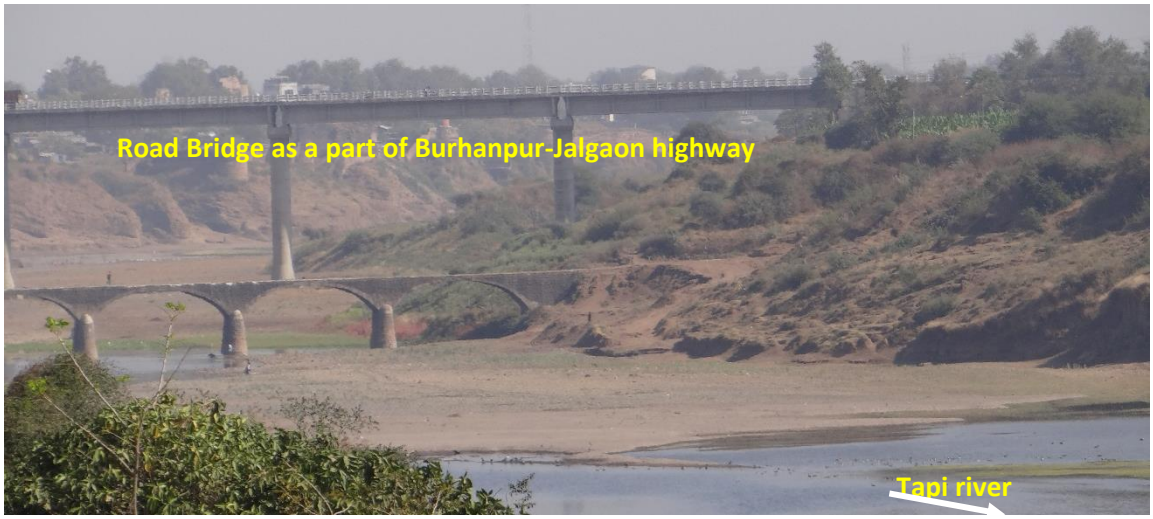


Photo 9.87 View of road bridge as a part of Burhanpur-Jalgaon highway (MP SH 50), 1.6 km downstream of the Mohona river confluence

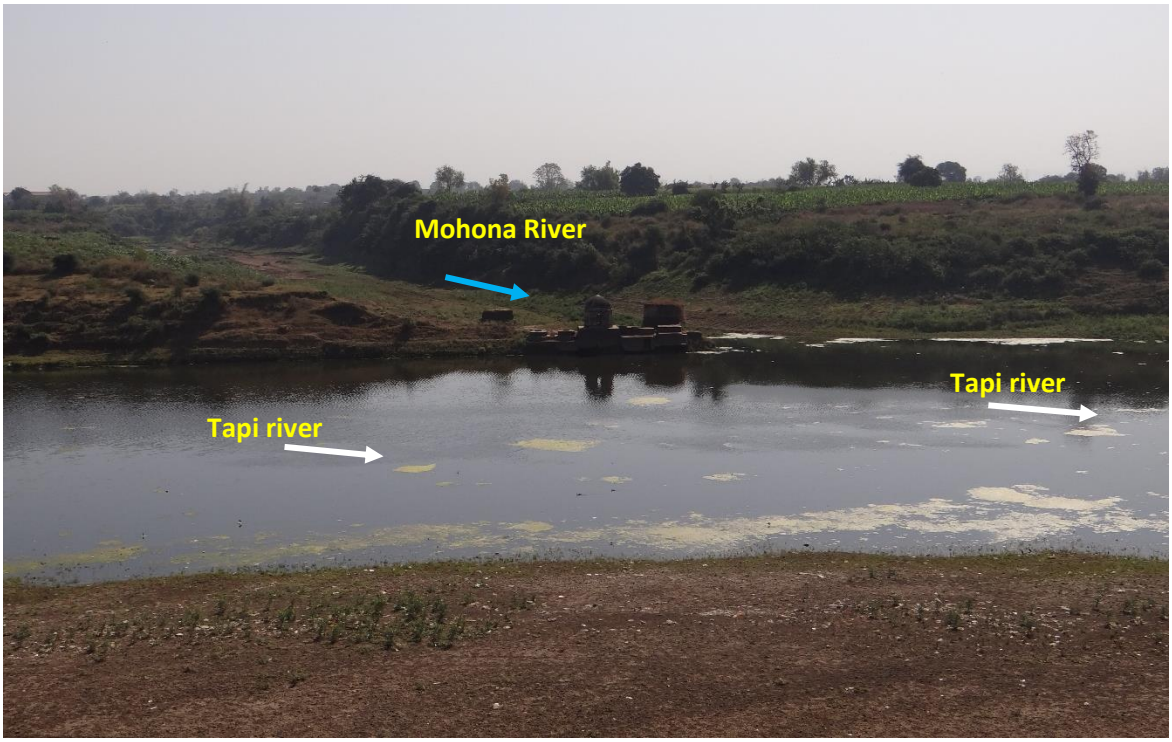


Photo 9.88 Confluence of Tapi and Mohona rivers in Burhanpur

The width of the Tapi river at this location varies from 180-210 m, while that of Mohana river varies from 50-60 m. The Mohana river is an ephemeral stream with steep slope and was found to carry no flow during the visit (lean period). A road bridge as part of Burhanpur-Jalgaon highway is located 1.6 km upstream of the confluence (Photo 9.87). On visual inspection, no critical erosion or deposition were observed at this location.

9.4.5 Dabalikhurd Villlage, Nepanagar

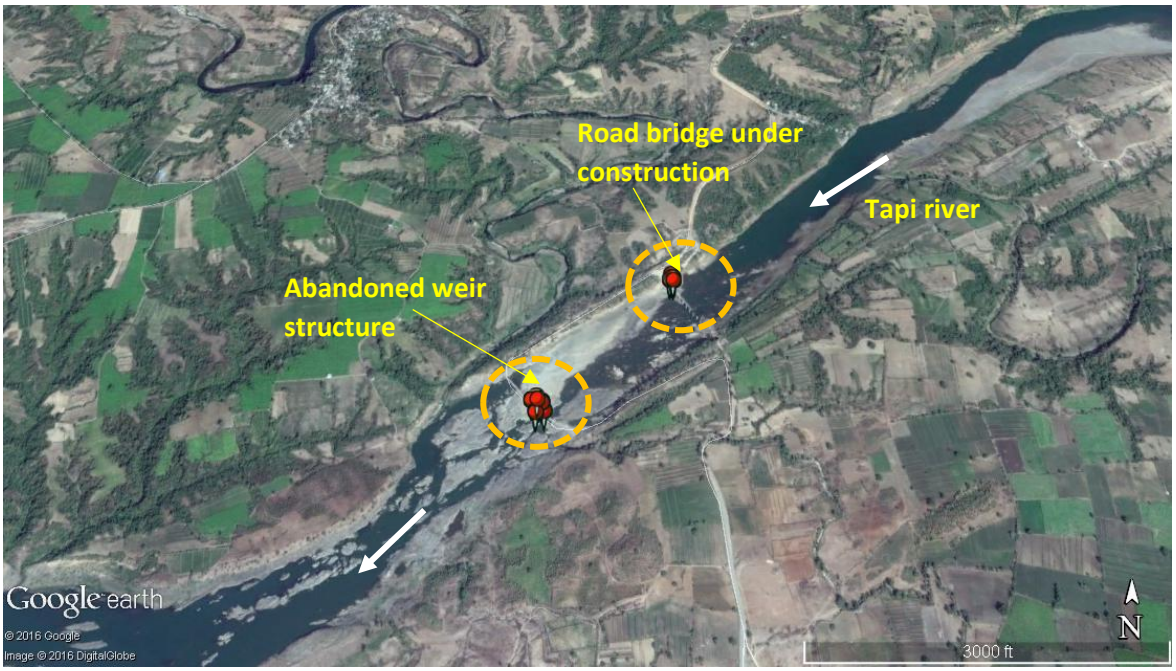


Fig 9.28 Location map of Dabalikhurd site in Nepanagar

The Dabalikhurd village is located near Nepanagar town in Burhanpur district in Madhya Pradesh state at a chainage CH: 288.50 km from the origin of the Tapi river (Fig 9.28). The width of the Tapi river at this location varies from 270-330 m in this stretch. At this location, there is a road bridge which is under construction and around 570 m downstream there is an abandoned weir (Photos 9.90 and 9.91).

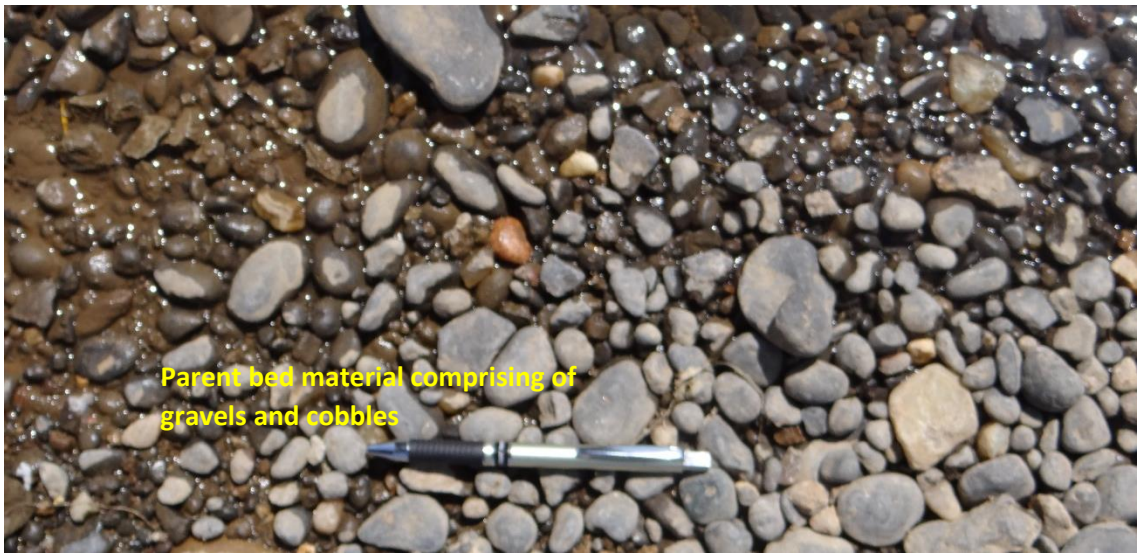


Photo 9.89 View of parent bed material in stream bed near Dabalikhurd, Nepanagar

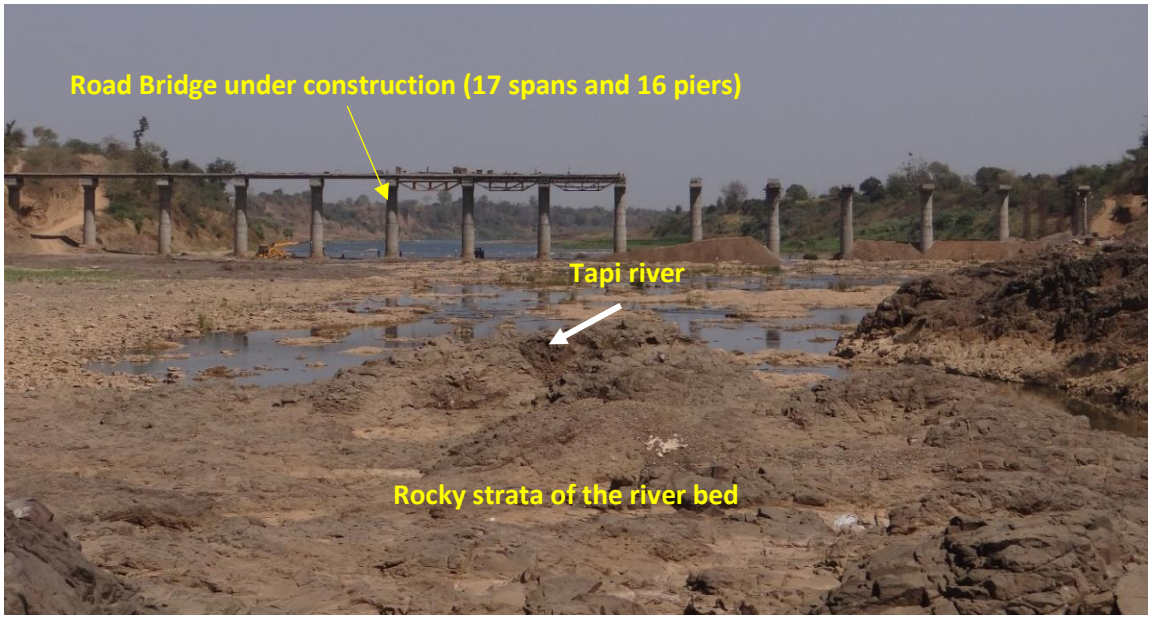


Photo 9.90 View of road bridge under construction near Dabalikhurd, Nepanagar



Photo 9.91 View of abandoned weir near Dabalikhurd, Nepanagar

The river bed at this location was found to be rocky and the bed material was seen to comprise of gravels and cobbles (Photo 9.92). Further, during the dry period it was observed that, the river was flowing in many small channels due to presence of large mass of rocks on the river

bed. Also, minor erosion in the right bank was observed due to cutting, however, no appreciable cutting was observed elsewhere (Photo 9.92).

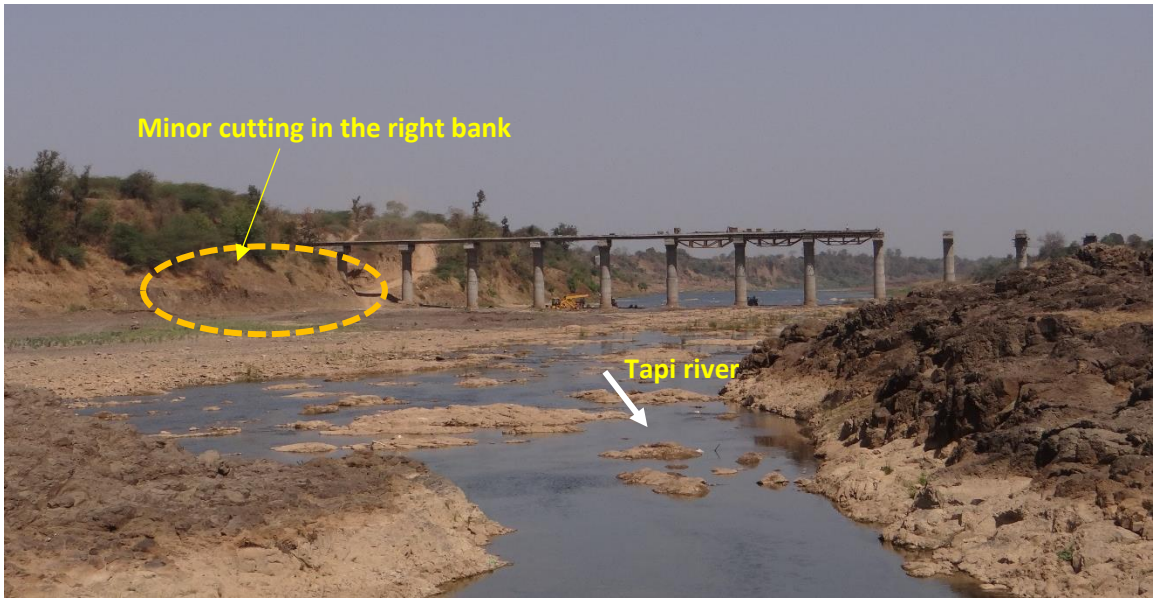


Photo 9.92 Minor cutting observed in the right bank near the bridge

9.4.6 Melchuka village, Madhya Pradesh

The Melchuka village is located near Khaknar town in Burhanpur district in Madhya Pradesh state at a chainage CH: 253.33 km from the origin of the Tapi river (Fig 9.29). The width of the Tapi river at this location varies from 250-280 m in this stretch.

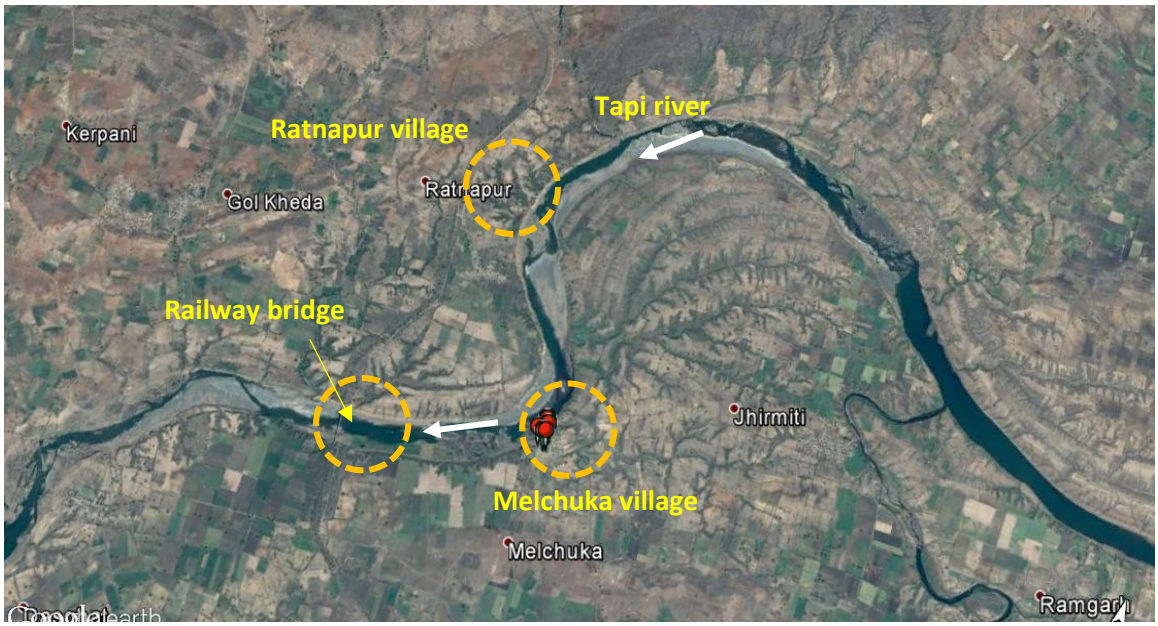


Fig 9.29 Location map of Melchuka village, Madhya Pradesh



Photo 9.93 View of Tapi river downstream of Melchuka village

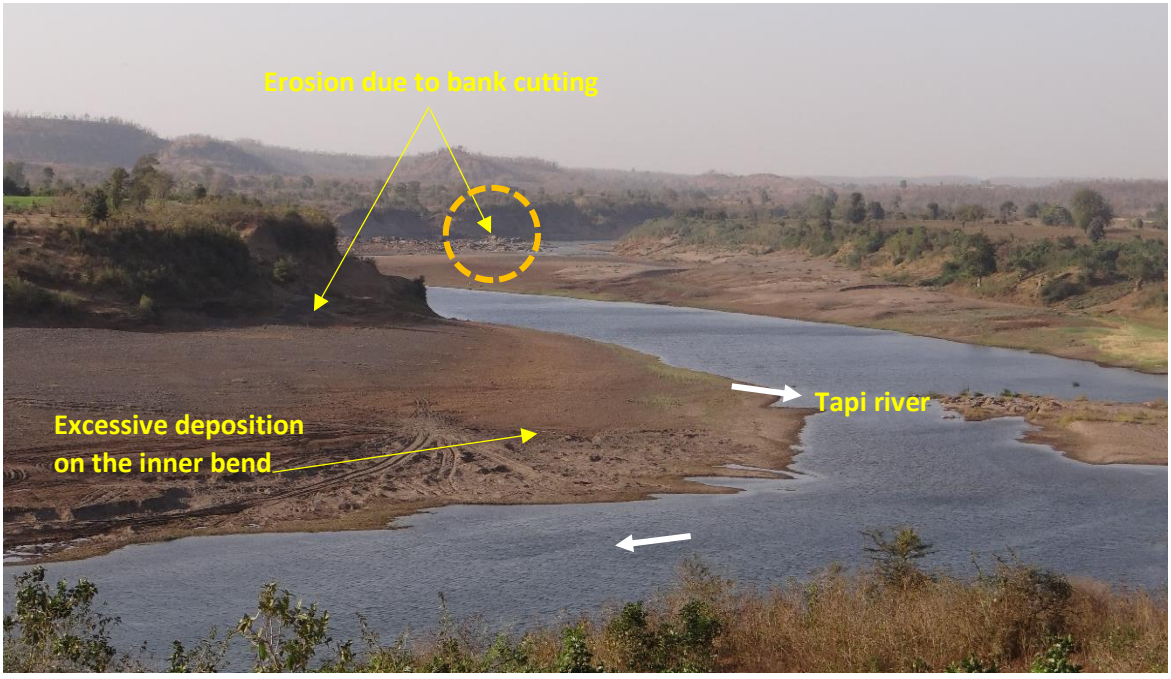


Photo 9.94 View of meander bend showing excessive deposition in the inner bend

The Melchuka village is located on the left bank while Ratnapur village is located on the right bank of Tapi river. It has been observed that there is significant deposition on the inner bend and significant erosion on the outer bank of the river (Photo 9.94). There is a railway bridge 1.4 km downstream of Melchuka village and the river bed appears to comprise of rocky strata (Photo 9.93).

9.4.7 Dedtalai CWC Stream Gauging site

The Dedtalai CWC stream gauging site is located Dedtalai town in Khandwa district in Madhya Pradesh state at a chainage CH: 236.34 km from the origin of the Tapi river (Fig 9.30). The CWC stream gauging site is located 500 m downstream of the road bridge which is a part of Khandwa-Dedtalai highway (MP SH 26) (Photo 9.95). The width of the Tapi river at this location varies from 200-220 m in this stretch.



Fig 9.30 Location map of Dedtalai CWC stream gauging site



Photo 9.95 View of Dedtalai CWC stream gauging site



Photo 9.96 View of Tapi river upstream of Dedtalai CWC stream gauging site

9.4.8 Rama Kheda village

The Rama Kheda village is located near Dedtalai town in Khandwa district in Madhya Pradesh state at a chainage CH: 228.71 km from the origin of the Tapi river (Fig 9.31). The width of the river at this location is around 170-200 m. The stream bed comprises of rocky strata and the rocks appear to be of sedimentary or metamorphic in origin (Photo 9.97). Further, it was observed that the left banks were higher than the right banks and, at many places, weathered rock in isolated patches were also found.

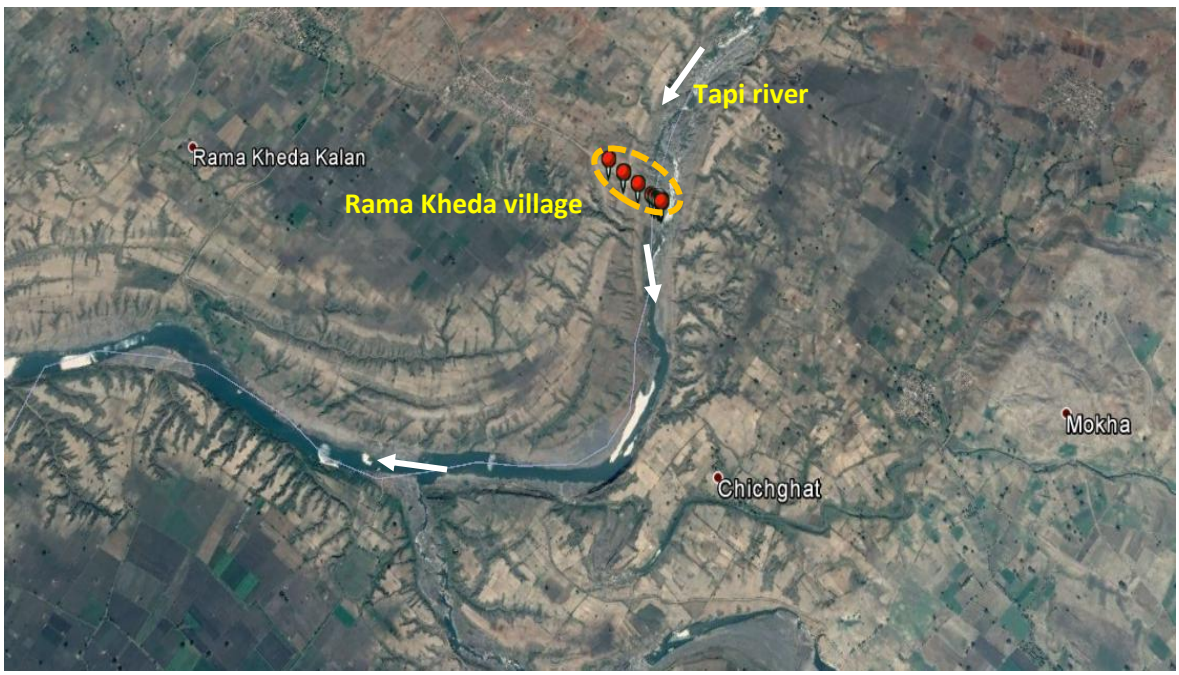


Fig 9.31 Location map of Rama Kheda village



Photo 9.97 View of rocky strata of river bed upstream of Rama Kheda village



Photo 9.98 View of river bed downstream of Rama Kheda village



Photo 9.99 Nominal erosion on the right bank near Rama Kheda village

Although, the banks are spaced quite apart but the stream is mostly confined in a small narrow channel during lean period. It was also observed that the right and left banks were subjected to nominal erosion at higher stages of the river (Photo 9.98 and 9.99).

9.4.9 Chandora Dam

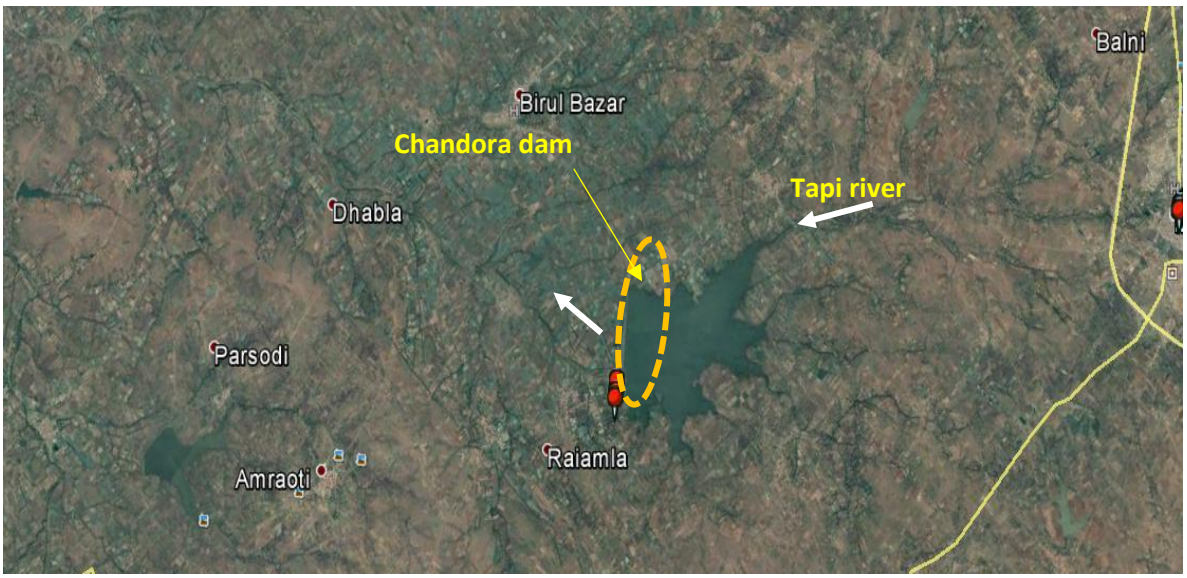


Fig 9.32 Location map of Chandora dam

The Chandora dam is located near Multai in Betul district of Madhya Pradesh state at a chainage CH: 12.34 km from the origin of the Tapi river (Fig 9.32). The Chandora dam is an earthern cum masonry dam having length of 2043 m with spillway length of 67.1 m. The dam was built in 1986 and has a design flood capacity of 681.8 m3/s with a gross storage capacity of 18.2 MCM. The main purpose of the dam is to provide irrigation facilities in the region and encompassing a culturable command area of 2800 ha. The dam is located at around 12 km downstream of Multai, from where the Tapi river originates (Photo 9.100).

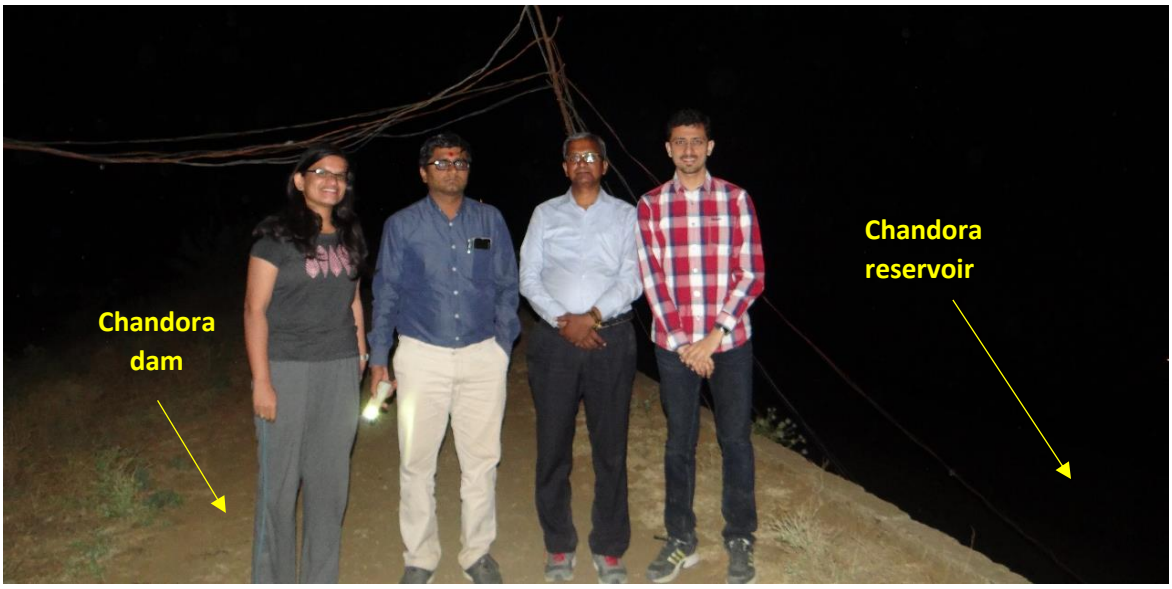


Photo 9.100 View of Chandora dam on Tapi river, 12 km downstream of Multai

9.4.10 Tapti Kund, Multai

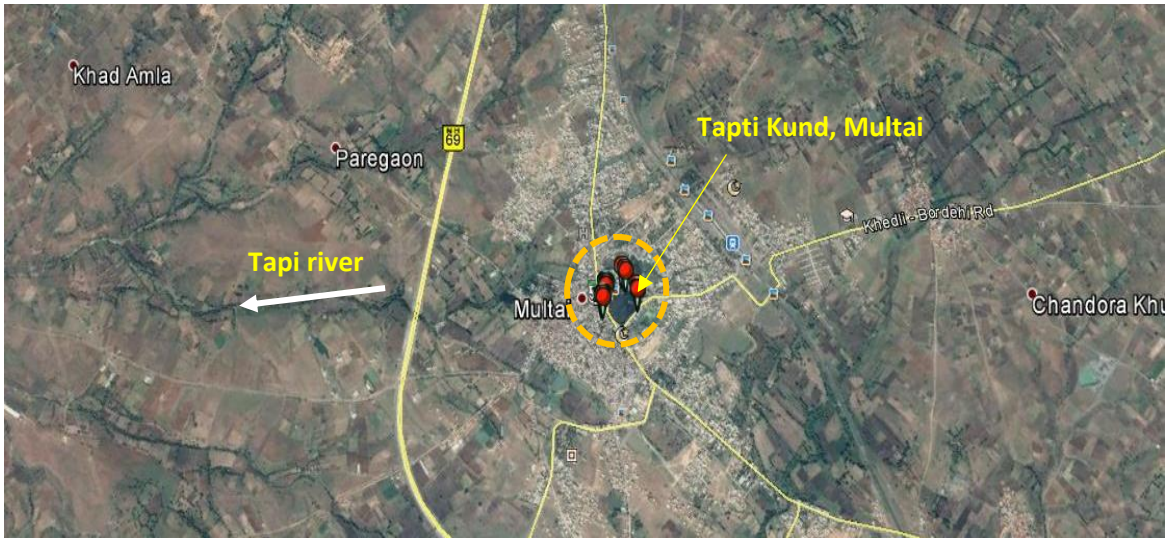


Fig 9.33 Location map of Tapti Kund, Multai



Photo 9.101 View of Tapti Kund, Multai



Photo 9.102 View of Gomukh near ancient temple from where Tapi river flows outside

The Tapti Kund is located in Multai in Betul district of Madhya Pradesh state which is marked as the origin of the holy Tapi river (Fig 9.33). In ancient Hindu mythology, Tapi is believed to be the daughter of Surya devta (Sun). The small streams which flows down from the Satpura Mountains get accumulated in Tapti Kund and at this place appreciable amount of water is collected which is marked to be the origin of the Tapi river and flows out from Gomukh in the ancient Temple (Photos 9.101 and 102).

CHAPTER 10
RIVER MORPHOLOGY

10.1 NATURAL RIVER CHANNEL MECHANICS

River channel changes such as bank accretion, down cutting and bank erosion are natural processes of alluvial rivers. Natural morphological dynamics of rivers change due to human activities such as sand mining, bank revetment, encroachment riverbanks, artificial cut-off, construction of reservoirs and variation in land use (Lane and Richards, 1997; Surian, 1999; Fuller et al., 2003; Rinaldi, 2003; Li et al., 2007). As a result, the stability of channel gets disturbed (Fuller et al., 2003; Grant et al., 2003; Kesel, 2003; Rinaldi, 2003). Such human activities may have greater impact in erosion than natural events such as landslides, droughts and floods (Surian and Rinaldi, 2003). Such human induced interferences may result in various socio-economic and environmental consequences in navigation, infrastructure and riparian land loss and the changes in aquatic and riparian ecosystems. The better understanding of morphological changes in alluvial rivers are needed for maintaining its stable course, ensure sustainable development of hydraulic structures and maintaining the ecosystem of the river.

Morphology is the science of structure or form. River morphology, sometimes used synonymously with fluvial geomorphology, is a branch of science which describes the shape of river channels and their changes over time. As a river takes along with it, water and sediments from the drainage area to sea, several changes occur along its course as well as the adjoining areas. River morphology relates the continuous changes in the structure and shape of rivers and adjoining areas caused by erosion, transportation and deposition of sediment by the running water. Both natural and anthropogenic influences such as changes in land and water uses caused by urbanization, agriculture, climate change, modifications to water infrastructure and water use etc., cause the evolution of a river system. The morphological changes could be in size, shape and composition of bed materials or the changes in plan form.

A river is said to be in equilibrium when its dimensions and slope are so adjusted over a period of time that it carries the incoming sediment load and water without appreciable erosion or deposition (Mackin, 1948). Such rivers are also referred to as graded/poised/balanced rivers. This equilibrium of the river can adversely be affected by both natural and anthropogenic causes (Garde, 2006). Some of the causes are listed below:

- A dam constructed across the river, resulting in aggradation upstream of the reservoir and degradation downstream.
- Changes in the stability of river due to construction of dams, channel widening, channel straightening, releasing extra water during low flows etc. as part of making the river suitable for navigation purposes.
- Large scale mining of sand and gravel from river bed, causing degradation in the downstream (Main River, tributaries and sub-tributaries).
- Instability between water quantity and sediment transport rate caused by the transfer of water from one basin to another on a large scale.
- Activities like construction of flood control works, flood embankments, reservoirs etc. which disturbs the natural equilibrium of rivers.
- Large scale dredging carried out along the rivers for navigation purposes.
- Changes in land use, owing to deforestation, reforestation, urbanization etc. resulting in changes in drainage basin characteristics.
- Long term changes in the climate or hydrologic regime lead to significant changes in discharge, type of sediment load and its quality which lead to change in channel dimensions, change in river course and/or change in plan-form or meander characteristics.
- Earthquakes and other tectonic activities

Some of the effects of morphological changes are:

- Increase in runoff and storm flow,
- Increased rate of land erosion,
- Increased sediment load in rivers,
- Reduced infiltration and lowering of ground water level,
- Discharge of untreated waste into rivers,
- Encroachment of flood plain leading to channel narrowing and higher flood levels.

Also, the status of current river channel is quantified by plotting the longitudinal profiles of the channel in the Upper, Middle and Lower Reaches of Tapi river; also by carrying out impaired stream analysis, to identify the river locations which are under the threat of chemical pollution. Based on aforesaid analyses, the major morphological problems that prevail in the river reaches and its flood plains are identified. Such factors, which play important role in shaping the

morphology of a river are required to be studied thoroughly, and their effects on the river course and shape must be effectively quantified to assess the changes the river system that had undergone over the period under consideration. This chapter includes the study of shifting of river course and changes in its planform (width of cross-section) with reference to base year (the survey year of SOI Toposheets on scale 1:50,000) till 2010, by collecting 4 sets of satellite imagery at 10 years interval, i.e., 1980, 1990, 2000 and 2010. The migration of banklines have been computed on decadal basis, and the critical river reaches have been identified where the river has undergone consistent shifting over the years. Based on the nature of shifting of river course and changes in width, the like future behaviour of the river course behaviour is quantified. The observed peak discharges at CWC HO stations that fall along the river have been classified into low flows, medium flows, floods and large floods based on the flood frequency relationship established at these stations, and the impacts of these flows on the morphological changes of Tapi river have been explored.

10.2 CHARACTERISTICS OF THE TAPI RIVER AND ITS BANKS

The SOI toposheets along the Tapi river, as shown in Fig. 10.1, were georeferenced with respect to WGS-1984 (Geographic Coordinate System) datum and projected on Lambert Conformal Conic (Projected Coordinate System) projection system using the projection parameters as specified by India-Water Resources Information System (India-WRIS). The parameters are already enumerated in Chapter 5 (Table 5.2). The respective toposheets were mosaicked and the banklines as well as centre line of the Tapi river were marked by digitizing them.

The satellite imageries were orthorectified with respect to WGS-1984 datum and projected on LCC projected coordinate system. The bank lines and centre lines were marked on the satellite imagery of years 1981, 1990, 2000 and 2010 respectively, starting from the upstream of the river. Zero chainage (CH: 0 km) of the river is taken as Tapi Kund, in Multai, Madhya Pradesh and the final chainage is the point where Tapi river drains into the Arabian Sea. The banklines and centre lines of the projected satellite imagery were overlaid on the banklines and centre lines of digitized toposheets for quantifying the migration of banklines and river course shifting, changes in the width at different cross-sections and other plan-form changes over the years.

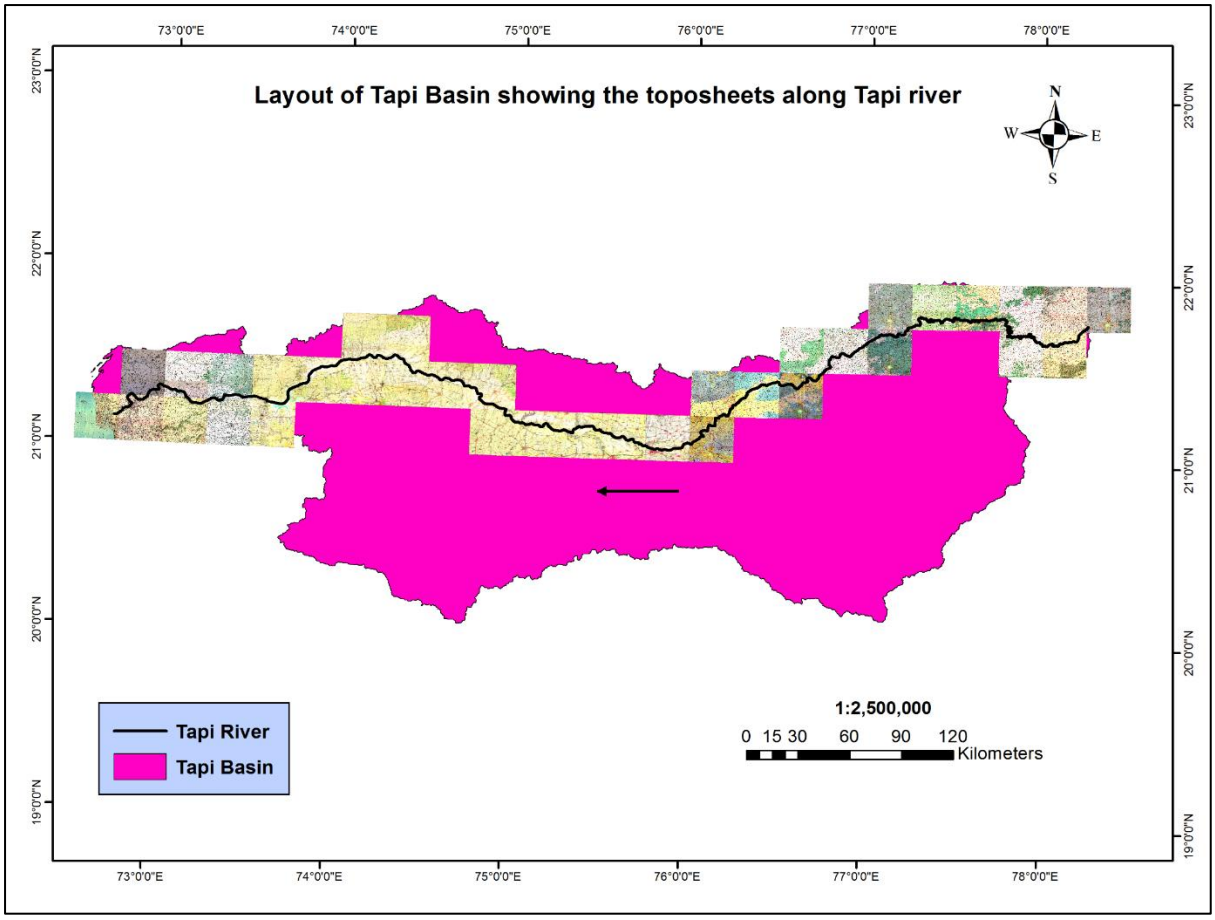


Fig 10.1 Layout map of Tapi Basin showing the toposheets that lie along the main river

The digitized lengths of banklines and centre lines of Upper Tapi river, that stretches from Tapi Kund (CH:0 km) to Hatnur Reservoir (CH: 350 km), Middle Tapi river that stretches from Hatnur dam (CH:350 km) to starting point of Ukai Reservoir (CH: 581 km) and Lower Tapi river that stretches from Ukai dam (CH:647 km) to where the river drains into Arabian Sea (CH:792 km) are shown in Table 10.1 for the base year, 1981, 1990, 2000 and 2010 respectively. The chainages are fixed based on the centre line of the river digitized on SOI Toposheets, i.e., the base year. From table 10.1, it is apparent that bank lines and centre lines of the satellite imagery for all the decades for all three stretches of Tapi river, seem to be shorter than corresponding dimensions in SoI toposheets. Such discrepancy may be due to existence of Hatnur and Ukai reservoirs and sea tidal conditions in the Arabian Sea at the time of satellite imagery capturing.

10.3 QUANTIFICATION OF RIVER BANK MIGRATION

The river bank migration is determined by overlapping the banklines of a particular decade with respect to given base year (SOI toposheets).

Table 10.1 The lengths of LBL, RBL and CL for Upper, Middle and Lower Tapi river

	UPPER TAPI RIVER (Zero chainage: Tapi Talab in Betul)				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	354	352	354	355	352
Left Bank Line	354	353	352	354	351
Centre Line	351	351	350	351	350
Bank lines	**MIDDLE TAPI RIVER (Zero chainage: Hatnur dam)**				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	256	234	244	251	237
Left Bank Line	257	236	245	251	237
Centre Line	251	233	242	249	235
Bank lines	**LOWER TAPI RIVER (Zero chainage: Ukai dam)**				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	136	132	130	132	131
Left Bank Line	126	123	122	123	123
Centre Line	128	129	125.5	125.8	125.8

If the river bank has the potential to bring significant modifications in the floodplain and translate itself into fluvial hazard (erosion) then the migration of river banks is considered to be of positive (+) nature. Migration due to channel widening, progressive shifting of meander bends (unidirectional) and avulsion (where the banks move away from each other) are considered as a positive change. When both the banks move towards each other which narrows the channel (deposition) then the migration is to be considered as negative (–) change as it does not hold any significant changes in the flood plain (Hazarika et. al., 2015). Fig 10.2 explains the sign convention adopted for river bank migration diagrammatically.

10.3.1 Quantification of Bank Migration in Upper Tapi river

The analysis of migration of bank lines has been carried out for Upper Tapi river, from Tapi Kund in Multai, Madhya Pradesh to Hatnur Reservoir in Maharashtra for the years 1981, 1990, 2000 and 2010 by comparing the bank lines of the same with the banklines digitized on SOI toposheets of base year 1971-1979.

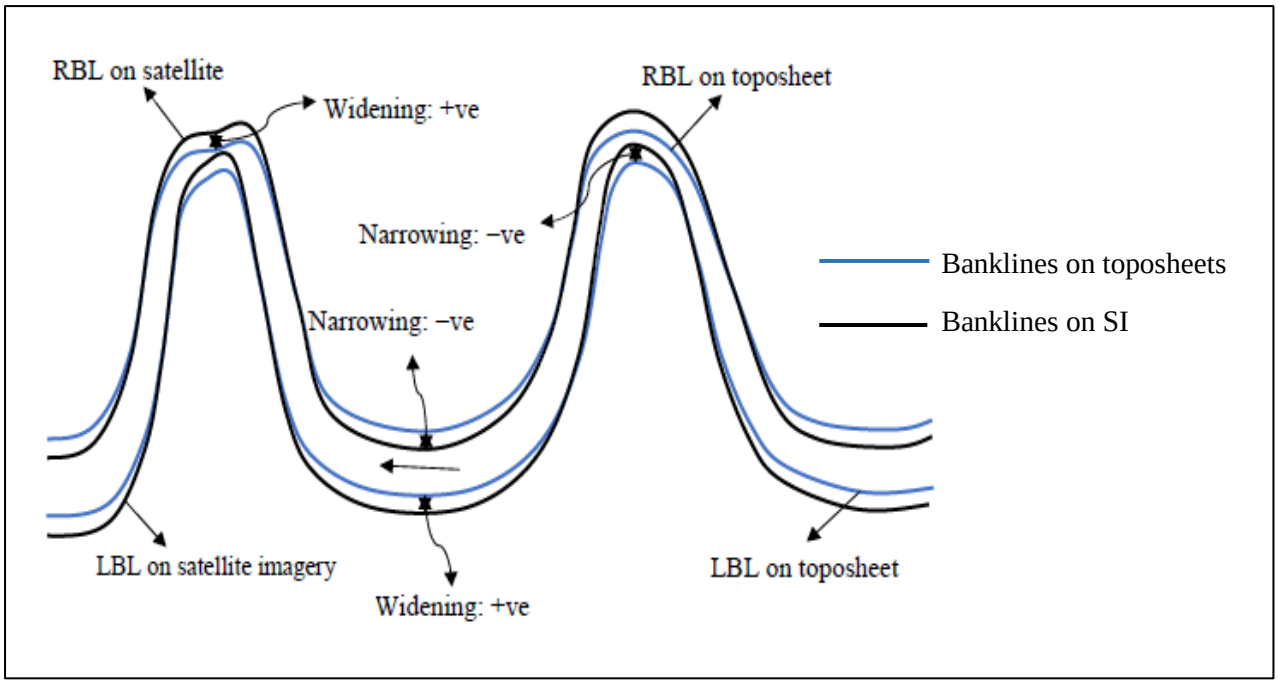


Fig 10.2 Sign convention adopted for river bank migration

The shift that has occurred, has been marked at every 20-km chainage of the river. The results are tabulated in Table 10.2 and represented separately for RBL to LBL in Figs 10.3 and 10.4 respectively.

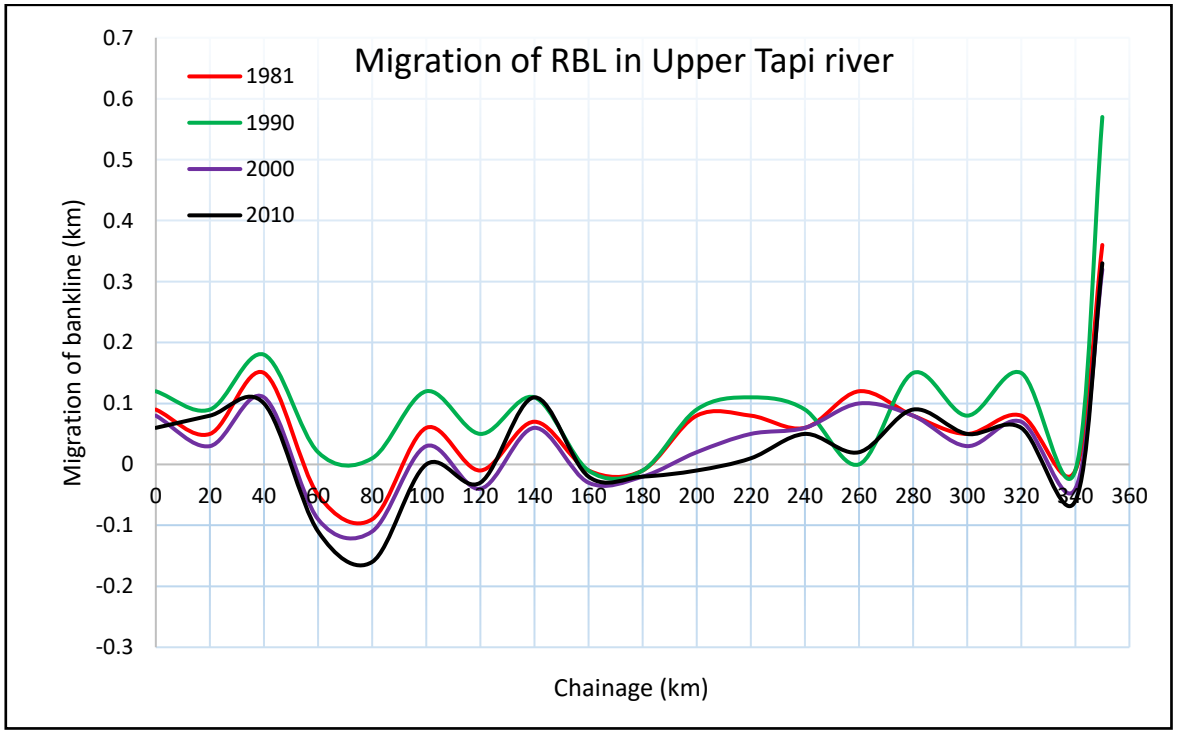


Fig 10.3 Migration of RBL in Upper Tapi river

Table 10.2 Shifting of right bank and left bank at 20 km chainages (Upper Tapi river)

Chainages (km)	Bank line shift (km) (+ve: widening, -ve: narrowing)							
	Base year-1981		Base year-1990		Base year-2000		Base year-2010	
	RB	LB	RB	LB	RB	LB	RB	LB
0 (Tapi Kund)	0.09	-0.05	0.12	-0.05	0.08	-0.06	0.06	-0.05
20	0.05	-0.03	0.09	-0.04	0.03	-0.04	0.08	-0.09
40	0.15	0.02	0.18	0.01	0.11	0.03	0.10	0.00
60	-0.05	0.11	0.02	0.10	-0.09	0.13	-0.11	-0.12
80	-0.09	0.12	0.01	0.13	-0.11	0.16	-0.16	0.25
100	0.06	-0.01	0.12	-0.02	0.03	-0.02	0.00	-0.03
120	-0.01	-0.01	0.05	-0.02	-0.04	-0.01	-0.03	0.02
140	0.07	-0.09	0.11	-0.09	0.06	-0.11	0.11	-0.14
160	-0.01	-0.01	-0.01	-0.02	-0.03	-0.03	-0.02	-0.09
180	-0.01	-0.01	-0.01	-0.03	-0.02	-0.02	-0.02	-0.01
200	0.08	-0.02	0.09	-0.05	0.02	-0.07	-0.01	-0.09
220	0.08	-0.08	0.11	-0.10	0.05	-0.11	0.01	-0.16
240	0.06	-0.07	0.09	-0.09	0.06	-0.12	0.05	-0.13
260	0.12	-0.11	0.	-0.12	0.10	-0.14	0.02	-0.22
280	0.08	-0.01	0.15	-0.02	0.08	-0.03	0.09	-0.10
300	0.05	-0.05	0.08	-0.06	0.03	-0.08	0.05	-0.12
320	0.08	-0.14	0.15	-0.17	0.07	-0.22	0.06	-0.20
340	-0.01	0.04	-0.01	0.02	-0.04	0.07	-0.06	0.05
350 (Hatnur Reservoir)	0.36	0.10	0.57	0.08	0.32	0.11	0.33	0.00

From 10.3, it can be observed that in Upper Tapi river, the RBL predominantly shows positive migration towards northern direction (+ve shift: widening), with respect to the base year considered (1971-1979). The migration at CH: 350 km is observed to be the maximum in all the years considered. This chainage falls just upstream of Hatnur dam, and just downstream of Changdev village where Purna River, one of the principal tributaries of Tapi river joins Tapi river. The significant shifting just upstream of Hatnur dam is due to impounding of reservoir and its backwater influence on Tapi river. It is to be noted that Hatnur dam was constructed during year 1982, while the base year for the period of analysis is 1971-1979. Thus, Hatnur Reservoir is not seen on the toposheets but its influence is seen satellite imagery of different decadal years. In case of negative southward migration, the RBL exhibits no significant shift except at CH: 60 km and CH: 80 km.

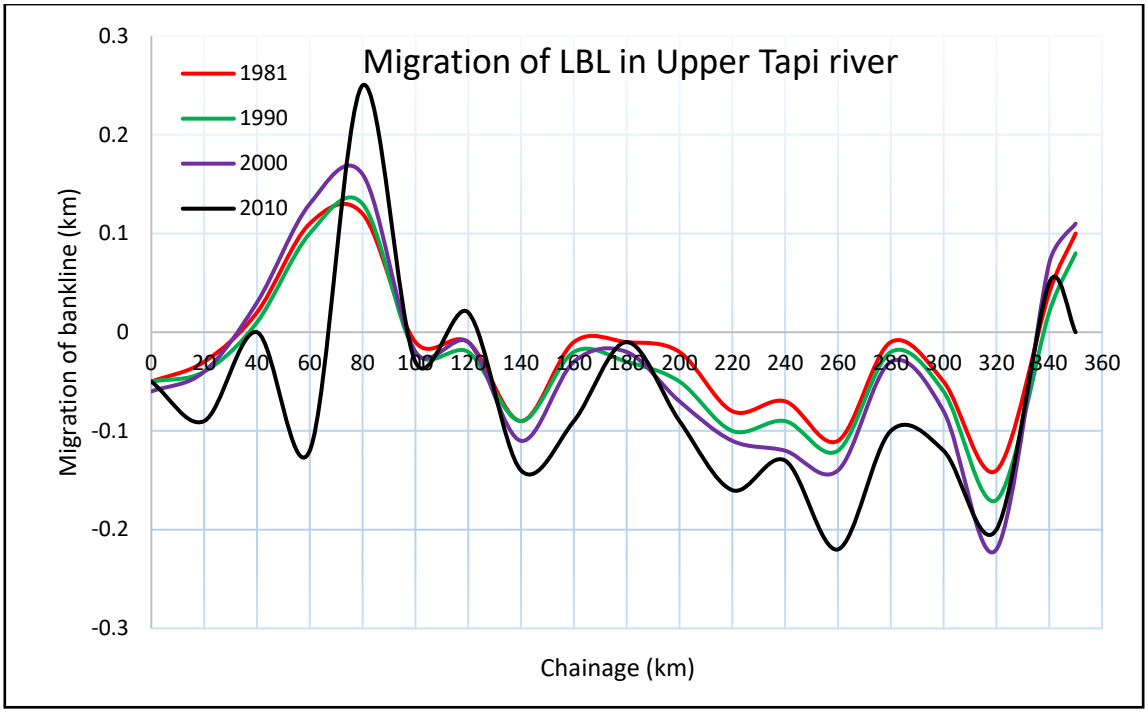


Fig 10.4 Migration of LBL in Upper Tapi river

This is observed at the inner meander bend that the river has formed at Layavani village in Madhya Pradesh. This is a clear indication of river undergoing narrowing of its cross-section by deposition of sediments at aforesaid locations.

The LBL of Upper Tapi river, in most of the chainages show negative shift, i.e., migration to the right side (narrowing). It can also be observed that over the years, this trend has increased (Fig 10.4). This clearly implies that the river is migrating constantly to the northern side, by depositing the sediments that it carries on the left bank. This phenomenon is observed predominantly at CH: 140 km (Kunkhedi village, Madhya Pradesh), CH: 220 km (Gogaipur Reserved Forest, Madhya Pradesh), CH: 240 km (Daiyat village, Madhya Pradesh), CH: 260 km (Dariyapur village, Madhya Pradesh), CH: 280 km (Nawtha village, Madhya Pradesh), CH: 300 km (Umarda village, Madhya Pradesh) and CH: 320 km (Sirsoda village, Madhya Pradesh). In CH: 80 km (Layavani village, Madhya Pradesh), the LBL shows positive migration to the south, and over the years there's an increasing trend in the same.

Overall, the shifts of RBL and LBL are opposite in nature, i.e., erosion on the right bank is compensated by corresponding negative shifts on left bank.

10.3.2 Quantification of Bank Migration in Middle Tapi river

The Middle Tapi river flows from downstream of Hatnur reservoir (CH: 350 km) and drains into the Ukai reservoir (CH: 581 km). The river bank migrations have been measured at 20 km chainages with reference to the base year (1971-1979) along the Middle Tapi river for years 1981, 1990, 2000 and 2010 years which is shown in Table 10.3. Also, the major river bank lateral migration, are shown in Fig 10.5 and Fig 10.6 respectively for RBL and LBL.

Table 10.3 Shifting of right bank and left bank at 20 km chainages (Middle Tapi river)

Chainages (km)	Bank line shift (km) (+ve: widening, -ve: narrowing)							
	Base year-1981		Base year-1990		Base year-2000		Base year-2010	
	RB	LB	RB	LB	RB	LB	RB	LB
350 (Hatnur Reservoir)	0.16	0.12	0.25	0.00	0.28	0.00	0.23	0.00
370	0.00	-0.02	0.03	-0.01	-0.02	-0.01	0.06	0.02
390	0.04	0.10	0.07	-0.11	0.02	-0.05	0.03	-0.09
410	0.02	0.10	0.05	-0.03	0.05	-0.05	0.03	-0.04
430	0.11	-0.16	0.17	-0.15	0.15	-0.15	0.12	-0.16
450	0.01	-0.01	0.03	-0.06	0.08	-0.10	-0.02	-0.03
470	-0.10	0.09	-0.17	0.13	-0.13	-0.07	-0.08	0.03
490	-0.09	0.07	-0.09	0.12	-0.12	0.14	-0.09	0.09
510	0.15	-0.05	0.04	0.03	0.07	-0.06	-0.07	-0.01
530	0.04	-0.02	0.06	-0.03	0.04	-0.01	0.05	-0.01
550	0.05	-0.05	0.16	-0.13	0.10	-0.11	0.12	-0.09
570	0.00	-0.01	0.00	-0.08	0.07	-0.05	0.03	-0.05
581 (Ukai Reservoir)	0.02	-0.02	-0.05	-0.06	0.01	0.05	0.11	0.00

It can be observed from Figs 10.5 and 10.6 that the Tapi river, in its middle reaches also, exhibits similar migration trend as that of its upper reaches. Both RBL and LBL are behaving approximately as a mirror image to each other except to the case of 1981 year may be due to poor resolution of satellite imagery in that reach due to which LBL is not depicting the same pattern.

The RBL shows positive migration in most of the chainages. The maximum shift is observed just the downstream of Hatnur dam at CH: 350 km. At this location, the RBL has shifted about 0.23 km (230 meters) from the base year. Also, the amount of shift observed here has been

increasing since 1981. The probable reason could be erosion of right bank due to release of clear water from the reservoir. The river tries to satisfy the need of sediment from the right bank of river due to the presence of rocky bed at the downstream of Hatnur dam site. Positive migration is also observed at CH: 430 km (Kathore village, Maharashtra),

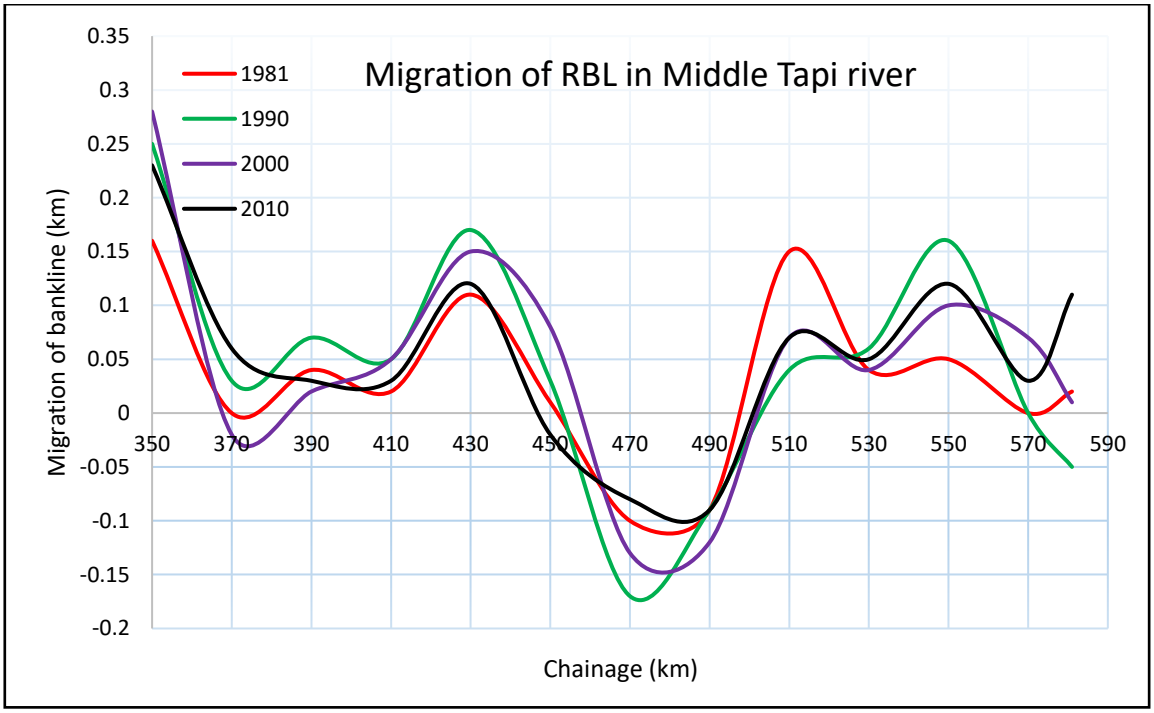


Fig 10.5 Migration of RBL in Middle Tapi river

CH: 510 km (Tekvade village, Maharashtra) and CH: 550 km (Shelti village, Maharashtra), but over the years the extent of migration is decreasing with time at these locations. Significant negative migration is observed in RBL between CH: 470 km (Piloda village, Maharashtra: Just downstream of the confluence of Atner Nadi with Tapi) and CH: 490 km (Kamkheda village, Maharashtra). From the base year to 2010 almost 0.1 km (100 meters) of maximum shift has taken place here. In case of LBL, except between CH: 470 km (Piloda village, Maharashtra: Just downstream of the confluence of Atner Nadi with Tapi) and CH: 490 km (Kamkheda village, Maharashtra), negative migration is observed everywhere. It can be observed from Fig 10.6 that at CH: 430 km (Kathore village, Maharashtra) river has migrated almost 0.16 km (160 meters) inwards. This is complementing the outward migration of RBL at this location.

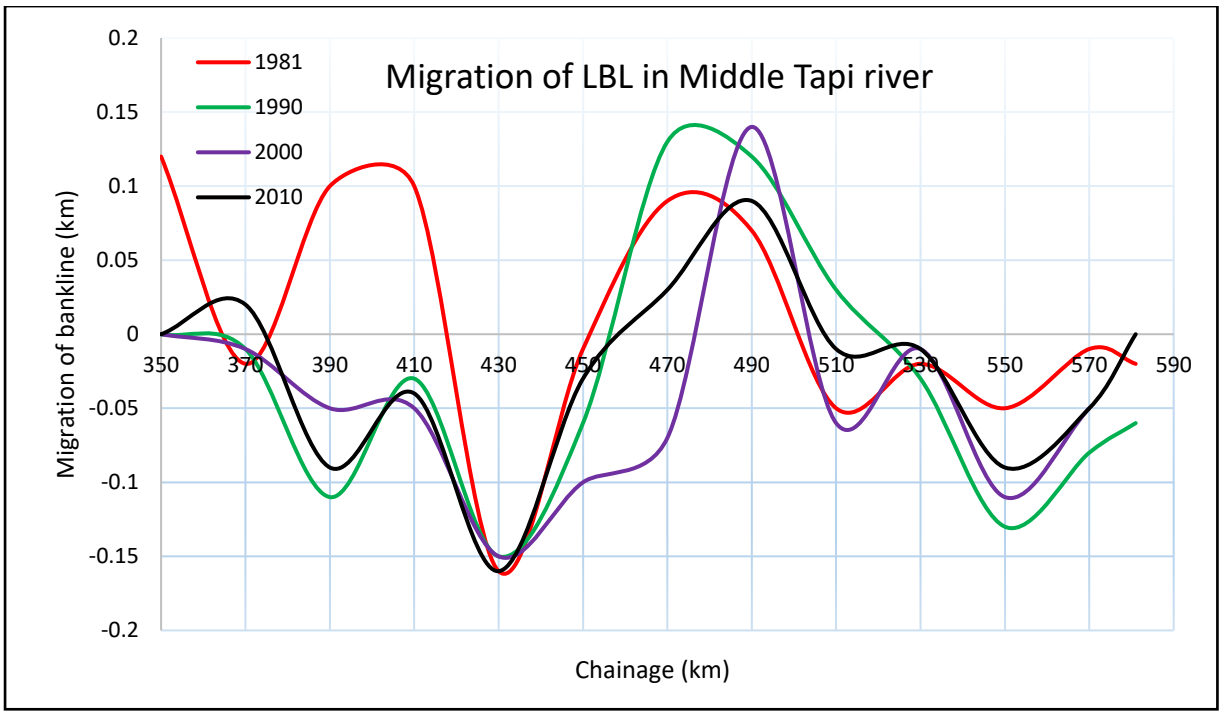


Fig 10.6 Migration of LBL in Middle Tapi river

10.3.3 Quantification of Bank Migration in Lower Tapi river

The digitized banklines for Lower Tapi river for the years 1981, 1990, 2000 and 2010 when laid over SOI Toposheet banklines, do not show any significant migration both in RBL and LBL except at last chainage, i.e., CH: 792 km (Table 10.4 and Figs 10.7-10.8). This chainage is located near Hazira, Gujarat where Tapi river joins Arabian Sea. In the year 1981, the RBL shows a maximum positive migration of 1.31 km (1310 meters) and over the years the river has shown a shift in the opposite direction and by 2010 a negative migration has been observed.

Table 10.4 Shifting of right bank and left bank at 20 km chainages (Lower Tapi river)

Chainages (km)	Bank line shift (km) (+ve: widening, -ve: narrowing)							
	Year: 1981		Year: 1990		Year: 2000		Year: 2010	
	RB	LB	RB	LB	RB	LB	RB	LB
647 (Ukai dam)	0.03	-0.16	0.03	-0.07	0.04	-0.07	0.06	-0.06
667	0.05	-0.09	0.08	-0.1	0.07	-0.15	0.06	-0.09
687	0.15	-0.07	0.21	-0.11	0.14	-0.12	0.12	-0.11
707	0.1	-0.16	0.13	-0.16	0.13	-0.15	0.1	-0.1
727	0.05	-0.08	0.05	-0.08	0.02	-0.11	0.04	-0.1
747	0	0.16	0.11	0.33	0.06	0.15	0.03	0.1
767	0.26	0.45	0.2	0.39	0.08	0.37	0.12	0.34
787	0.54	-0.23	0.53	-0.28	0.56	-0.59	0.52	-0.58
792 (Arabian Sea)	1.31	3.04	0.16	1.33	-0.68	3.01	-1.39	2.75

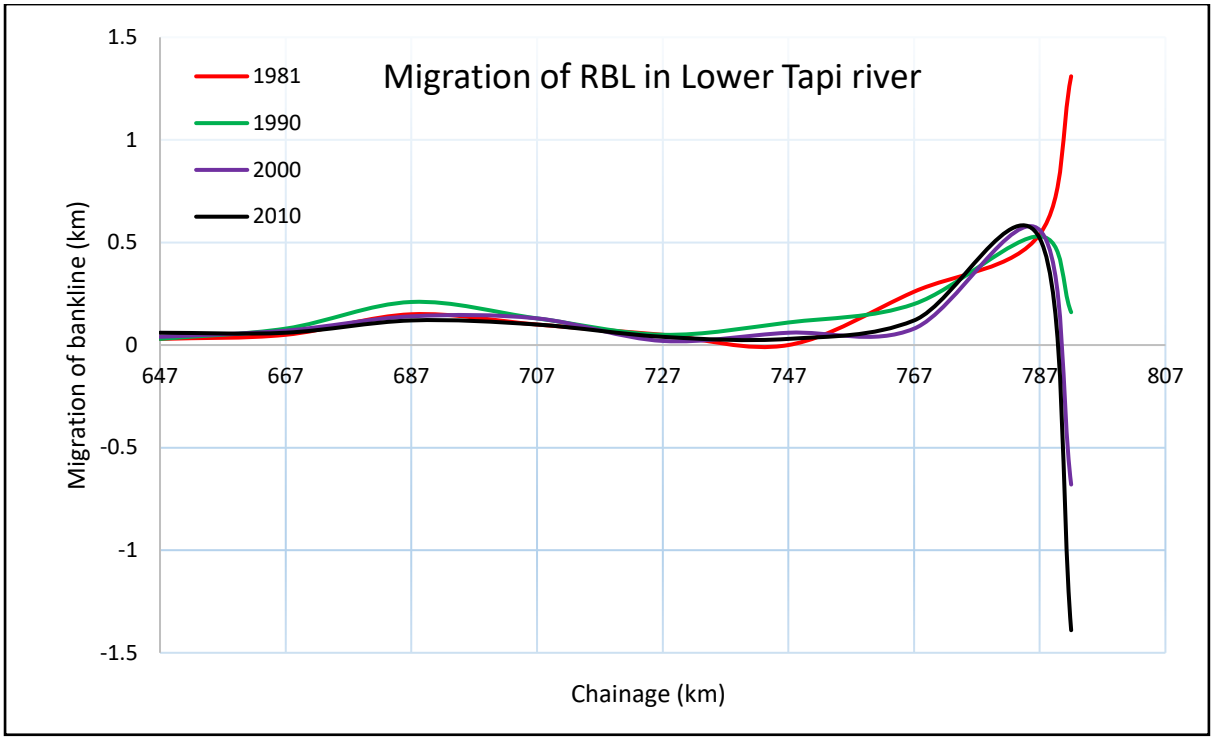


Fig 10.7 Migration of RBL in Lower Tapi river

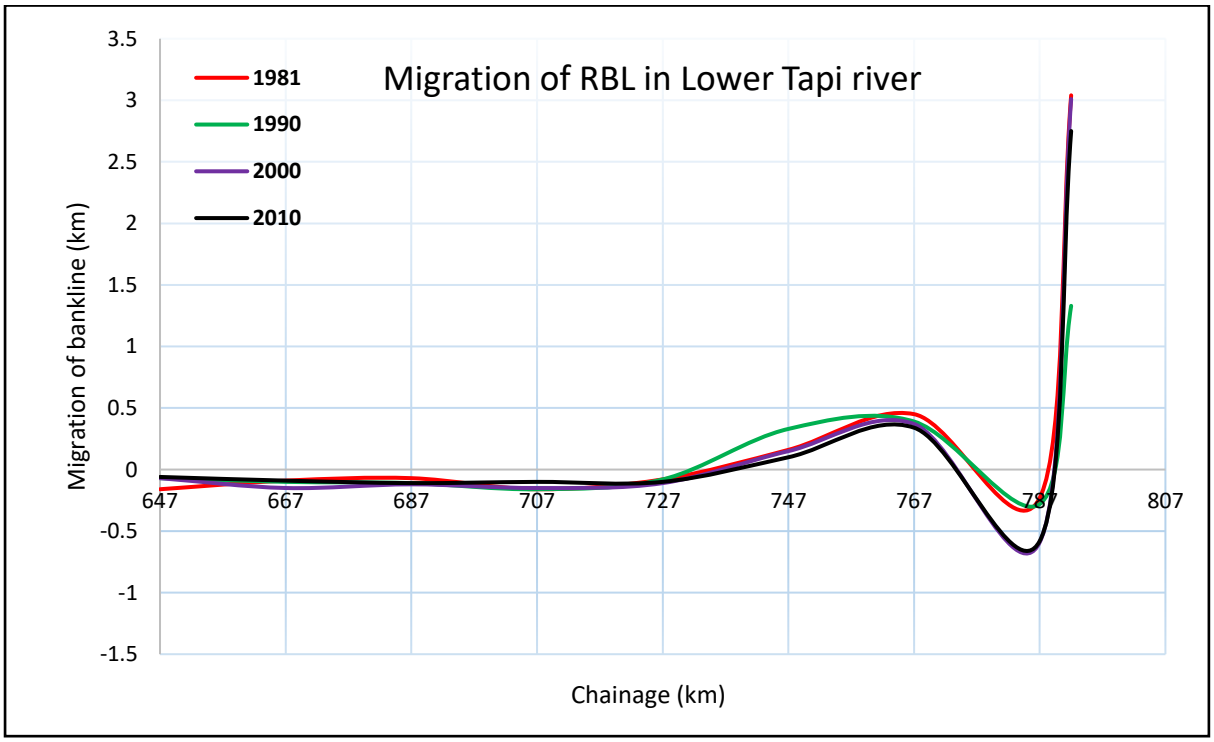


Fig 10.8 Migration of LBL in Lower Tapi river

At CH: 792 km, the LBL shows a positive outward migration for all the years under consideration. There is consistency in the observed shift in the recent years i.e., satellite imagery of 2000 and 2010. In all the other chainages, no significant migration has happened in the Lower Tapi river from base year. Compared to the Upper and Middle reaches of Tapi river,

the Lower Reaches exhibit stability in the course due to artificial bank protections provisioned on either bank of the river starting from Ambola village to Rundh Magdalla village in Gujarat. The large shifting of either banks in the last chainages is due to effect of tidal conditions in the Arabian Sea.

10.4 QUANTIFICATION OF CHANGE IN RIVER WIDTH

The bank width is the width between the left bank line and right bank line of the channel measured perpendicular to the stream flow. The channel width is an important parameter to relate with the hydraulic geometry parameters of the rivers and observe the behaviour along the river length. It gives an idea of whether the channel has undergone narrowing or widening over the period of consideration. In this study, the channel widths have been measured at every 50 km chainages along the river length for the base year, 1981, 1990, 2000 and 2010 for Upper Tapi, Middle Tapi and Lower Tapi rivers separately (see Table 10.5 and Fig 10.9).

Table 10.5 Variation in channel width along river length (Upper Tapi river)

Chainage (km)	1981	1990	2000	2010
	*BW (km)	BW (km)	BW (km)	BW (km)
0 (Tapi Kund)	0.04	0.04	0.04	0.01
50	0.18	0.14	0.14	0.10
100	0.15	0.10	0.12	0.10
150	0.32	0.24	0.24	0.24
200	0.13	0.15	0.13	0.10
250	0.21	0.20	0.23	0.26
300	0.21	0.26	0.27	0.22
350 (Hatnur Reservoir)	0.58	0.97	0.92	0.83

***BW: Bank width**

The significant widening in the banklines just upstream of Hatnur Reservoir is due to the influence of afflux in the upstream reaches of the river. From Table 10.6 and Fig 10.10, it is clear that, the channel width attains maximum value at CH: 350 km, downstream, of Hatnur dam and then attains lowest value around CH: 400 km near Thorgavhan village. Widening of the channel is also observed at CH: 581 km, upstream of Ukai dam. The larger width of the channel just downstream of Hatnur Reservoir could be due to erosion of either banks due to release of relatively clear water from the reservoir during the monsoon. The larger width of the channel at the periphery of Ukai Reservoir is due to the afflux in the channel. There is progressive influence of enhanced channel width due to possible deposition of coarse sediment

in the periphery of reservoir, and consequent shifting of bank lines to accommodate the discharge during the monsoon.

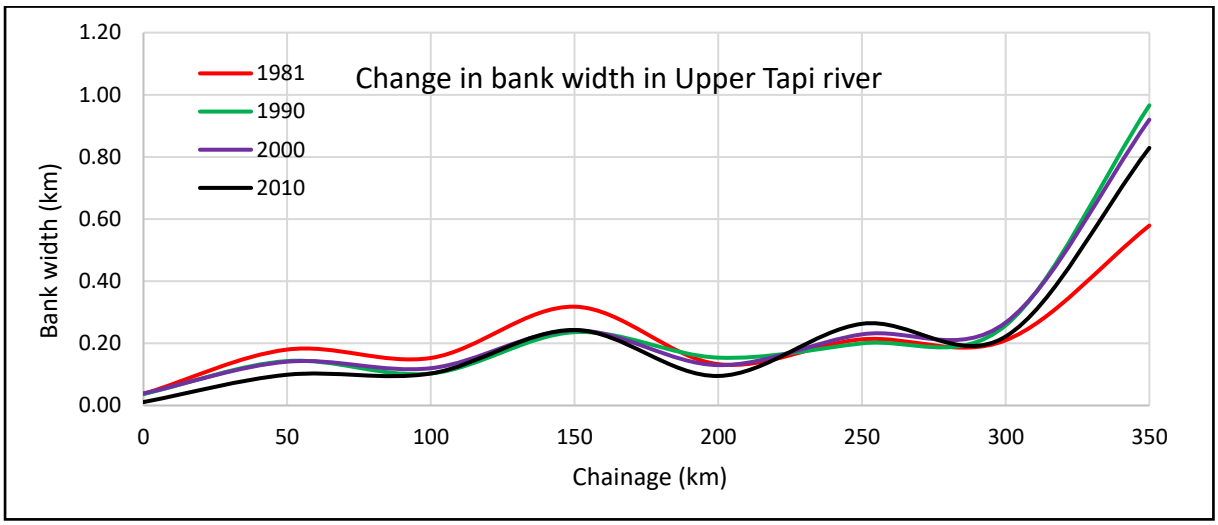


Fig 10.9 Changes in bank width in Upper Tapi river

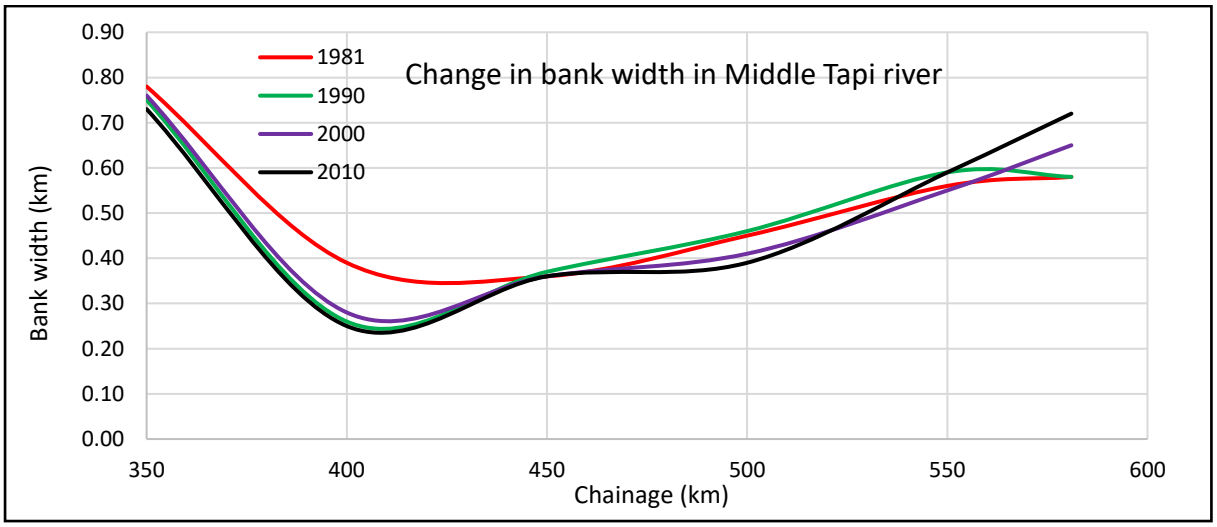


Fig 10.10 Changes in bank width in Middle Tapi river

Table 10.6 Variation in channel width along river length (Middle Tapi river)

Chainage (km)	1981	1990	2000	2010
	BW (km)	BW (km)	BW (km)	BW (km)
350 (Hatnur dam)	0.78	0.75	0.76	0.73
400	0.39	0.26	0.28	0.25
450	0.36	0.37	0.36	0.36
500	0.45	0.46	0.41	0.39
550	0.56	0.59	0.55	0.59
581 (Ukai Reservoir)	0.58	0.58	0.65	0.72

Table 10.7 Variation in channel width along river length (Lower Tapi river)

Chainage (km)	1981	1990	2000	2010
	BW (km)	BW (km)	BW (km)	BW (km)
647 (Ukai dam)	0.59	0.53	0.49	0.49
697	0.74	0.68	0.68	0.68
747	0.60	0.54	0.63	0.63
792 (Arabian Sea)	5.53	4.87	4.77	4.76

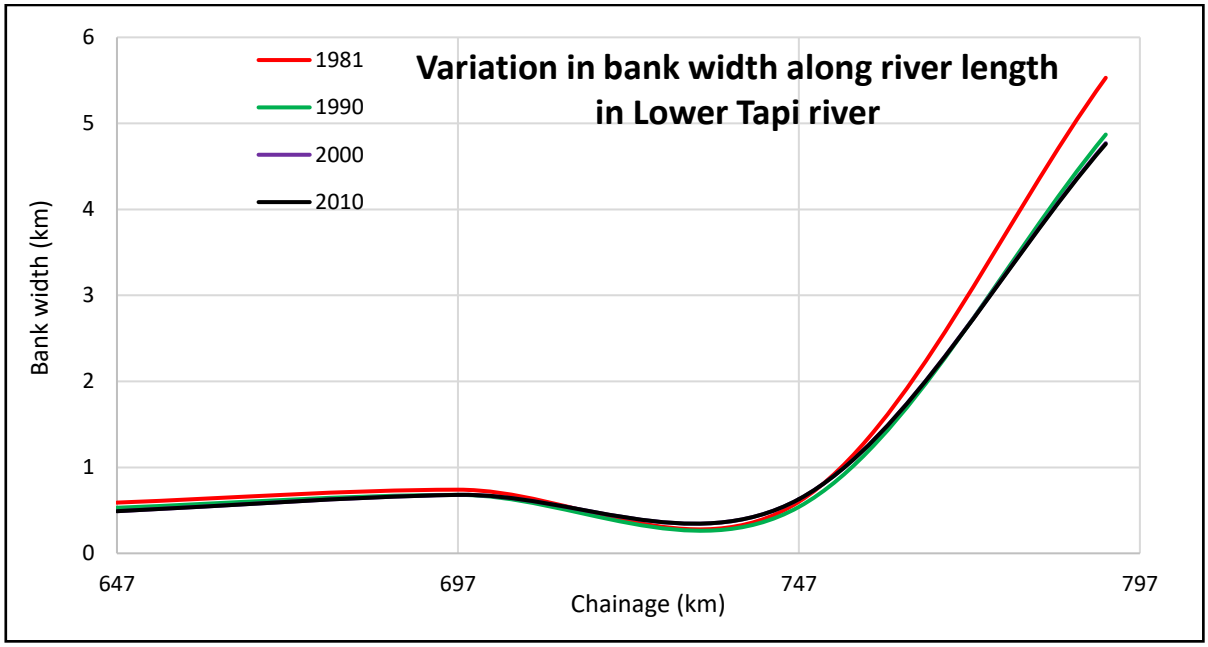


Fig 10.11 Changes in bank width in Lower Tapi river

In Lower Tapi river, no significant changes in width is observed except at CH: 792 km, where the river meets Arabian Sea. At this chainage, significant bank migration was also observed (see Fig 10.7 and Fig 10.8). This chainage, located near Hazira, Gujarat, is observed to undergo a wide variety of dynamics owing to both the effect of Tapi river as well as Arabian Sea. The width of the river is observed to reduce over the years. This is one of the most important elements of Surat Metropolitan Region which is the base for major industrial and shipping facilities like Essar, Kribhco, Shell, Larsen & Toubro, NTPC, ONGC, GAIL, Gujarat State Petroleum Corporation, UltraTech Cement and Reliance Industries. The narrowing down of river at this location implies to the flood plain getting encroached and the reduction in the carrying capacity of the river. The problem has been tried to address through the analysis of bank erosion and bank deposition and the gravity of the same has been evaluated by conducting field reconnaissance trips to the identified critical river reaches.

10.5 EFFECT OF PEAK FLOWS ON RIVER MORPHOLOGY

In order to evaluate the geomorphic effectiveness of peak flows on river morphology, four flow categories were defined on the basis of return period of daily annual peak discharge data at Dedtalai, Burhanpur, Sarangkheda and Gidhade stream gauging stations which fall along the Tapi river. The flood frequency analysis carried out for these stations using Gumbel Distribution (Section 6.4.3 of Chapter 6) was employed for the flow categorization. Using Gumbel Distribution (Kale and Hire, 2004), the flow categories were defined as follows:

- Low flows (Q_L) : Flows that occur once in 1.2-1.5 years
- Medium flows (Q_M): Flows that occur once in 1.5-2.33 years
- Floods (Q_F): Flows that occur once in 2.33-6.93 years
- Large floods (Q_{LF}): Flows that occur once in > 6.93 years and equal to or less than the maximum observed flow at the station for the period of consideration.

In order to evaluate the role of small, moderate and large flows on river morphology, the hydraulic geometry equations were developed for the stations under consideration (Section 6.5.3) to derive the values of different hydraulic parameters, such as width, mean depth, mean velocity, width–depth ratio and unit stream power for discharges of different flow categories. The variations of these parameters were estimated on decadal basis (Table 10.8-10.10).

Table 10.8 Variation in hydraulic geometry parameters with different flow categories (1980-1990)

Station	*Q* (m^3/s)	Hydraulic parameters				
		W **(m)**	***D*** **(m)**	***W/D***	***U*** **(m/s)**	**ω (W/m^2)**
Dedtalai	Q_L = 1613	229	5.90	38.85	1.11	3.45
	Q_M = 2803	231	5.94	38.94	2.04	7.49
	Q_F = 4488	235	8.32	28.24	2.30	28.10
	Q_{max} = 9664	255	12.00	21.24	3.16	89.23
Burhanpur	Q_L = 2398.6	286	5.01	37.86	2.52	74.35
	Q_M = 5203	275	6.04	37.86	3.77	111.64
	Q_F = 11305	229	7.28	37.86	5.64	132.86
	Q_{max} = 13259	190	7.56	37.89	6.13	151.34
Sarangkheda	Q_L = 4248	466	4.91	94.90	1.86	13.42
	Q_M = 6593	556	5.75	96.68	2.06	23.28
	Q_F = 13750	532	7.66	69.46	3.38	50.71
	Q_{max} = 16084	607	9.99	60.81	2.65	85.72

Table 10.9 Variation in hydraulic geometry parameters with different flow categories (1991-2000)

Station	Q (m^3/s)	Hydraulic parameters				
		W (m)	D (m)	W/D	U (m/s)	ω (W/m^2)
Dedtalai	Q_L = 1489	224	3.51	63.86	1.90	26.08
	Q_M = 2982	230	6.11	37.69	2.12	63.51
	Q_F = 6713	248	10.17	24.40	2.66	159.33
	Q_{max} = 17628	275	14.48	18.96	4.44	299.31
Burhanpur	Q_L = 2528	186	5.58	33.36	2.43	39.97
	Q_M = 5181	210	7.82	26.89	3.15	72.52
	Q_F = 12339	244	11.75	20.74	4.31	149.02
	Q_{max} = 25261	275	16.53	16.65	5.58	306.87
Gidhade	Q_L = 3916	405	5.05	80.17	1.91	34.15
	Q_M = 6538	412	7.44	55.4	2.13	31.13
	Q_F = 12521	407	10.85	37.53	2.22	60.33
	Q_{max} = 17578	415	11.71	35.41	3.62	83.19

Table 10.10 Variation in hydraulic geometry parameters with different flow categories (2001-2010)

Station	Q (m^3/s)	Hydraulic parameters				
		W (m)	D (m)	W/D	U (m/s)	ω (W/m^2)
Dedtalai	Q_L = 1305	222	2.97	74.75	1.98	38.64
	Q_M = 3302	238	7.47	31.86	1.86	45.37
	Q_F = 4537	250	9.32	26.83	1.95	62.31
	Q_{max} = 5584	261	10.66	24.48	2.01	69.96
Burhanpur	Q_L = 2463	206	5.31	38.77	2.25	35.19
	Q_M = 5300	244	8.08	30.13	2.69	42.70
	Q_F = 11498	260	9.89	26.30	4.47	144.61
	Q_{max} = 21200	321	13.58	23.62	4.87	216.14
Sarangkheda	Q_L = 4160	508	5.04	100.86	1.63	16.07
	Q_M = 7618	564	7.06	79.92	1.91	26.50
	Q_F = 11977	580	9.62	60.27	2.15	34.44
	Q_{max} = 25259	600	15.10	39.74	3.01	133.62

Tables 10.8 to 10.10 show that the width–depth ratio remains high at low flows (Q_L) which occur on average more than once every year, and is minimum during large floods and maximum

flood (Q_{LF} and Q_{max}) which have a return period of >6.93 years. Remarkable increase in the hydraulic parameters, such as depth and velocity, and the decrease in the width–depth ratio with discharge indicate that the hydraulic efficiency and the stream power increase significantly during extreme floods. It is, therefore, likely that high-magnitude events can perform a variety of tasks including erosion of bed and bank material and transportation of coarse sediments.

Results show that the unit stream power values range between 3.45 W/m^2 to 151.34 W/m^2 during 1980-1990, 26.08 W/m^2 to 333.89 W/m^2 during 1991-2000 and 16.07 W/m^2 to 216.14 W/m^2 during 2001-2010 at various stations in Tapi Basin. From Table 10.8, it is apparent that unit stream power, ω, at Sarangkheda stream gauging station is higher than Dedtalai stream gauging station due to high discharges at former station for the floods of all return periods.

10.6 EFFECT OF CHANGES IN ANNUAL RAINFALL IN THE BASIN ON RIVER MORPHOLOGY

10.6.1 Floods in Lower Tapi river

As discussed in Chapter 6 about the trends in total annual rainfall and number of rainy days observed in rain gauge stations of Upper, Middle and Lower Tapi Basins, it has been found that in Lower Tapi Basin alone, there has been an increasing trend in both total annual rainfall and number of rainy days during 1977-2010. Also, the average annual rainfall fall Lower Tapi Basin is about 1042.33 mm, which is much higher than that of Upper Tapi Basin (935.55 mm) and Middle Tapi Basin (631.50 mm) [Source: CWC Tapi Basin Report-2014]. Lower Tapi Basin falls within the zone of severe rainstorms, and flood-producing heavy rainfall spells have been observed in the recent past with a maximum 24-h heavy rainfall ranging from 86 to 459 mm (Timbadiya et al., 2015). As per historical records, Tapi river has experienced large floods in the years 1727, 1776, 1782,1829, 1837, 1872, 1944, 1959, 1968, 1970, 1994, 1998 and 2006. The lower reaches of the Tapi river, especially the Surat City has faced maximum destruction due to the havoc caused by severe floods. The flood in 2006 resulted in the loss of about 150 human lives and a financial loss in tune of 4200 million US Dollars (Timbadiya et al., 2014). The average annual rainfall in Lower Tapi Basin during 2006 was around 1655 mm and the peak discharge of 25,780 m^3/s was released from Ukai dam. Almost 80% of the area of Surat City was flooded with a maximum water level of 12.50 m observed at Nehru bridge. The flood carrying capacity of Tapi river has been reduced significantly in its Lower Reaches, especially in Surat, due to rapid urbanization and flood plain encroachment. The land use land cover

classification as well as the analysis of changes in width of Lower Tapi river also, justifies the same. For example, a discharge of merely 25,780 m^3/s during the flood in 2006 had attained a level of 12.50 m at the Nehru bridge in Surat city compared to the level of 12.09 m attained by the historically maximum flood of discharge 42,500 m^3/s in 1968.

10.6.2 Failure of Chandora dam in Upper Tapi river

The Chandora dam is an earthen dam which is about 2043 m long and 17 m high and is located about 16 km downstream of Tapi Kund, the origin of Tapi river. The dam was constructed during 1979-1986. The catchment area up to the dam location is about 71 km^2. The dam breached on 30th July 1991, owing to a heavy rainfall of about 450 mm in 24 hours, which resulted in the overtopping of the dam (Saxena and Sharma, 2004). 40% of the total annual rainfall was received in one day and the reservoir was drained in less than one hour (Kale, 2005). The breach had occurred, covering the full height of the dam and foundations, due to deep cuts on the downstream side. As per the study carried out by Kale (2005), the 1991 flood was an exceptional geomorphic and hydrologic event capable of producing flow depths of about 16 m, a velocity of about 11 m/s and a maximum stream power per unit area of 6300 W/m^2 (simulated results at Dhanora: 33 km D/S of Chandora dam). A stream power of such quantum was able to transport sediment of the size of boulders.

10.7 IDENTIFICATION OF MAJOR MORPHOLOGICAL PROBLEMS IN TAPI RIVER

The major morphological problems existing in Tapi river have been identified initially by analysis of bank migration and changes in the bank width and then by evaluating the present status of the river reaches through field reconnaissance trips. They are listed out as follows, separately for Lower Tapi, Middle Tapi and Upper Tapi rivers.

The Tapi estuary System is a part of the Gulf of Khambat in Suvali Gam, Hazira, Gujarat, located at the Northern part of the India's west coast. This area marks the end of Tapi river System where the river drains into Arabian Sea.

The field visit to this place which is located at CH: 787 km, has shown that, over the time the estuary has been silted up extensively. This area serves the navigational purpose for industrial firms like Essar, but it has been reported that owing to heavy siltation, the operation of ships is greatly restrictred (Ranganath et al., 2013). The location experiences strong semidiurnal tides

and the spring tides of amplitude greater than 5 m at the mouth of the estuary. The effect of the tide is maximum in and aound the estuary mouth and weakens away from the mouth. Fresh water discharge in the river is maximum during the monsoon period (July to September). During the monsoon period, a complex coastal system with high turbulence is formed here and the region experiences the combined effects, of sea waves, tidal effect and flow in the river.

10.7.1 Lower Tapi river (Ukai dam-CH: 647 km to Arabian Sea-CH: 792 km)

10.7.1.1 Tapi Estuary System, Suvali Gam, Hazira (CH: 787 km)



Fig 10.12 Location Map of Tapi Estuary System, Suvali Gam, Hazira

Owing to these effects, it was observed that the right bank of Tapi river has undergone an outward migration at a high rate leaving only about a 100 m distance between the river bank and the main road (Photo 9.1). The observation is in tune with the analysis that has been carried out for Lower Tapi river regarding the migration of banks. Owing to this, huge erosion has occurred in the right bank. Even though bank protection works have been carried out here to arrest river migration, the erosion of the right bank is still progressive. Systematic river bank protection measures are required to arrest further erosion of right bank. Hazira is an industrially important location in Surat Metropolitan Region which is a base for major industrial and shipping firms like Essar, KRIBHCO, SHELL, Larsen & Toubro, NTPC, ONGC, GAIL, Gujarat State Petroleum Corporation, Ultra-Tech Cement and Reliance Industries. The Tapi river forms three channels here, in between which there are two islands as shown in Fig 10.12. These islands are valuable reserves of mangrove vegetation, which protect vulnerable coastlines from the wave action and coastal erosion by holding the soil together. They also

shield the inland areas during storms and minimizes the damage. Special effort is needed for the conservation of above mangroves.

10.7.1.2 Utran-Kapodara bridge (CH: 750 km)

The right bank of Tapi river has undergone major erosion at this location (Fig 10.13). During field visit, it was observed that no proper bank protection works are provisioned at this location to arrest erosion. At the left bank of the river, human intervention in the form of flood plain encroachment was observed (Photo 9.13). This observation agrees with the analysis of bank migration of the river, where it was observed that the left bank has been migrating inward (northern side) during the period of consideration (base year-2010).



Fig 10.13 Location Map of Utran-Kapodara bridge

10.7.2 Middle Tapi river (Hatnur dam-CH: 350 km to Ukai Reservoir-CH: 581 km)

10.7.2.1 Kavithe-Kukarmunda bridge, Gujarat (CH: 589 km)

During the field visit to middle Tapi river reaches, it was observed that vertical cutting and falling off soil due to caving has happened in the left bank, upstream of Kavithe-Kukarmunda bridge (Fig 10.14). A lift irrigation scheme is located on the left bank, just upstream of the bridge, and bank protection works have been built just to protect this scheme. Vertically cut banks were also observed downstream of the bridge at the left bank. Agricultural lands as well as small houses are located near the left bank (Photo 9.26-9.27). This location has been identified as one of the critically erosion prone areas along the Tapi river and requires

immediate action. The exposed left banks, if not taken care of, may fall off soon during floods, causing huge loss in the adjoining land.

10.7.2.2 Mudawad, Maharashtra (CH: 478 km)

This location marks the confluence of Panjara, a left bank tributary of Tapi river (Fig 10.15). Field visits have been conducted in this particular location both during monsoon period and non-monsoon period. The observations during monsoon period showed that both the banks of Panjhra River are subjected to erosion, and has high bed slope in comparison to the Tapi river. The Tapi river was observed to undergo erosion at its left bank and huge amount of deposition at the right bank, which has resulted in the formation of a point bar (see Fig 10.15).

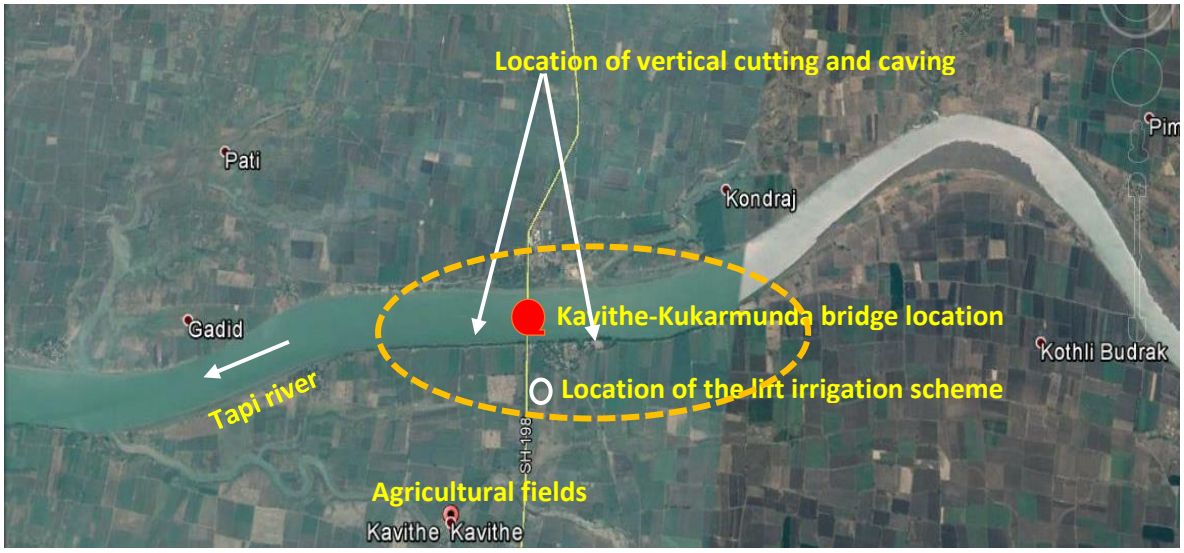


Fig 10.14 Location Map of Kavithe-Kukarmunda bridge

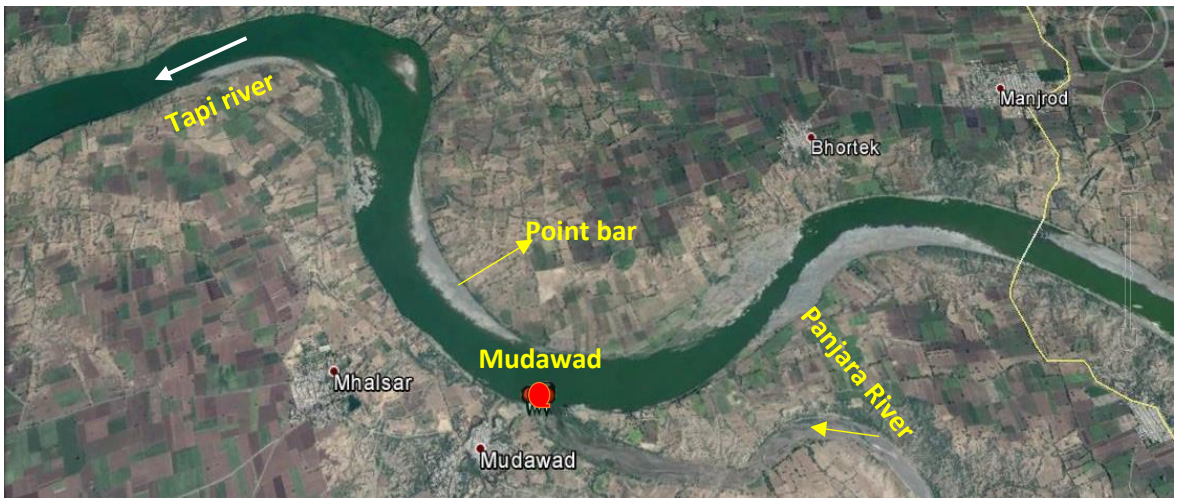


Fig 10.15 Location map of Mudawad, Maharashtra

An old temple is located on the right bank of Panjara River and on the left bank of Tapi river. During monsoon period, the temple walls and steps are subjected to river action and the temple walls and steps are eroded. This location has been identified as a zone of high turbulence owing to meeting of two rivers with entirely different velocities and sediment types. The temple is to be protected against the severe erosion of left bank of Tapi river (Photo 9.52-9.53).

10.7.2.3 Gangapuri, Jalod, Maharashtra (CH: 454 km)

The specified location is a bridge site, where a bridge called Budhgaon bridge is constructed across the Tapi river (Fig 10.16). The Tapi river follows a sinuous path here, showing prominent erosion in the form of bank cutting, on its left banks. The effect of secondary currents is clearly visible here, and a well developed point bar has been formed on the right bank due to huge deposition of sediments.

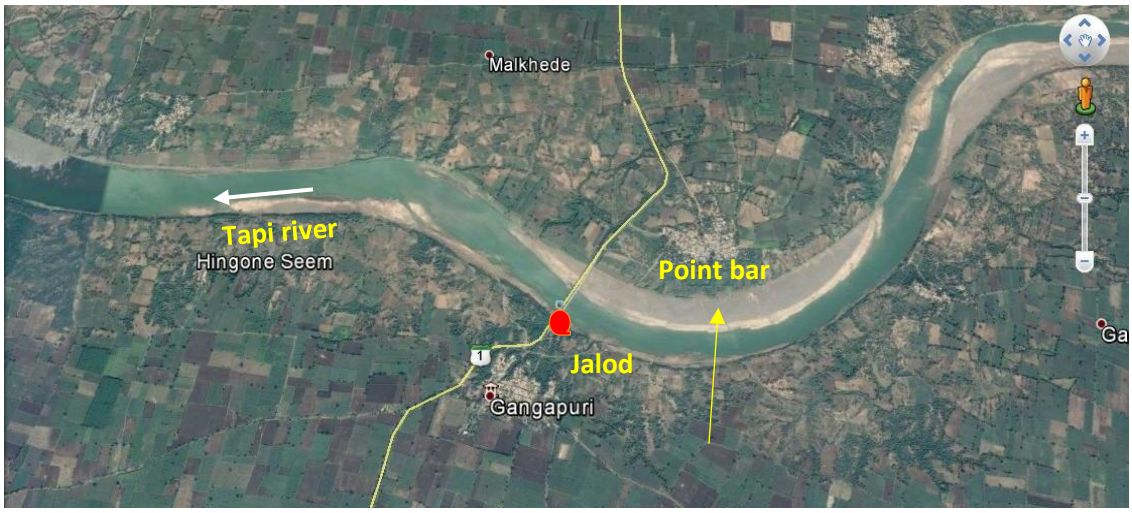


Fig 10.16 Location Map of Jalod, Maharashtra

The erosion phenomenon if continues may pose threat to the bridge, which may result in bridge scouring. Adding to the threat of river dynamics, sand mining is also observed on the left bank, downstream of the bridge location (Photos 9.62-9.66).

10.7.3 Upper Tapi river (Tapi Kund-CH: 0 km to Hatnur Reservoir-CH: 350 km)

Compared to the Lower Tapi and Middle Tapi river reaches, the Upper Tapi river which extends from Tapi Kund to Hatnur Reservoir is not subject to significant threat of effect of bank migration, i.e., bank erosion/ bank deposition, except in its downstream reaches. A few critical locations are discussed below.

10.7.3.1 Hatnur dam Site, Madhya Pradesh (CH: 350 km)

Just upstream of Hatnur dam, Purna, a principal tributary of Tapi makes its confluence with Tapi river (Fig 10.17). The afflux and subsequent deposition of sediments in upstream of reservoir causes shifting of bank lines of Tapi river. The bed stratum being rocky, the effect of erosion is not prominent here, in aforesaid locations (Photos 9.81-9.83).

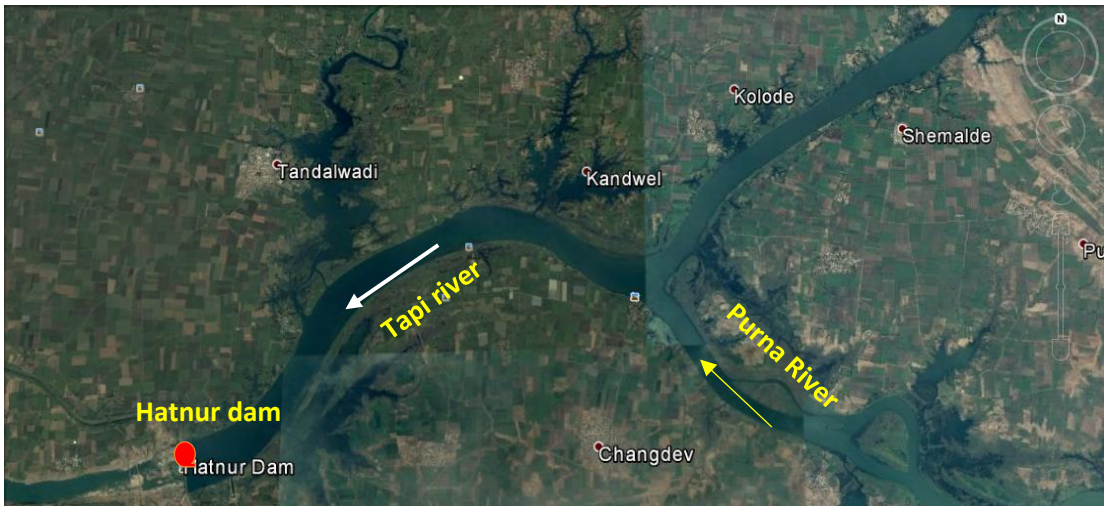


Fig 10.17 Location Map of Hatnur dam site, Maharashtra

10.7.3.2 Burhanpur Fort, Sanjaynagar, Madhya Pradesh (CH: 308 km)

Burhanpur Fort is located on the right bank of Tapi river (Fig 10.18). The location is popularly known as Rajghat. At this location, the river reach is alluvial, and the river follows a sinuous path. Significant erosion of RBL was observed near the fort. The part of the structure was also seen in damaged condition due to prevailing flow conditions in the river. Contrary to above, the left bank has been noticed to have significant deposition on the inner bend (LBL), see Fig 10.18 (Photos 9.85-9.87).

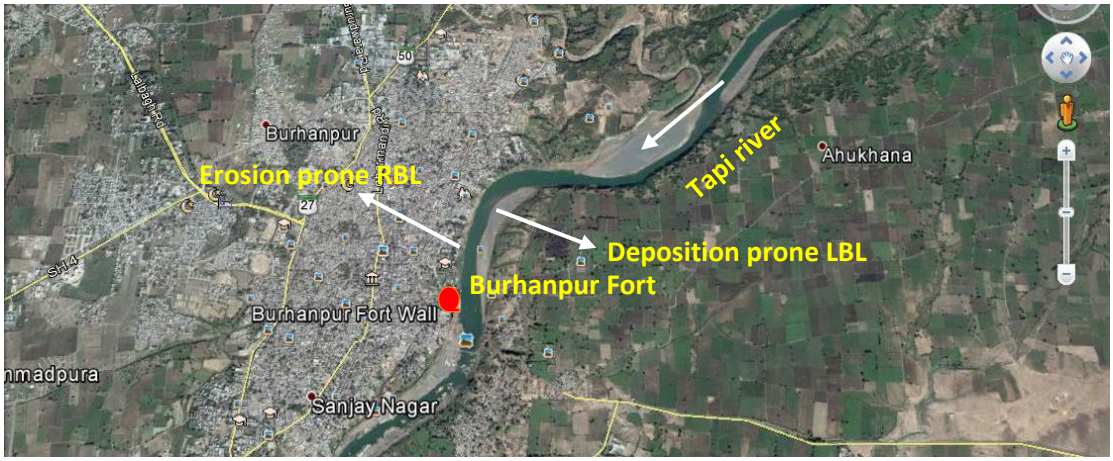


Fig 10.18 Location Map of Burhanpur Fort, Maharashtra

10.8 IMPACTS OF MAJOR HYDRAULIC STRUCTURES ON RIVER MORPHOLOGY

10.8.1 Ukai dam (CH: 647 km)

The Ukai dam, constructed across Tapi river, is the largest dam on the river. Its reservoir is known as Vallabh Sagar. The construction of the dam began in 1969 and was completed in 1972. The dam is a multipurpose project serving the requirements of irrigation, hydropower, municipal and industrial water supplies and partial flood control. Having a catchment area of about 62,255 km^2 and a water spread area of about 52,000 hectares, its capacity is almost same as that of the Bhakra Nangal dam. The dam site is located 94 km upstream of Surat City (Fig 10.19).

Floods have been a frequent phenomenon downstream of Ukai dam, especially in Surat City. The Surat city is situated in the delta region of Tapi river. Major floods have been recorded in Surat city during the years 1883, 1884, 1894, 1942, 1944, 1945, 1949, 1959, 1968, 1998 and 2006. The history of floods that have occurred in Surat City is given in Table 10.11. It can be observed that floods were a regularly occurring phenomena prior to the construction of Ukai dam.

Table 10.11 Historical record of floods in Surat City

Flood Event	Discharge (10^5 cusecs)	Water level at Nehru bridge (m)	Month
1883	10.05	11.05	July
1884	8.46	10.05	September
1894	8.01	10.33	July
1942	8.60	10.56	August
1944	11.84	11.32	August
1945	10.24	11.09	August
1949	8.42	10.49	September
1959	12.94	11.55	September
1968	15.50	12.08	August
1994	5.25	10.10	August-September
1998	7.00	11.40	September
2006	9.09	12.40	August



Fig 10.19 Location Map of Ukai dam, Gujarat

From Table 10.11, it can be observed that even though the frequency of floods has significantly reduced after construction of Ukai dam, the maximum water levels that the floods produce at Surat city have increased. For example, the maximum recorded flood in the river (15.50 lakhs cusecs) is the 1968 flood had caused the water to rise to a level of 12.08 m at Nehru bridge. Whereas, 2006-year flood (9.09 lakhs cusecs), in spite the discharge less than the 1968 flood, resulted in an increased level of 12.40 m at Nehru bridge and caused more fatalities. This points out the excessive silting and encroachment that have occurred in Tapi river, especially in its lower reaches, downstream of Ukai dam in its urban floodplain. This has led to reduction in the effective waterway of Tapi river, in terms of width, which has led to reduction in its carrying capacity. It is to be noted that the carrying capacity of Tapi river at Surat city just after the completion of Ukai dam was around 8 lakhs cusecs. At present, the warning level (8 m) at Surat city is attained at 3.5 lakhs cusecs only. This calls for immediate remedial measures to improve the capacity of the channel in the Surat city with due consideration of the changed morphological components of the river.

10.8.2 Hatnur dam (CH: 350 km)

Hatnur dam is an earthfill dam on Tapi river, near Bhusaval in Jalgaon District of Maharashtra, which started operating in the year 1982. The Hatnur Reservoir is located just 10 km downstream of confluence (near Changdev village) of Tapi and Purna Rivers. Previous studies reported abnormal silting in the Hatnur reservoir (Ladhe et al., 2008 and Chandra, 2016.

Reservoir Sedimentation Study was undertaken by Maharashtra Engineering Research Institute (MERI) during 2007-2008, using Differential Global Positioning System (DGPS) upto RL 212.50 m (FRL of Hatnur dam is 214.00 m). The observed rate of sedimentation in Hatnur Reservoir was 2.374 Ha.m/100 sq.km/year, which is five times the rate adopted in planning of the reservoir, i.e., 0.451 Ha.m/100 sq.km/year (Annual Research Report, MERI, 2007-2008). Their major observations are tabulated in Table 10.12.

Table 10.12 Silt accumulated in Hatnur Reservoir (Annual Research Report, MERI, 2007-2008).

Silt accumulated in Hatnur Reservoir (MCM)		
Dead zone (up to 207.70 m)	Live zone (207.70 m to 212.50 m)	Total (up to 212.50 m)
108.33	66.37	174.70

Ladhe et al. (2008) reported that the annual reservoir sedimentation rate is quite alarming in Hatnur Reservoir at 1.8%. Similar findings were also reported by Prabhat Chandra (2016), by comparing the sedimentation statistics at two stream gauging stations at Burhanpur and Yerli falling on Tapi river and Purna River respectively.

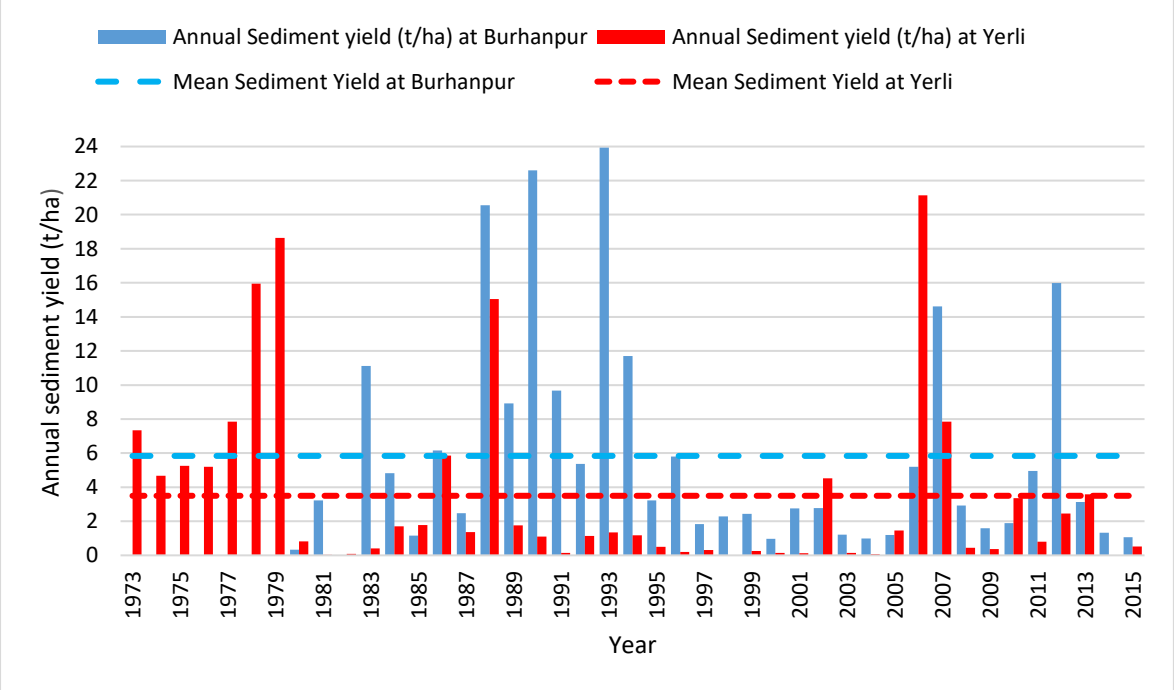


Fig 10.20 Trend of sediment yield rate (t/ha) from Burhanpur vis-à-vis Yerli sub catchments (The data for the period 1973-1979 were not available for Burhanpur)

The suspended sediment data observed at Burhanpur and Yerli stream gauging stations were used to compare the sediment yield from respective sub-catchments. Total load was computed

by considering bed load as 10% of the total suspended load. The annual sediment yield (tonnes/ha) from 1973-2015 and 1980-2015 for Yerli and Burhanpur stream gauging stations respectively, are shown in Fig 10.20.

From Fig 10.20, it is revealed that average annual sediment erosion rates from Burhanpur and Yerli sub-catchments are 5.839 t/ha and 3.98 t/ha respectively. Thus, the catchment area of Burhanpur sub-catchment has been observed to be highly eroding vis-à-vis Yerli sub-catchment.

Excessive deposited sediments into Hatnur Reservoir can be used for construction of flood protection measures along the river or other construction purposes near the structure. Appropriate measures for reservoir desilting can be devised in consultation with Tapi Irrigation Development Corporation (TIDC), Jalgaon. This may also enhance the capacity of the reservoir for longer run, and reservoir may serve the society for meeting irrigation and potable industrial requirements.

10.9 CHANNEL EVOLUTION ANALYSIS

Any river system, whether it is gravel-bed river or alluvial river, undergoes various stages of evolution as it proceeds from upstream to downstream. The rivers are categorized into three different stages according to their specific characteristics. These are youthful stage, mature stage and old stage. The youthful rivers are the most dynamically active of all the rivers. They are found at higher elevations, in mountainous and steep gradient areas. The velocity of flow is very high in such rivers. The youthful rivers can be a tributary of a larger and older river, close to the headwaters (the beginning) of that larger river. The mature rivers flow with a moderately steep slope and less velocity than the youthful rivers. Many tributaries contribute to its flow and its channel erodes wider rather than deeper. Old rivers are characterized by low gradient and low energy to erode sediments. Oxbow lakes exist within the floodplain, formed by the cutting off meanders from the main river due to extensive erosion and deposition. These lakes will eventually dry up and form meander scars, due to lack of replenishment of water.

Apart from these evolutionary stages, the process of erosion, transport and deposition of sediments occurring in different intensities as well as anthropogenic effects like construction of dams, weirs/barrages, bridges etc. also determine the evolution of the river. The evolutionary stage of Tapi river, in its Upper, Middle and Lower reaches with respect to the drainage network

(Fig 4.2), landforms that have formed in and along the river, river bed material, stream power at various locations and the course that river follows is discussed in the subsequent paragraphs.

10.9.1 Upper Tapi river

The Upper Tapi river which marks its beginning at Tapi Kund situated in Multai, Madhya Pradesh traverses approximately 350 km until it drains into Hatnur Reservoir in Maharashtra. The longitudinal bed profile of Upper Tapi river is given in Fig 10.22. Starting from Tapi Kund (elevation: 756 m), the river travels through uneven rocky bed stratum for about 35 km before entering the Tapi Gorge located in Dhanori (elevation: 584 m), Madhya Pradesh (Fig 10.21).



Fig 10.21 Upper Tapi river from Tapi Kund to Dhanori

The Tapi Gorge extends from Dhanori, Madhya Pradesh to Ratamati (Elevation: 458 m), Madhya Pradesh. During this course, the river traverses through narrow, deep and sinuous reaches till Teska. Here, the bed and banks are covered with basaltic deposits. Thereafter till Ratamati, the river follows almost straight course, and then enters alluvial reaches (Fig 10.24). In the alluvial reaches, it can be observed that the river follows straight course almost everywhere and forms occasional sinuous path (Fig 10.23). Until the river enters the alluvial reaches (Fig 10.24), a proper flood plain doesn't exist, and the river travels through confined bedrock reaches only. The cross-sections of Upper Tapi river (based on surveyed data of year 2015) at Taikheda (CH: 11.42 km) which falls in the undulating rocky bed stratum reach; Mendha (CH: 75.08 km) which falls in the Upper Tapi Gorge portion and Burhanpur (CH:

312.17 km) and Changdev (CH: 345.45 km), which falls in the alluvial reaches of Upper Tapi river are shown in Fig 10.25.

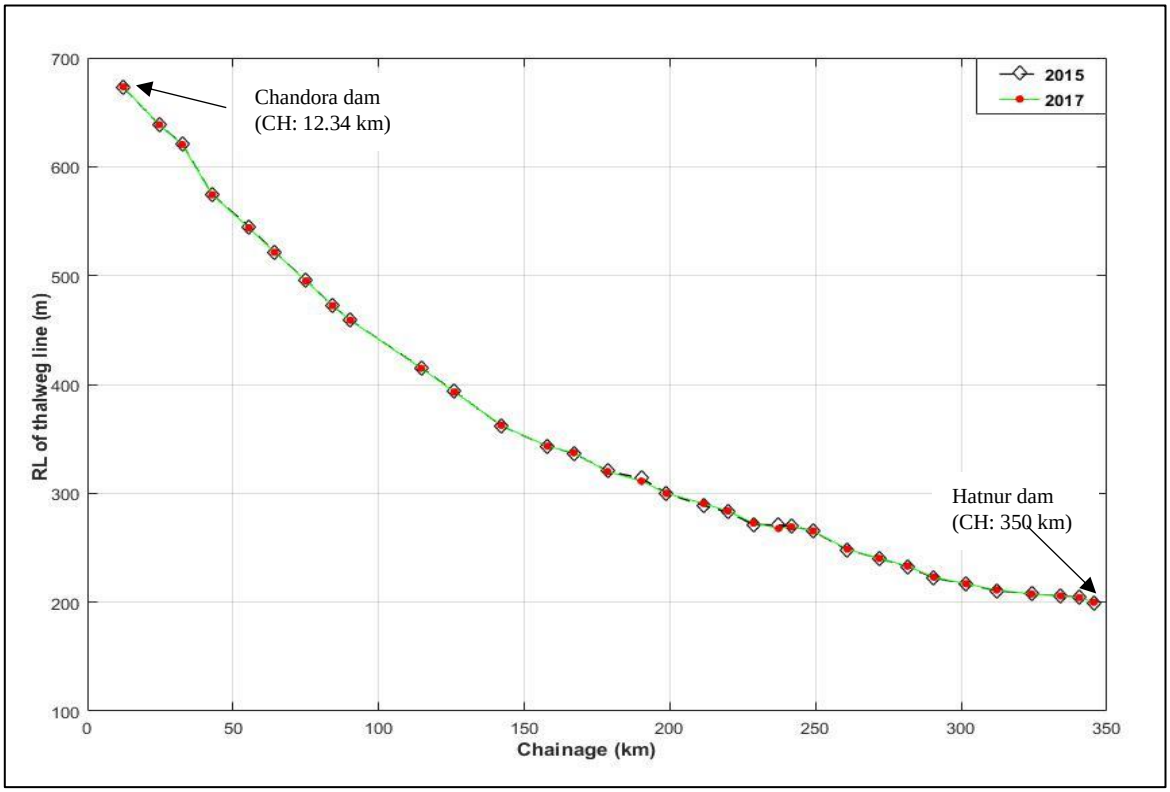


Fig 10.22 Longitudinal bed profile of Upper Tapi river

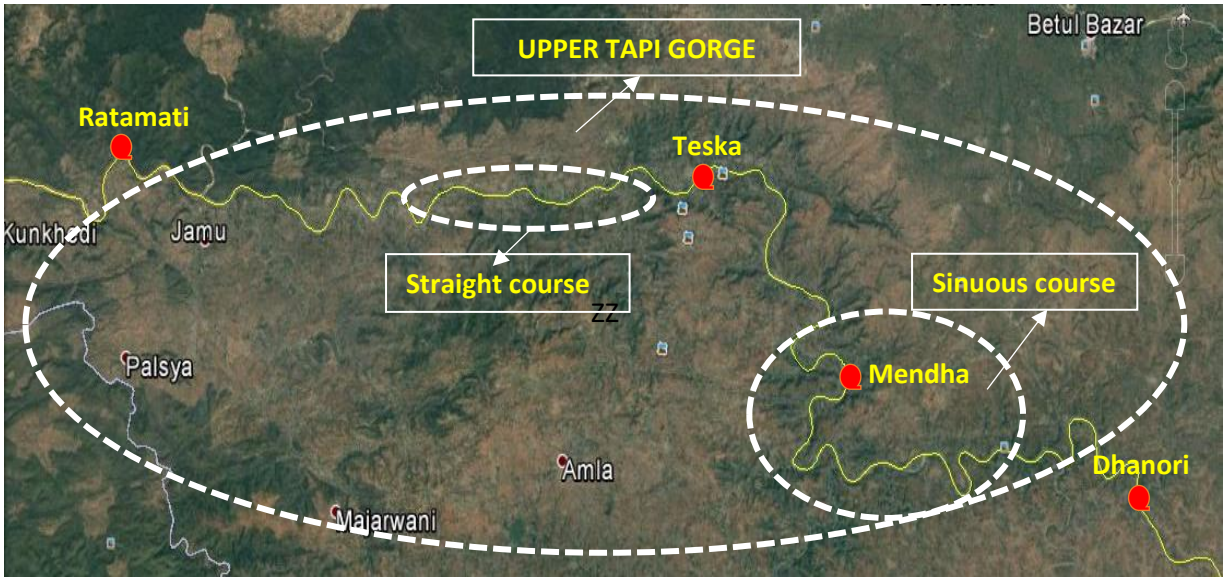


Fig 10.23 Upper Tapi Gorge (Dhanori to Ratamati)

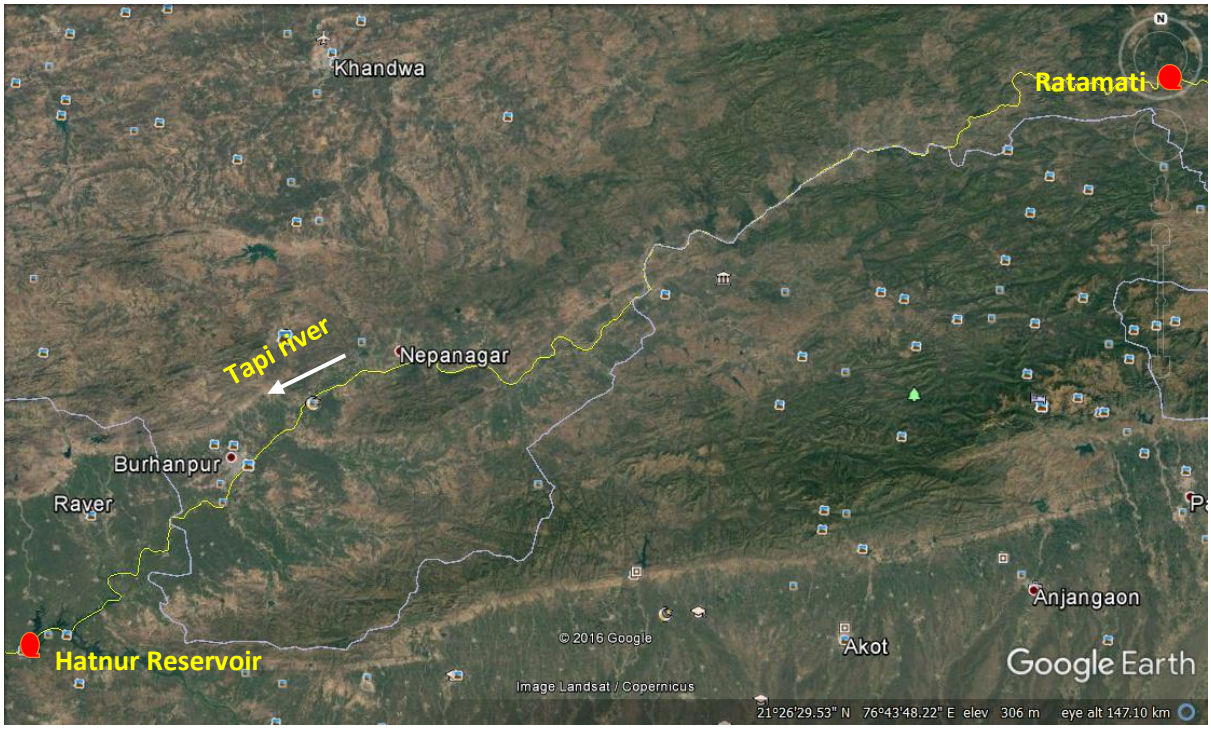


Fig 10.24 Alluvial reach in Upper Tapi river (Ratamati-Hatnur Reservoir)

The drainage network of Upper Tapi Sub-basin is depicted in Fig 4.2. It can be observed that Tapi river originates as a first order stream and along its course, various tributaries make their confluence with it. The maximum order of Tapi river is **four** in Upper Tapi Sub-basin. The drainage pattern is not well developed in the Upper Reaches, and the number of streams is also less. More than the drainage network of Tapi river, the drainage network of Purna River, a major tributary of Tapi river are observed to be well developed. Also, during the years 2001 to 2010, the stream power generated varies from 35.19 W/m^2 to 216.4 W/m^2 at various locations in Upper Tapi river (Table 10.9). This high energy along with the low width/depth ratios that prevail in the upper reaches is an indication that the Tapi river in its upper reaches is still in its youthful stage, flowing with high depth, low width and high velocity. The decadal variation in channel cross-section at Dedtalai and Burhanpur stream gauging stations were analysed for both pre-monsoon and post-monsoon periods. Also, the cross-section before and after flood have been analysed and the major changes, if any, have been reported. From Fig 10.26, it can be observed that no major changes have occurred in the cross sections during neither pre-monsoon nor post-monsoon period in Dedtalai and Burhanpur stream gauging stations. Dedtalai stream gauging station is characterized by the presence of basaltic bed rock, and the cross-section is box shaped, whereas Burhanpur has alluvial bed materials and is characterized by the presence of U-shaped cross-section.

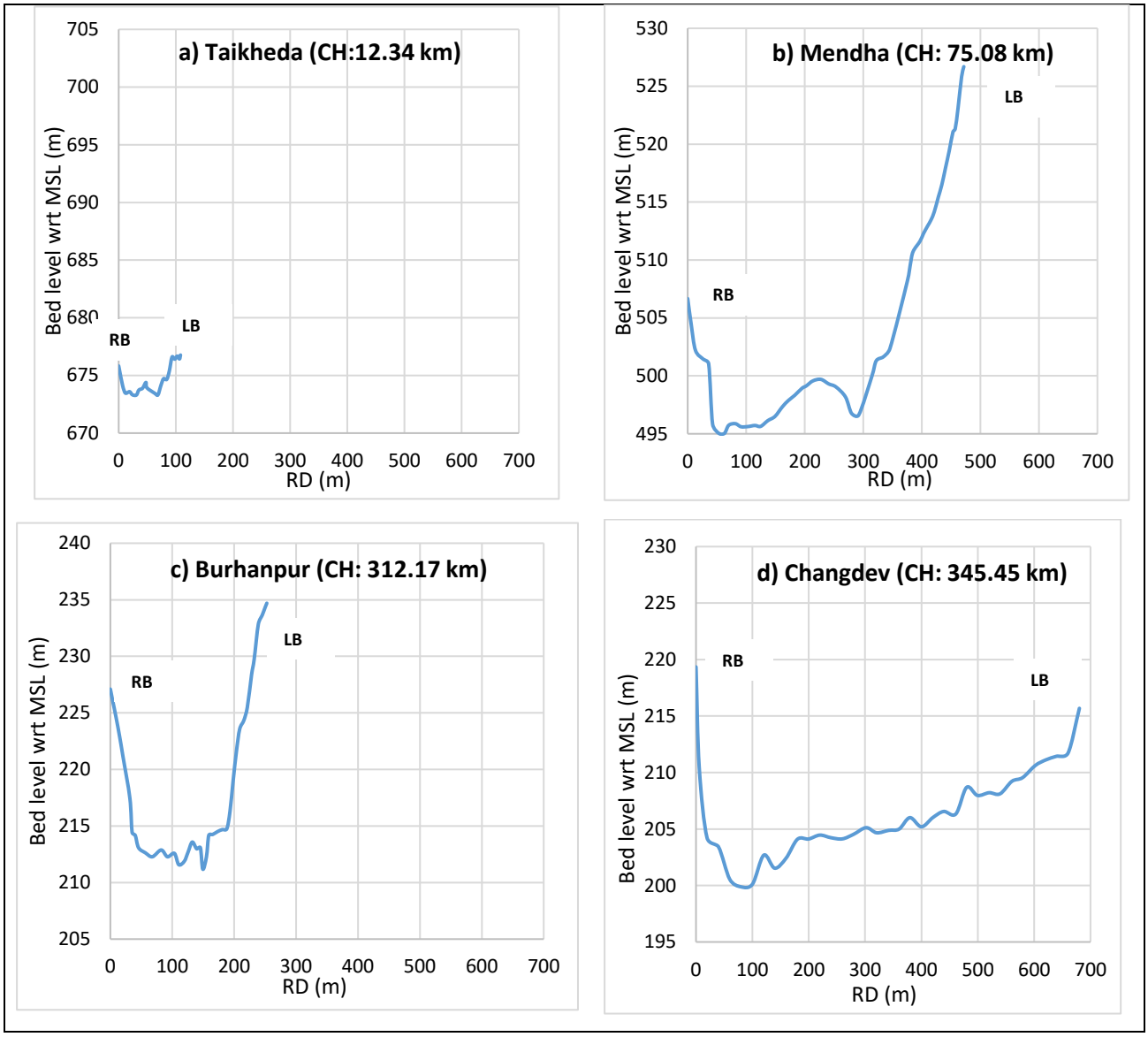
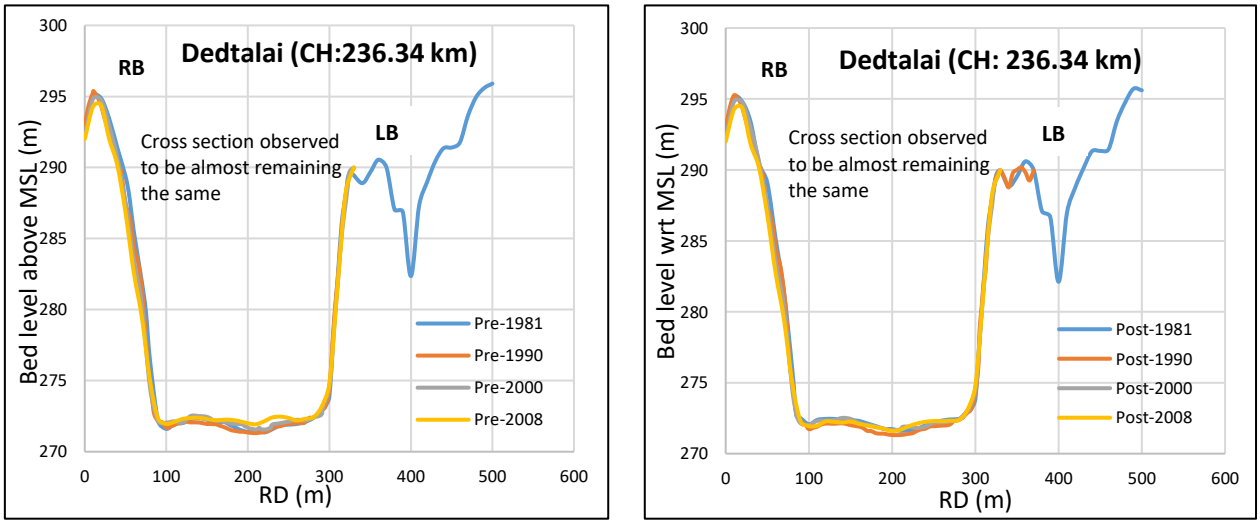


Fig 10.25 Cross sections of Upper Tapi river at various locations; a) Taikheda; b) Mendha; c) Burhanpur and d) Changdev (based on surveyed data of year 2015)



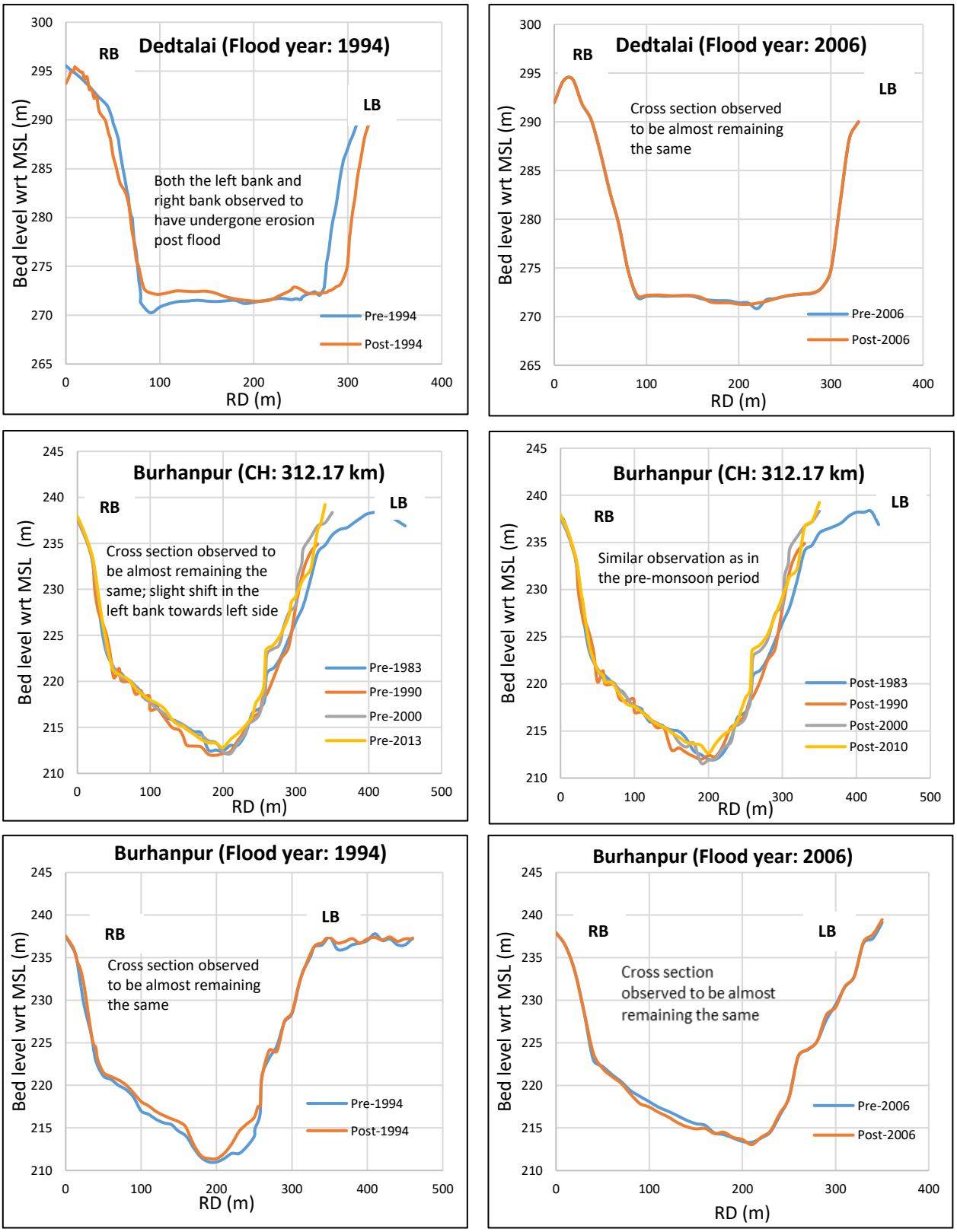


Fig 10.26 Variation in cross-sections at stream gauging stations of Upper Tapi river

The analysis of cross-sections before and after the occurrence of floods in years 1994 and 2006 reveals that the cross-sections of the Upper Tapi river have not majorly been altered, except at

Dedtalai stream gauging station in 1994 (Fig 10.26). Both the right bank and left bank of the river were observed to get eroded during flood of 1994 at Dedtalai. It is worth noting that the highest stream power at Dedtalai during flood of year 1994 was 299.31 W/m^2 which might have altered the cross-section.

Fig 10.22 depicts the longitudinal profile of Upper Tapi river, which shows the variations in the reduced level (RL) of thalweg line of various cross-sections in Upper Tapi river for the years 2015 and 2017. Thirty-three cross-sections were available along the Upper Tapi river starting from Taikheda village (CH: 12.34 km) to Changdev village (CH: 345.45 km). It can be observed that no major changes have occurred in the elevation, and the thalweg line is almost constant during the said period. This can be attributed to the rocky bed materials which are present in most of cross-sections that fall in the Upper Tapi river.

10.9.2 Middle Tapi river

The Middle Tapi river extends from Hatnur dam till it drains into the Ukai Reservoir. The river passes through alluvial reaches in well-defined flood plains. The longitudinal bed profile of Middle Tapi river is given in Fig 10.27. From Fig 4.2, it can be seen that the tributary system of Tapi river is well developed in its middle reaches. Many principal tributaries of Tapi river like Girna River, Gomai River, Bori River and Panjhra River join Tapi river in its middle reaches. A well-developed dendritic drainage pattern can be seen in the Middle-Tapi Sub-basin where the stream order of the Tapi river comes out as **five**, the highest order observed in the catchment. The river flows with high velocity, but still less when compared to Upper Tapi river, producing moderate stream powers ranging from 16.07 W/m^2 to 133.62 W/m^2 (observed at Sarangkheda during 2001-2010; Refer Table 10.10) which are capable of moving particles of the order of cobbles and small boulders. Middle Tapi river shows a transition state from youthful stage to mature stage of the river as it progresses along its course, by formation of multiple channels (braids) owing to sudden change in slope from steep to mild, and meandering bends with less curvature. The braided channel formation between Vagdud (CH: 368.65 km) and Bhusawal (CH: 376.39 km) is shown in Fig 10.28. The river cross-sections at Gidhade and Bhusawal based on surveyed data of year 2015 are shown in Fig 10.29.

Fig 10.30 shows the nature of pre-monsoonal, post-monsoonal and before-after flood (year 1994 and 2006) cross-sectional geometries at Sarangkheda stream gauging station which falls

along Middle Tapi river. It can be observed that, post monsoon of year 1979, the river cross-section adjacent to the left bank got eroded. However, the river cross-sections were maintained as original cross-sections in subsequent years. Post flood of the year 2006, the right bank is observed to get eroded slightly. A rise in river bed level has been observed both after the floods of 1994 and 2006. The variation in RL of thalweg line of eighteen cross-sections in Middle Tapi river are presented in Fig 10.27. In contrast to the observations in Upper Tapi river, Middle Tapi river exhibits local aggradation between certain locations. These include, the river reach between Kanasvadi village (CH: 394.58) km and Dharadi village (CH: 414.43 km) and the river reach between Nim village (CH: 473.97 km) and Nevada village (CH: 506.38 km). The former site which is located just upstream of Shelgaon barrage (CH: 396 km) exhibiting a rise in bed level of the order of 1.5 m and the latter site, located just upstream of Sulwade barrage (CH: 496.68 km), exhibiting bed level rise of the order of 3 m. Also, at Sarangkheda (CH: 537.9 km), local scouring of the order of 2.5 m has been observed during 2015-2017. The site is located approximately 0.12 km downstream of Sarangkheda barrage.

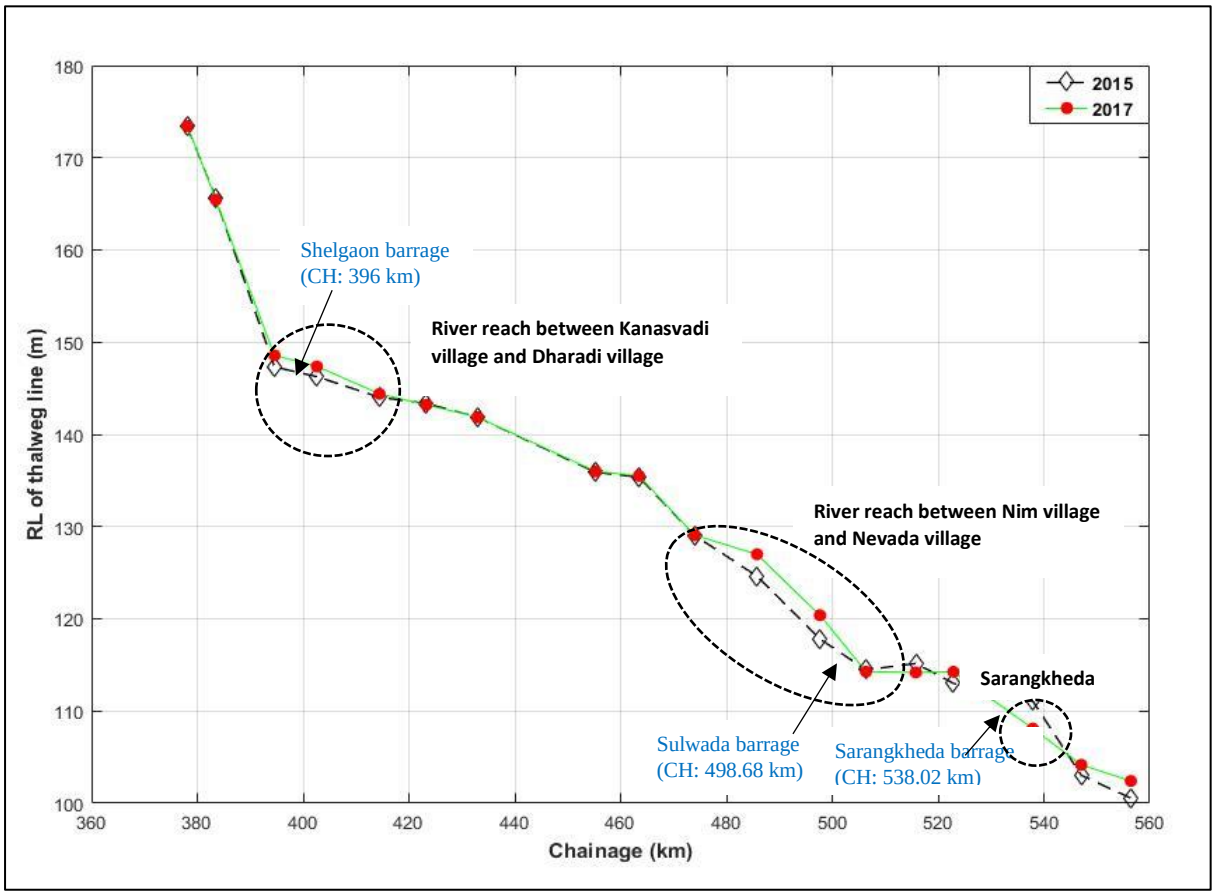


Fig 10.27 Longitudinal bed profile of Middle Tapi river

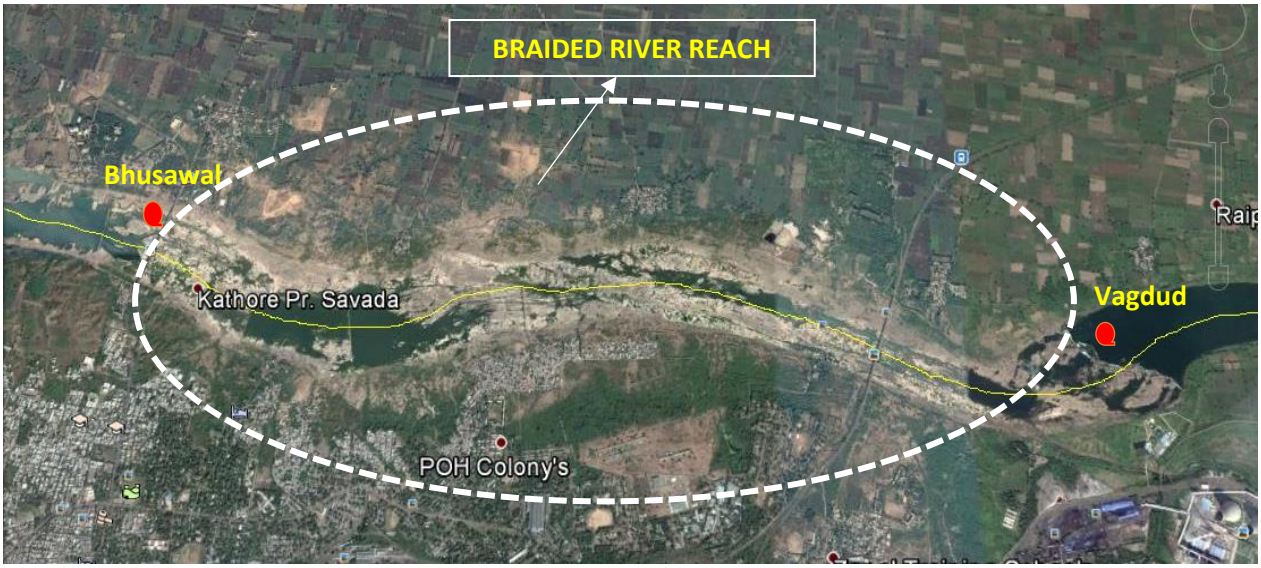


Fig 10.28 Braided reach between Vagdud and Bhusawal in Middle Tapi river

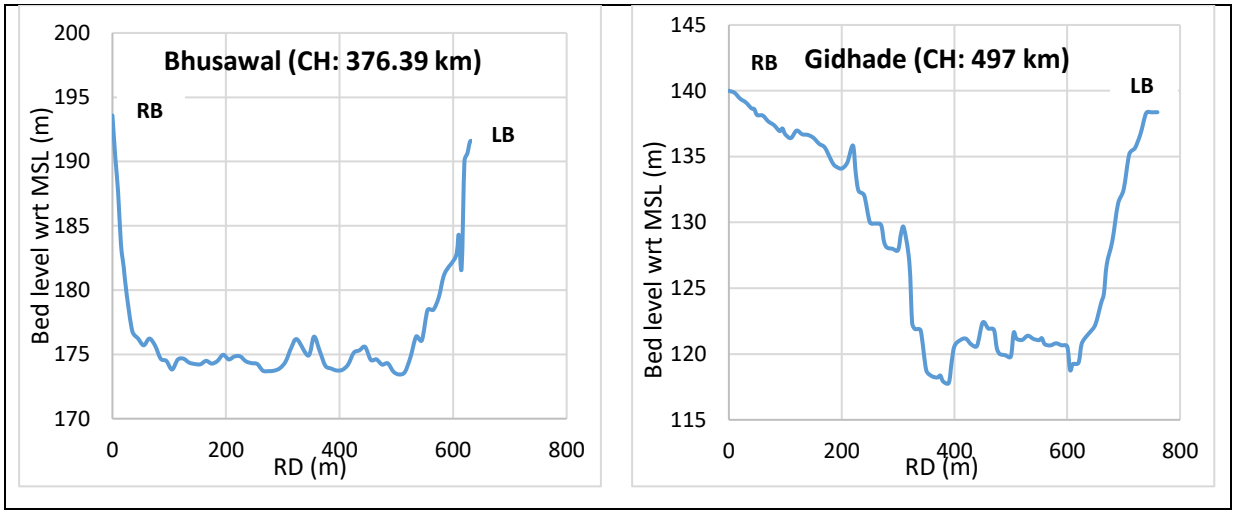
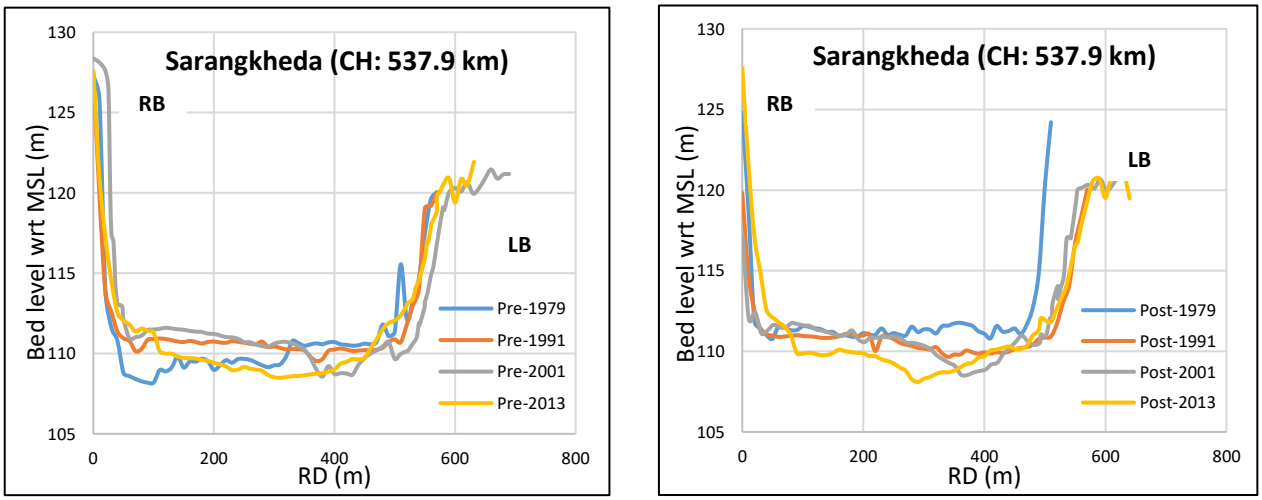


Fig 10.29 Cross-section of Middle Tapi river at Gidhade and Bhusawal
(Based on surveyed data of year 2015)



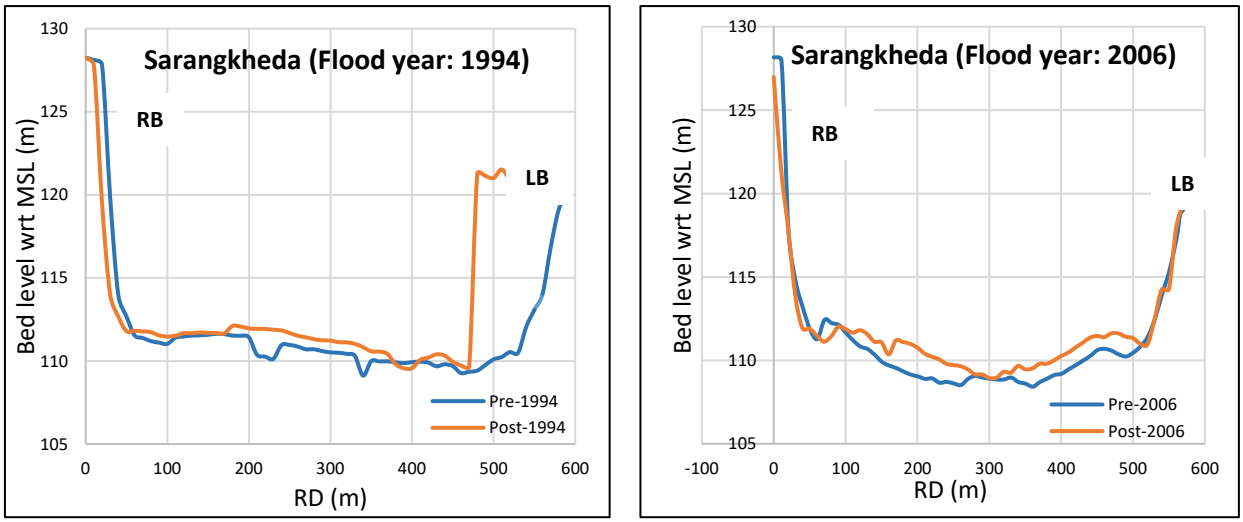


Fig 10.30 Variation in cross-sections at stream gauging stations of Middle Tapi river

10.9.3 Lower Tapi river

As the Tapi river enters its lower reaches, the width of the river considerably increases, and wide alluvial flood plains are developed. The longitudinal bed profile of Lower Tapi river is given in Fig 10.31. The river bed material is finer in nature and is mainly composed of silty clay and sand.

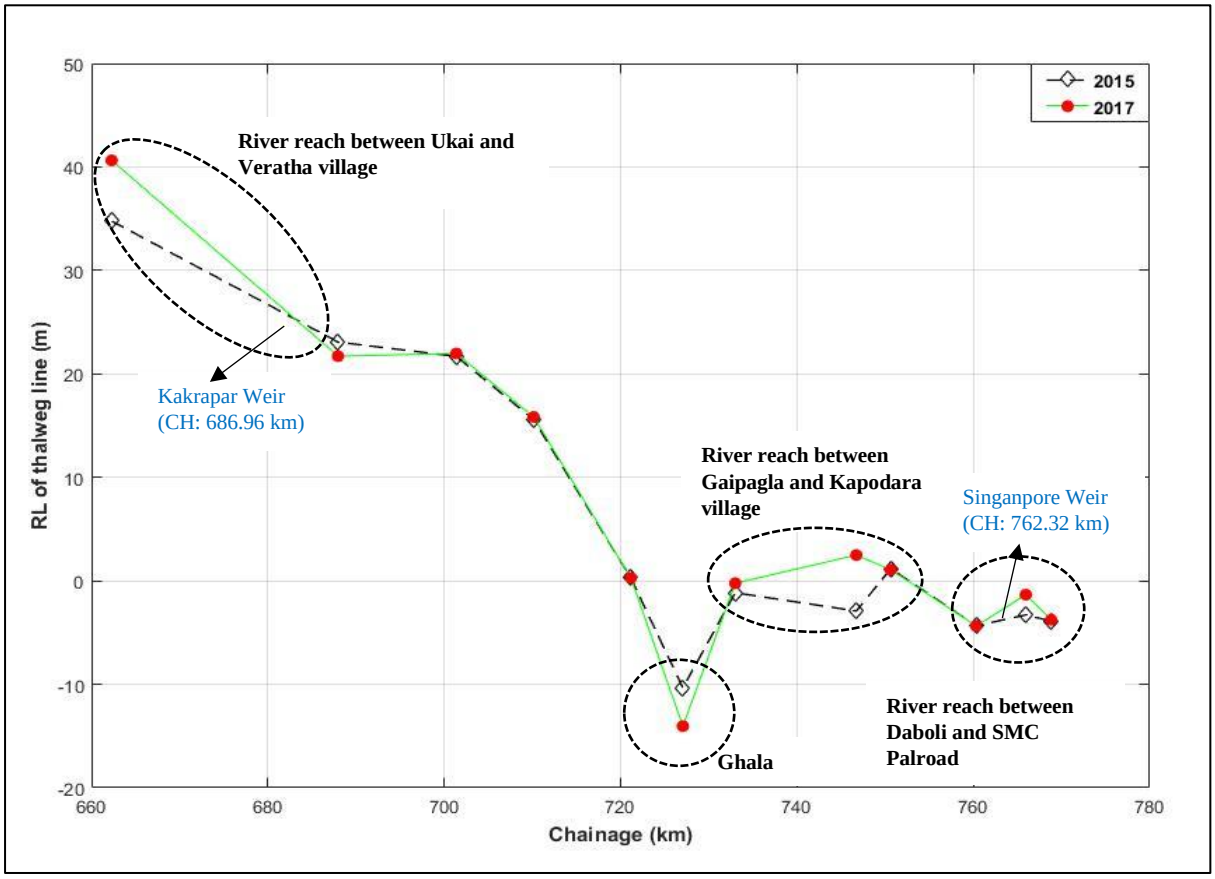


Fig 10.31 Longitudinal bed profile of Lower Tapi river

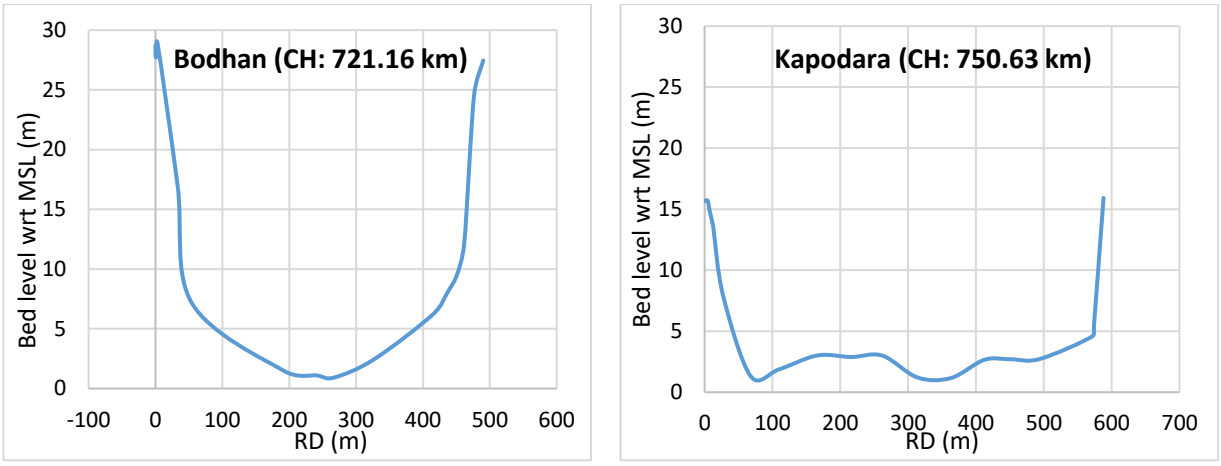


Fig 10.32 Cross-section of Lower Tapi river at Bodhan and Kapodara
(Based on surveyed data of year 2015)

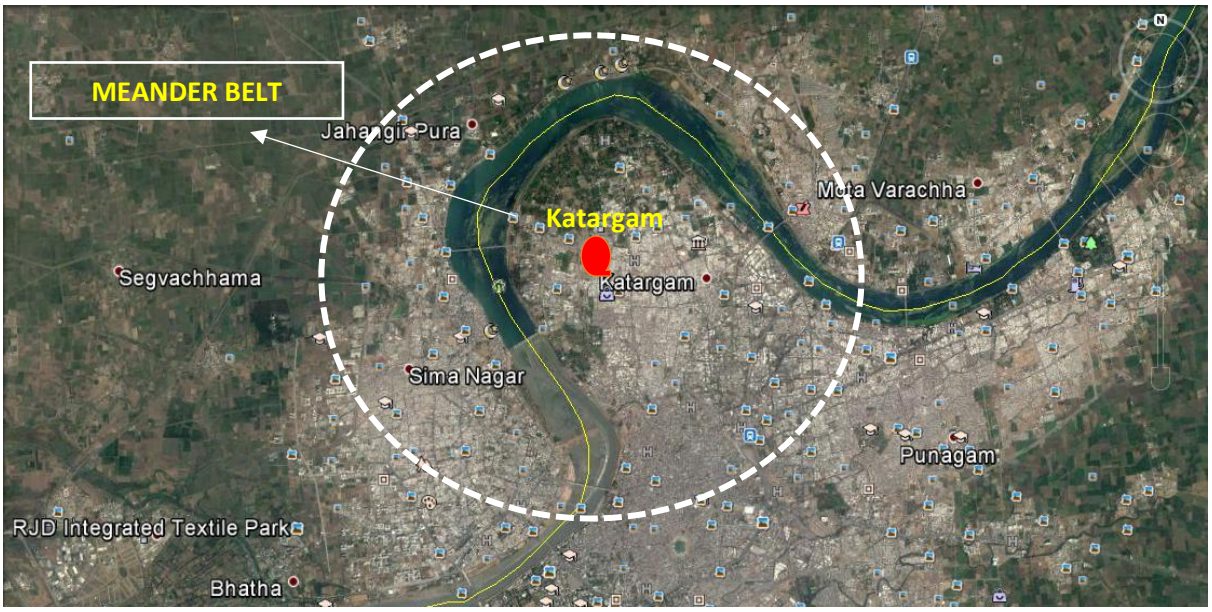
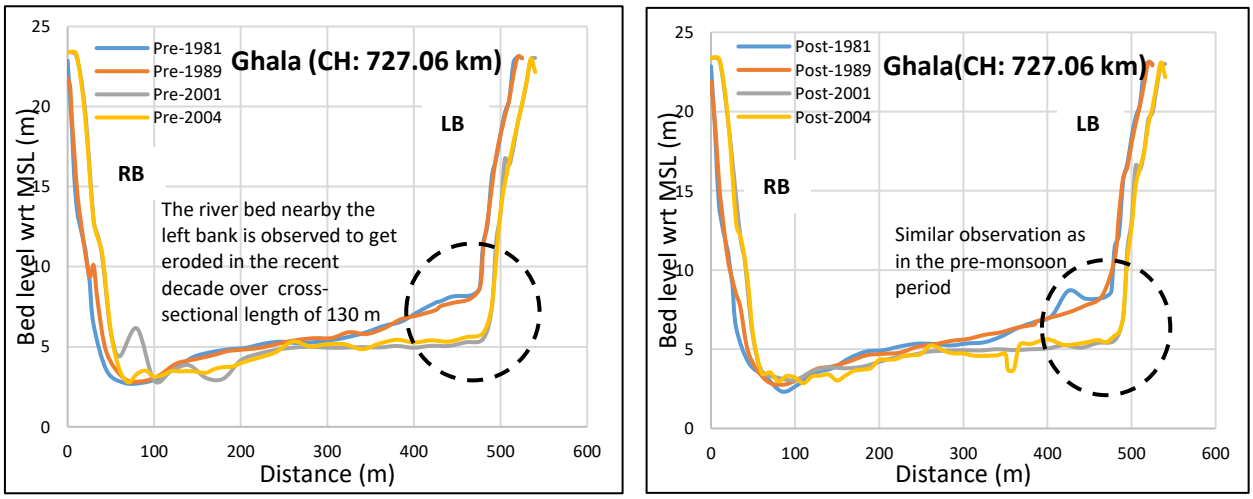


Fig 10.33 Lower Tapi river meander belt in Katargam, Gujarat



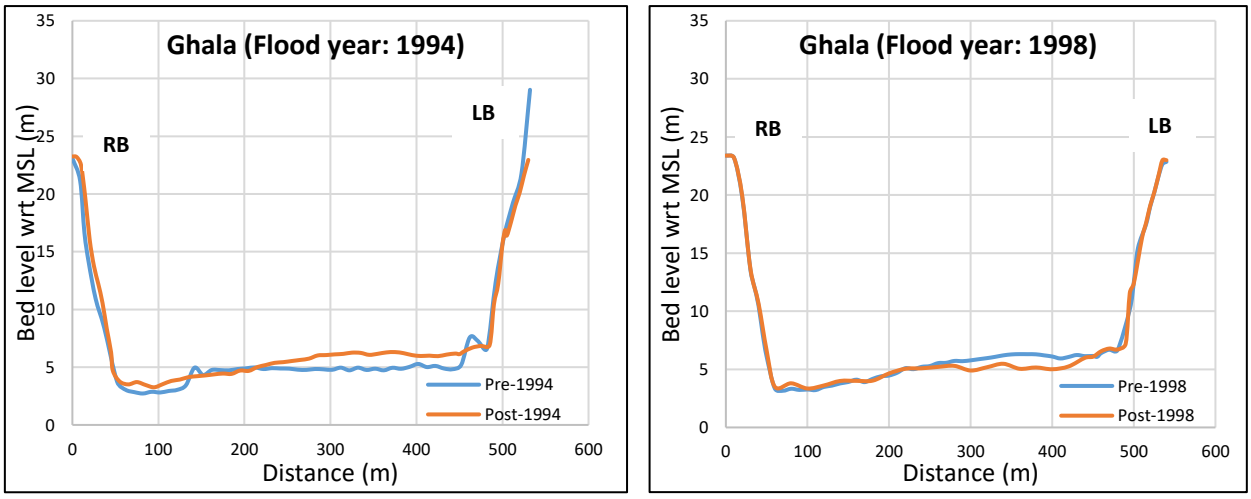


Fig 10.34 Variation in cross-sections at stream gauging stations of Lower Tapi river

The river reach of length around 120 km, extending from Ukai dam to Arabian Sea, is characterized by the presence of well-defined U-shaped cross-sections (Fig 10.32). The large meander bends (Fig 10.33) and huge siltation was observed in river bed in Surat City owing to the deposition of sediments due to the presence of Tapi Estuary and existence of Singanpore Weir (Fig 10.12). Here, the river bed levels are very low compared to Upper and Middle Tapi river reaches. The river floods are frequent in monsoon period owing to water spreading out of the banks quickly. The drainage network of Lower Tapi river shows that no major tributaries join the river in its lower reaches (Fig 4.2).

While analysing the variation in cross-sectional geometry of Ghala stream gauging station that falls in Lower Tapi river, it is observed that the river bed adjacent to the left bank has undergone local scouring, during 1989-2004, over a length of 130 m (Fig 10.34). Such erosion at Ghala stream gauging station could be due to extensive sand mining activities, prevalent near the station. While plotting the variation of RL of thalweg line of the twelve available cross-sections of Lower Tapi river during 2015-2017 (Fig 10.31), it is seen that, between Ukai (CH: 662.28 km) and Veratha village (CH: 687.96 km) a rise in bed level has occurred. This phenomenon has been observed upstream of Kakrapar Weir for a length of around 20 km (downstream of Ukai dam). Similar rise in bed level is also observed between Gaipagla (CH: 733 km) and Kapodara village (CH: 750.63 km) (upstream of Singanpore weir) and between Dabholi village (CH: 760.32 km) and SMC Pal Road (CH: 768.82 km) (downstream of Singanpore weir). The aggradation in upstream of Singanpore weir is due to afflux created from the reservoir and the aggradation reported downstream of Singanpore weir is due to bringing of huge sediments

through tidal currents from the Arabian Sea. In contrast to these observations, a fall in bed level by about 5 m is observed at Ghala village (CH: 727.06 km). This may be the effect of extensive sand mining activities that prevail here. Excessive sediments aggraded/deposited in upstream/downstream of Singanpore Weir (Fig 10.31) can be desilted, in consultation with Surat Municipal Corporation (SMC) and Narmada, Water Resources, Water Supply and Kalpsar Department, Government of Gujarat, for using the same in construction of levees along the river, and other constructional activities in the Surat city and adjoining areas.

10.9.4 Variation of Bed Level in Lower Tapi river from Ghala stream gauging station to Arabian Sea

The Tapi river has an average bed slope of 0.10 % and carrying annually sediment load of 25x 10^6 t/yr (Kale, 2005). It is observed that part of Lower Tapi river for about 75 km from Ukai dam, consist of rocky river bed. The section of the Tapi river between Kholwad to Ghala has widely been used for dredging of sand for the construction purposes. Fig 10.35 shows the thalweg lines for years 2007 and 2009 of the Tapi river from Singanpore weir to Ghala village. It is observed the bed level at various point in year 2009 were higher than the bed level observed in year 2007. The decrease in bed level at Ghala village is observed during 2009 vis-a-vis during 2007. This may be due to possible sand mining in the river bed. Fig 10.36 shows the thalweg line for years 2007 and 2009 from Singanpore weir to the Sea. It is observed that bed level at various point in year 2009 were higher than the bed level observed in year 2007 in the downstream of Singanpore weir. The aggradation in downstream of Singanpore weir may be due to possible effect of tidal currents downstream of Singanpore weir. The tidal currents bring huge sediments with them, and drop down in the downstream of Singanpore weir. The tidal water affects up to Singanpore weir at the tail of the lower Tapi river. Before construction of Singanpore weir in 1995, the tidal current used to travel about 50 km upstream of the river mouth.

The contours of Lower Tapi river at 1m interval for the years 2007 and 2009 were used to generate the Digital Elevation Model (DEM) and the volume of water corresponding to an elevation of 5.5 m was obtained between Singanpore Weir to Ghala stream gauging station and ONGC bridge site to Singanpore Weir respectively using ArcGIS 10.4©. From Table 10.13, it can be observed that there has been a reduction in volume of water from 69.80 MCM to 55.00 MCM during 2007-2009 between Singapore weir and Ghala stream gauging station and from

75.80 MCM to 55.08 MCM during 2007-2009 between ONGC bridge site and Singanpore Weir. This reduction in volume of water can be attributed to the reduction in carrying capacity of Lower Tapi river, due to huge sedimentation upstream and downstream of Singanpore weir. The excessive sedimentation upstream of Singanpore weir is responsible for reduction in the volume of potable water in the reservoir and possibility of more flooding due to the reduction in carrying capacity of the channel.

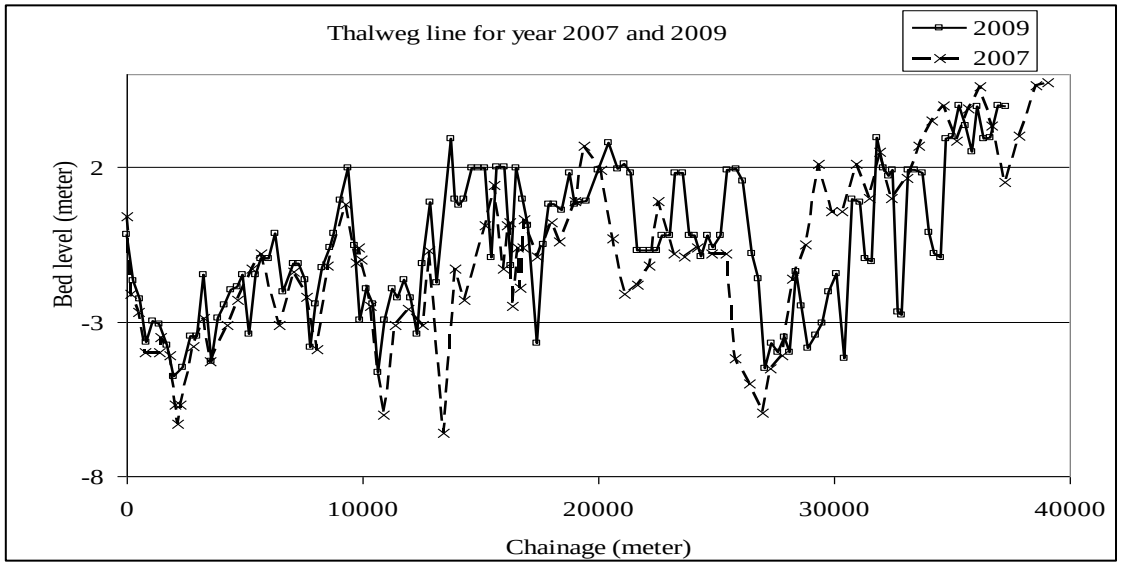


Fig 10.35 Variation of Thalweg line of Lower Tapi river from Singanpore weir to Ghala (Here zero chainage is taken at Singanpore weir and measuring upstream to Ghala stream gauging station)

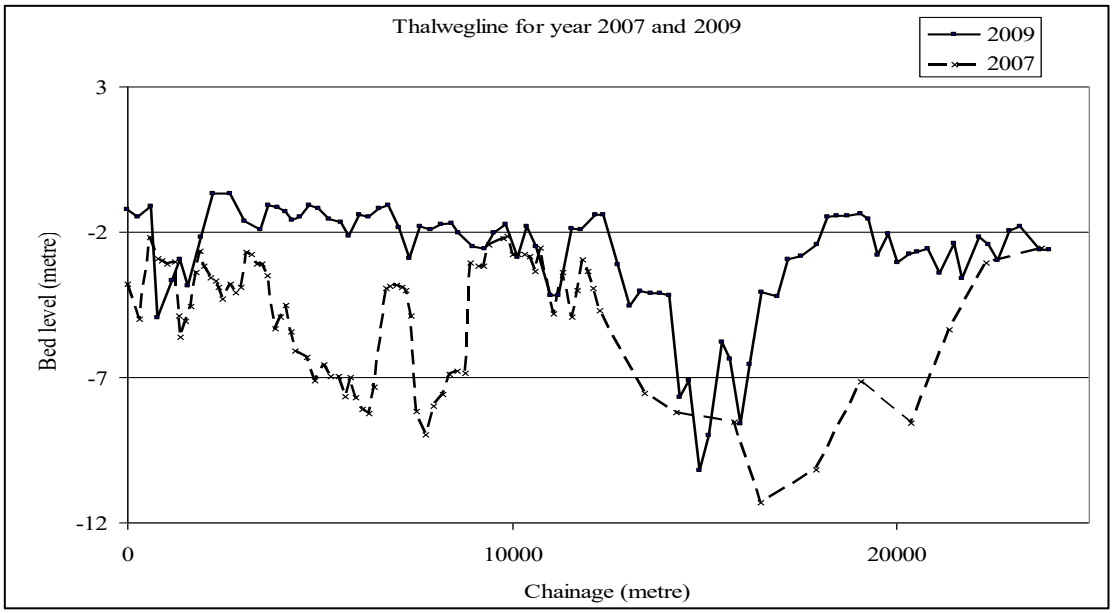


Fig 10.36 Variation of Thalweg line in Lower Tapi river from Singanpore Weir to Arabian Sea (Here zero chainage is taken at Singanpore weir and measuring downstream to the Arabian Sea)

Table 10.13 Reduction in volume of water during 2007-09 in Lower Tapi river reaches

River Reach	Volume of water in 2007	Volume of water in 2009
Between Singanpore Weir and Ghala stream gauging station	69.80	55.00
Between ONGC bridge site and Singanpore Weir	75.80	55.08

10.10 WATER QUALITY AND IMPAIRED STREAM ANALYSIS

10.10.1 Water Quality

The data on water quality parameters, measured at four different stations on a systematic sampling schedule (One per month), were obtained from Central Water Commission (CWC). The water samples are being collected as per APHA [American Public Health Association] guideline by the Central Water Commission. As mentioned in Chapter 5, Para. 5.1, the Water quality data, i.e., physical parameters (discharge, colour, total suspended solids, total dissolved solids, turbidity etc.), chemical parameters (Calcium, Magnesium, Sodium, Potassium, Sulphate, Nitrate, Nitrite etc.), biological parameters (BOD and dissolved Oxygen), Aluminium trace, and chemical indices like total hardness and Calcium hardness were obtained for Gopalkheda, Burhanpur, Sarangkheda and Ghala for a period of 1990-2013 from Central Water Commission, and data regarding the same for Ukai, Surat and Kakrapar were collected for the period of 1999-2015 from State Water Data Centre (SWDC), Govt. of Gujarat.

10.10.2 Trend in Water Quality Parameter

The water quality at Burhanpur, Sarangkheda and Ghala are analysed for the trend of different water quality parameters tabulated in Table 10.14, were along the Tapi river. The water quality data usually exhibit characteristic like non-normal distribution, presence of outliers, missing values and serial correlation. To minimize the effect of missing data, value of a particular month was filled using the average value of three-year data of same month. The parameter values are arranged in format of month wise yearly data.

Table 10.14 Water quality parameters analysed at different station.

Sr. No.	Classes	Parameter*
1	Organoleptic and Physical Parameter	pH
		Total Dissolved Solid (TDS)
		Turbidity
2	Chemical Parameter	Aluminium (Al)

		Ammonia (NH_3-N)
		Chloride (Cl)
		Fluoride (F)
		Calcium (Ca)
		Magnesium (Mg)
		Nitrate (NO_3-N)
		Sulphate (SO_4)
3	Biological Parameter	Biological Oxygen Demand (BOD)
		Dissolved Oxygen (DO)
4	Chemical Indices	Total Hardness

* **All parameters except pH and Turbidity are in ppm. The Tubidity unit is NTU (Nephelometric Tubidity Unit).**

The Mann-Kendall Test (Yue et al., 2002) was employed for trend analysis of the above water quality parameters. The results of the analysis is summarized below with probable reason:

1) The consumption of Nitrogen-Phosphorus-Potassium (NPK) fertilizers have reasonably increased in the recent decades. This leads to the subsequent increase in the Nitrate content of the Tapi river. During summer season, the observed flows at Burhanpur and Gopalkheda are very low. The high nitrate content and low flow in the river results in increased eutrophication rate during summer season (Csaba and Csaba, 2011). As the rate of eutrophication increases, growth of Algae and other aquatic plants also increases. This results in an increased Oxygen demand during the summer season. This has been verified by the trend calculated for Biological Oxygen Demand (BOD) for the summer season.
2) As per the details provided in Water Resources Informative System (WRIS) of India by CWC, soil type near Gopalkheda and Burhanpur is Medium black soils, which contain high lime reserve. In monsoon season, runoff passes through this soil type shows an increasing trend in Calcium, total Hardness and Magnesium content at Burhanpur and Gopalkheda respectively.
3) The anaerobic bacteria are the ones that do not require Oxygen for their growth. Their growth rate gets enhanced in the wet soil condition. They are sulphate reducing bacteria, and reduce sulphate ions into sulphide ions as per Eq 10.1

$$\boldsymbol{SO_4^{2-} + 4H_2 \longrightarrow S^{2-} + 4H_2O} \qquad \mathbf{10.1}$$

Because of these phenomena, sulphate ion shows decreasing trend in most of months at Burhanpur, Gopalkheda and Sarangkheda stations.

4) During photosynthesis, the dissolved Carbon dioxide is used up by aquatic plants. The removal of Carbon Dioxide reduces the acidity of water, as the dissolved Carbon Dioxide is in the form of carbonic acid (H_2CO_3) (Michaud, 1991). Hence, pH shows an increasing trend in January, February, March and April at Burhanpur, Gopalkheda and Sarangkheda stations. The BOD shows increasing trend in May, June and July at Burhanpur due to eutrophication. Aquatic plants use Phosphorus for their growth. Solubility of Phosphorus increases with decreases in pH value (Moore, 1989). Hence, pH shows decreasing trend in May, June and July at Burhanpur station.
5) Overall, the water quality of the above stations is observed within the prescribed criteria. As the grading of the water quality done by CPCB. According to Central Pollution Control Board (CPCB), 'C' grade water is good for drinking after its treatment. The 'D' grade water is good and suitable for wildlife and fisheries. 'E' grade water is inferior for all but, can be used for irrigation and in industries. The Tapi river water was categories as 'C' grade.

10.10.3 Impaired Stream Analysis

The Surat city, fall on the flood plain of lower Tapi rivers, is a major city with huge population. The natural processes such as surface runoff from urban catchments, erosion as well as anthropogenic influences, viz., urban development and expansion, industrial practices, municipal and industrial wastewater discharge and agricultural practices, together may further deteriorate the water quality in the river in urban centres. To study the spatial-temporal variation in water quality of the Tapi river near to the Surat city, the impaired stream analysis has been carried. The impaired stream analysis has been carried out by cluster analysis technique which demonstrate the spatial and temporal variations caused by natural and anthropogenic factors, and linked to seasonality (Vega et al., 1998; Reisenhofer et al., 1998; Helena et al., 2000).

10.10.4 Data Used

In the present study, the water quality data for nine sites, namely Mandvi (Site-1), KAPP bridge (Site-2), Kathor N.H. 8 (Site-3), Varachha (Site-4), Rander (Site-5), Weir cum Causeway (Site-6), Swami Vivekanand bridge (Site-7), Sardar bridge (Site-8) and ONGC bridge (Site-9) were collected from Gujarat Pollution Control Board (GPCB). The sites 1 to 3 are in the relatively unimpaired region (RUR) and upstream of Surat city. Sites 4 to 9 are in the relatively impaired region (RIR) out of which sites (4 to 8) are located along Surat city, and site-9 is located

downstream of Surat. In the present study, 19 water quality parameters were selected for analysis at all stations for the period of January 2013 to August 2016. Table 10.15 shows the parameters and their respective mean values at different sites.

10.10.5 Methodology

In the present study, spatial variation of water quality data is analysed by Multivariate Statistical methods cluster analysis (CA), factor analysis/principal component analysis (FA/PCA) (Wunderlin et al., 2001; Simeonov et al., 2003).

10.10.6 Results and Discussions

The Cluster Analysis rendered a dendogram (shown in Fig 10.37) where all the nine sites on the river were grouped into two statistically significant cluster at (Dlink/Dmax)*100 < 40. The clustering process produce two clusters or group of sites as sites in these groups have similar characteristic feature and natural background source. Cluster 1 (sites 1-6) and Cluster 2 (sites 7-9) correspond to a Relatively Unimpaired Region (RUR) and Relatively Impaired Region (RIR) respectively. It can be observed that in the downstream reaches of Lower Tapi river, the water quality is getting deteriorated. At sites 7 (Swami Vivekanand bridge), 8 (Sardar bridge) and 9 (ONGC bridge), the dissolved oxygen content is much less than the sites upstream. On the contrary, the parameters like alkalinity, Calcium content, Chloride content, total hardness, total suspended solids, sulphide content etc. show a tremendous increase as the Tapi river passes through the aforesaid sites (Table 10.15). These observations point fingers towards the reduction in the quality of water within the limits of Surat city, and necessitates the initiative towards treating the water and controlling the industrial and household effluents being dumped into the river.

Moreover, Surat Municipal Corporation (SMC) is having eight intake wells with total capacity of 2280 MLD between site 3 to 6 as tabulated in Table 10.16 SMC severs about 1150 MLD water to the citizen of the city with 96% area covered with pipe line network. Although, the Tapi river water was categorised as C grade, water quality of the river has deteriorated to D and E grades within the city limits (TOI Report, 2017). Also, on the upstream of the Singapore weir, thick mat of water hyacinth has substantially depleted DO, which may be responsible for the presence of the odour in water. To manage it, SMC has decided to put aerator in Tapi river between near to site 4 to 6 to increase the quantity of DO (TOI Report, 2017).

Table 10.15 Water quality parameters with mean value at the different sites

Parameters	Mandvi (Site-1)	KAPP bridge (Site-2)	Kathor NH 8 (Site-3)	Varachha (Site-4)	Rander (Site-5)	Weir cum Causeway (Site-6)	Swami Vivekanand bridge (Site-7)	Sardar bridge (Site-8)	ONGC bridge (Site-9)
Alkaline (ppm)	159.8	157.7	159.1	169.7	170.0	164.2	247.8	248.5	303.0
BOD (ppm)	0.99	0.89	1.12	1.15	1.17	1.13	2.19	2.36	2.91
Calcium (ppm)	33.7	32.1	38.0	36.9	38.3	35.7	610.2	723.1	801.1
Chloride (ppm)	53.2	52.7	64.2	67.1	67.5	64.9	4270.2	4617.2	8913.5
COD (ppm)	8.6	7.1	8.5	8.8	9.2	8.9	22.8	22.4	30.4
Dissolved Oxygen (ppm)	3.7	7.3	7.2	7.0	6.9	7.0	5.5	5.4	5.2
Fluoride (ppm)	0.21	0.23	0.19	0.28	0.19	0.20	0.34	0.34	0.38
Magnesium (ppm)	21.2	21.1	21.3	23.3	27.1	23.8	379.4	322.8	633.1
Ammonia (ppm)	0.20	0.46	0.56	0.51	0.49	0.60	0.75	0.80	0.81
Nitrate (ppm)	0.09	0.09	0.10	0.11	0.12	0.11	0.14	0.15	0.15
pH	8.2	8.2	8.1	8.1	8.1	8.1	7.7	7.7	7.8
Total Suspended Solids (ppm)	12.3	10.2	14.1	10.4	12.4	33.0	753.1	670.5	545.9
Sulphide (ppm)	27.6	16.2	19.8	21.9	19.2	19.4	454.6	495.3	961.2
Total Hardness (ppm)	128.9	120.4	143.1	143.7	158.7	144.6	1964.0	1892.3	3212.7
Total Carbon (ppm)	179.1	45.6	356.6	792.6	261.9	229.4	454.2	977.7	436.5

Total Dissolved Solid (ppm)	204.6	197.7	254.2	262.0	289.0	256.7	9304.0	9459.1	18450.
Total Kjeldahl Nitrogen (ppm)	2.2	2.4	2.3	2.3	2.1	1.3	1.5	1.5	2.9
Temperature (ºC)	26.8	27.4	27.6	27.7	28.0	27.7	27.8	27.9	28.0

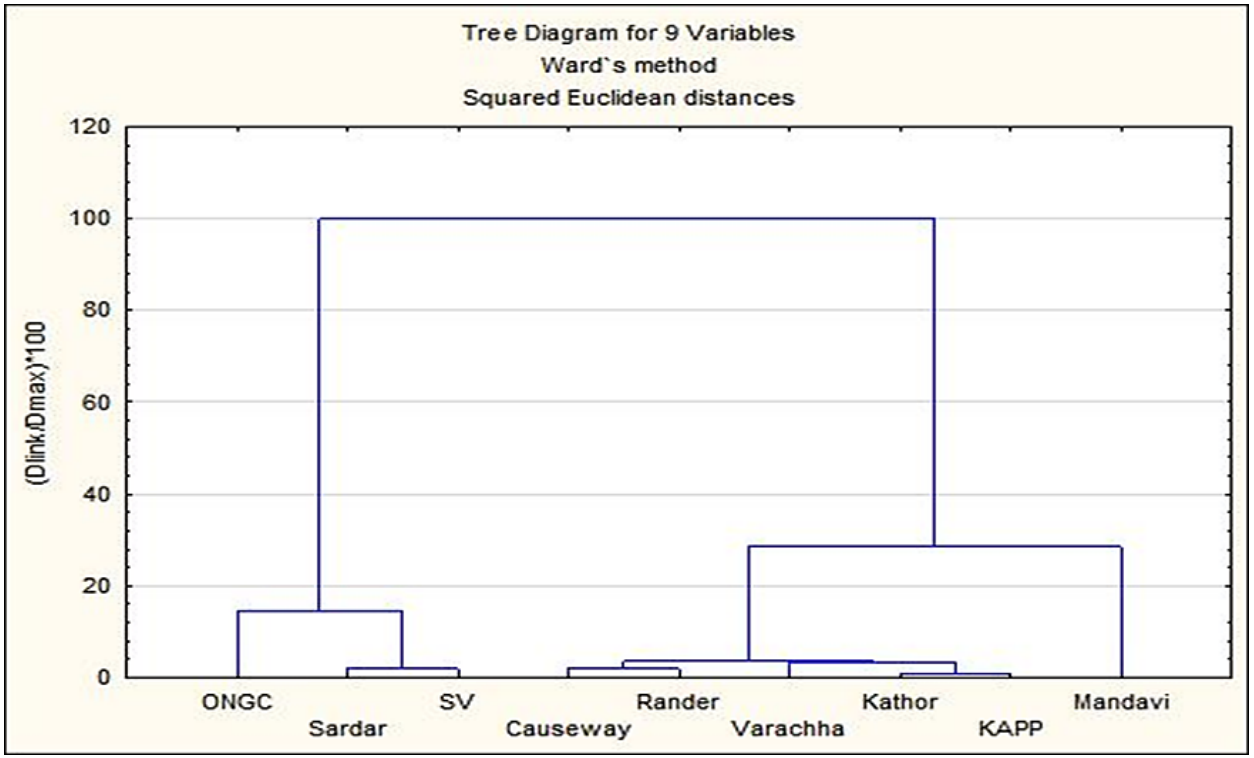


Fig 10.37 Dendogram of Cluster Analysis

Table 10.16 Details of the intake wells of the SMC

Sr. No.	Name of Intake Well	Capacity (MLD)
1	Sarthana Well-1	360
2	Sarthana Well-2	240
3	Valak Well	360
4	Rander Well	360
5	Katargam Well-1	240
6	Katargam Well-2	360
7	Mota Varachha Well	360

CHAPTER 11
STREAM BANK EROSION ANALYSIS

11.1 GENERAL

The quantification of the rate, at which the banks of the Tapi river have undergone erosion/deposition owing to the migration of its banklines is required in protecting the valuable lands, monuments and stabilising the river courses. Along with the migration of banklines, the rivers may undergo a variety of changes in their planforms, like sinuous meandering, braiding characteristics etc. The present chapter includes the detailed methodology that has been adopted to quantify the bank erosion and deposition as well as the planform changes in the Tapi river. The results of the analyses are included with suitable interpretation. The reaches of Upper, Middle and Lower Tapi rivers are prioritized, i.e. assigned ranks, according to the descending order of land area lost due to erosion.

11.2 METHODOLOGY

In order to achieve the objectives, the toposheets and satellite imagery on decadal time scale have been used as the major inputs for processing in ArcGIS 10.4© and image processing software. The detailed procedure of foregoing morphological study of Tapi river is illustrated in flow chart as shown in Fig. 11.1. In Fig. 11.1, the abbreviations included are, CWC: Central Water Commission, SoI: Survey of India, LCC: Lambert Conformal Conic, WGS: World Geodetic System and SI: Satellite Imagery.

One set of Survey of India toposheets (Base year: 1971-1979) and digital satellite images of Landsat-3, LISS-II and LISS-III sensors, comprising scenes of the years 1981, 1990, 2000 and 2010 were used in the present study. The georeferencing of toposheets was done using the Georeferencing toolset in ArcGIS 10.4© with residual value less than 10^{-4} m and nearest neighbourhood re-sampling technique to create a geo-referenced image. Subsequently, other satellite images were also registered and ortho-rectified with the georeferenced image using the image-to-image registration technique. The ortho-rectified images for different dates pertaining to study area were used for further analyses.

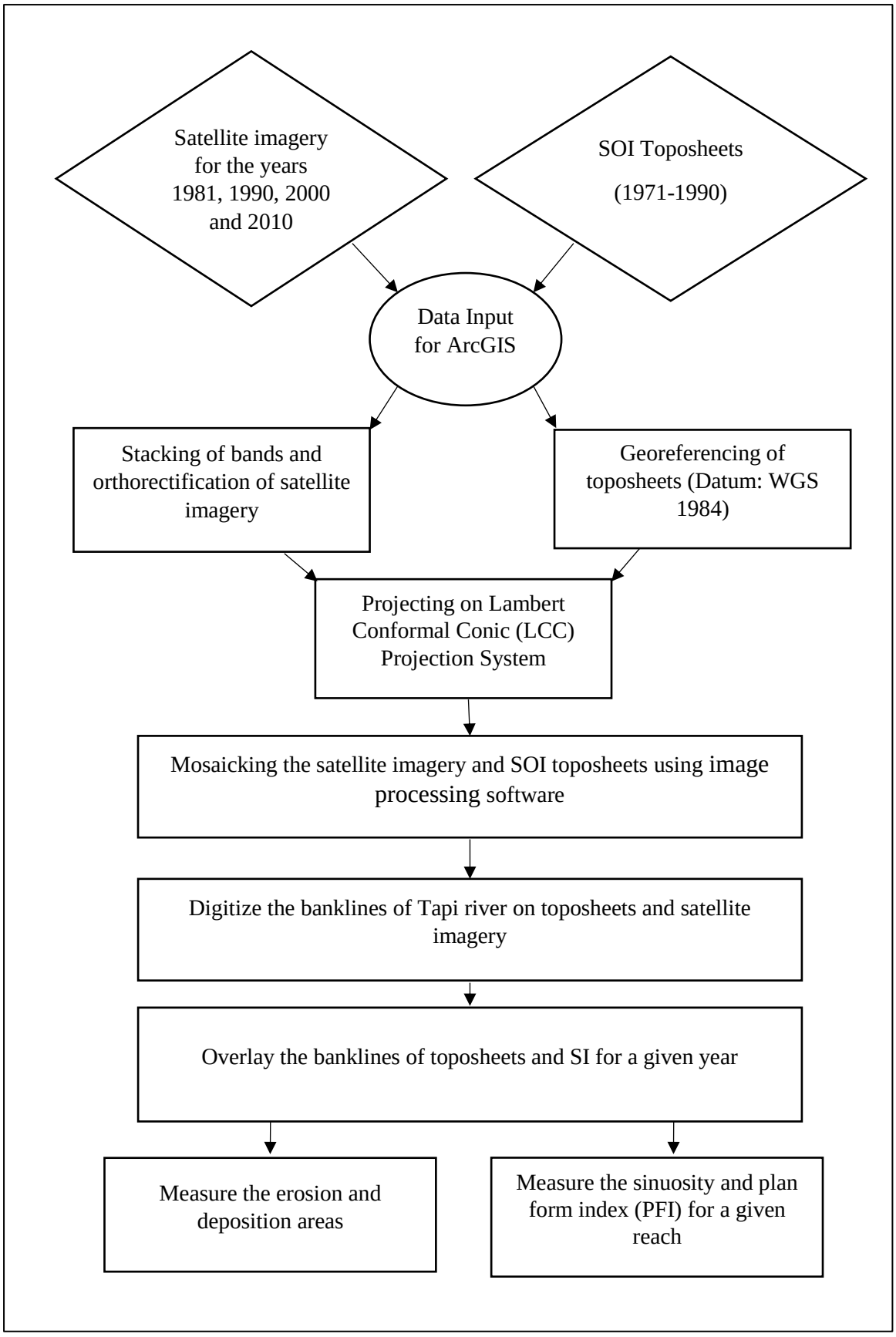


Fig 11.1 Methodology adopted in morphological study

11.3 DELINEATION OF RIVER BANK LINE

The delineation procedure adopted to digitize the banklines and centre line of Tapi river in both Survey of India (SOI) toposheets and satellite imagery for the years 1981, 1990, 2000 and 2010 has been discussed in Section 10.2 of Chapter 10. For convenience, the main Tapi river has been sub-divided into three sub-sections Upper, Middle and Lower Tapi rivers. The lengths of the right bankline (RBL) and left bankline (LBL) for Upper, Middle and Lower Tapi rivers are given in Table 11.1.

Table 11.1 The lengths of RBL and LBL for Upper, Middle and Lower Tapi river

	UPPER TAPI RIVER				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	354	352	354	355	352
Left Bank Line	354	353	352	354	351
Bank lines	**MIDDLE TAPI RIVER**				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	256	234	244	251	237
Left Bank Line	257	236	245	251	237
Bank lines	**LOWER TAPI RIVER**				
	SOI Toposheets (km)	**1981**	**1990**	**2000**	**2010**
Right Bank Line	136	132	130	132	131
Left Bank Line	126	123	122	123	123

11.4 PLAN FORM OF THE RIVER

River channel change is defined as anything that causes a deviation from a state of its dynamic equilibrium. Dynamic equilibrium is a state where the channel is adjusted to its regime discharge. Although the processes like erosion and deposition continue, the overall form is preserved to produce and sustain a dynamically stable pattern (Lewin et al., 1988).

According to the static and dynamic characteristics, alluvial river patterns are in general categorized as (1) straight, (2) meandering, and (3) braided rivers (Leopold and Wolman, 1957). Straight rivers have minimal sinuosity (< 1.1) at the bank full conditions. Usually, rivers, as simple straight open channels, exist only over short reaches while long, straight rivers seldom occur in nature. At low flow stages, alluvial bars exist on either side of the stream. The thalweg may wind in a sinuous route along the bars, even though the channel is straight. The thalweg may move with alternate bars as they migrate downstream. Meandering rivers (sinuosity > 1.5) consist of a series of turns with alternate curvatures connected at the points of inflection or by short straight crossing. They have a relatively low gradient. The natural

meandering rivers are quite unstable due to predominant bank erosion downstream of concave banks. Deeper flows are prevalent in the bends and higher velocities along the outer concave banks. The flow depth at crossings is relatively shallow compared to that at bends. Meandering rivers migrate gradually and hence sinuosity tends to increase. Eventually, the channel forms almost a closed loop and the meander gets often cut-off during a flood. Meandering is therefore the result of streambed instability; in particular, when instability acts on the banks. Here, it is pertinent to mention that the rivers with a sinuosity of less than 1.1 is described as straight, those between 1.1 and 1.5 are sinuous; and meandering rivers are having a sinuosity greater than 1.5. Braided rivers are wide and shallow and divided into branches by many semi stable or unstable bars or islands. More specifically, braided river can be defined as one that flows in two or more channels around alluvial bars or islands. They have a braided look at the low flow stages with exposed bars, but all or some of the bars are submerged during the high flow stages.

In the present chapter, two parameters, sinuosity index (*P*), and planform index (*PFI*) are used to evaluate variations in plan form of Tapi river, starting from the base year till 2010.

11.4.1 Sinuosity Index

Sinuosity is the parameter used to measure the meandering behaviour of the stream and defined as the ratio of thalweg length to valley length (Leopold and Wolman, 1957). Friend and Sinha (1993) gave two modification which was adopted to measure the meandering behaviour in terms of sinuosity. First modification was made that the line which runs midway of the channel have been the channel length which have enabled to measure the line from topographical maps, satellite images and aerial photographs readily. In India, the rivers exhibit their behaviour between single-channel and braided morphologies. So, there should be a clear definition to discriminate them and hence, they employed second modification by extending the meandering (sinuosity) parameter to multi-channel situations, which is based on the mid-channel length of the channel that is widest in each reach of the channel belt.

The modified sinuosity parameter, *P*, is defined as:

$$\boldsymbol{P = \frac{L_{Cmax}}{L_R}} \qquad \textbf{11.1}$$

where, L_R is the overall length of the channel-belt reach measured along a straight line, and L_{Cmax} is the mid-channel length for the same reach, or the mid-channel length of the widest channel, where there is more than one channel (Fig 11.2).

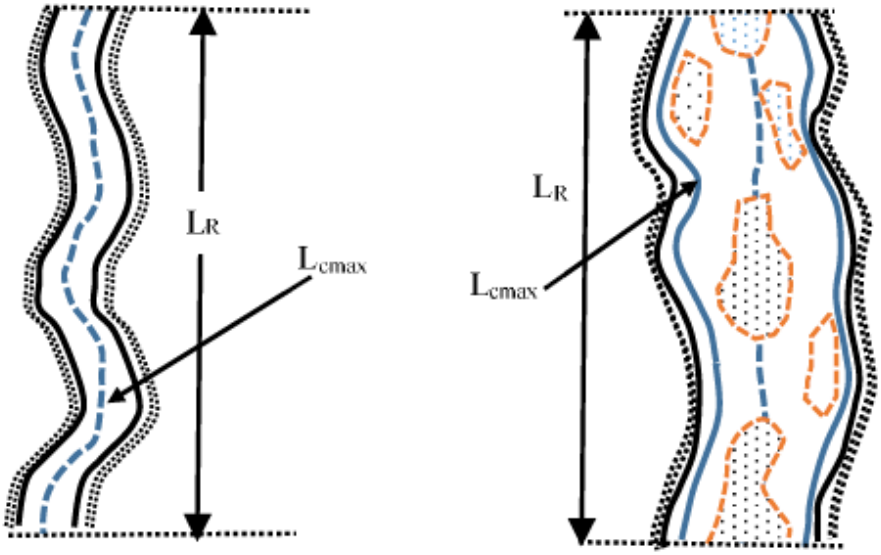


Fig 11.2 Diagram representing the calculation of the sinuosity for Single-channel and Multi-channel Rivers (Friend and Sinha, 1993)

The Upper, Middle and Lower Tapi river reaches were sub-divided into 50 km length reaches starting from upstream to downstream, and the degree of meandering in terms of Sinuosity Index (***P***) was calculated using Eq. 11.1. The results are tabulated in Table 11.2 to Table 11.4.

Table 11.2 Sinuosity Index (*P*) for different years in Upper Tapi river

Reach No.	Reaches (km)	Sinuosity Index (*P*)			
		1981	**1990**	**2000**	**2010**
1	0-50	1.44	1.41	1.43	1.42
2	50-100	1.79	1.84	1.84	1.85
3	100-150	1.36	1.37	1.34	1.33
4	150-200	1.22	1.22	1.22	1.22
5	200-250	1.30	1.30	1.30	1.31
6	250-300	1.18	1.19	1.19	1.18
7	300-350	1.32	1.28	1.31	1.32

From Table 11.2, it can be observed that for Upper Tapi river that extends from Multai to Hatnur Reservoir, the sinuosity values do not cross the limit of meandering except in reach 2, which extends between Tipnapur Village (CH: 50 km) and Teska Village (CH: 100 km) in Madhya Pradesh. The high value of sinuosity in this reach can be attributed to the Tapi river

following meandering path through confined bedrock reaches of Upper Tapi Gorge between Tipnapur Village and Teska (Fig 11.3). Also, it can be seen that the sinuosity index values are marginally increasing with every decade for reach 2. This can be an indication of the river trying to dissipate its excess energy by following a curved path, which may in turn accelerate the bank erosion rate.



Fig 11.3 Meandering course between Tipnapur and Teska in CH: 50 km to CH: 100 km river reach

Table 11.3 Sinuosity Index (*P*) for different years in Middle Tapi river

*Reach No.	Reaches (km)	Sinuosity Index (*P*)			
		1981	1990	2000	2010
8	350-400	1.12	1.13	1.13	1.14
9	400-450	1.18	1.20	1.20	1.20
10	450-500	1.25	1.30	1.27	1.23
11	500-550	1.19	1.21	1.21	1.15
12	550-581	1.13	1.14	1.13	1.13

* Reach No. in continuation with the Upper Tapi river reaches

The sinuosity values for reaches 8-12 that fall in the Middle Tapi river, which extend between Hatnur Dam and Ukai Dam, are given in Table 11.3. The values show that the river follows sinuous course throughout its translational path. Although occasional bends are present in the Tapi river in its Middle reaches, no prominent meander reaches are found. Hence, the sinuosity

index values are never found to cross the meandering threshold 1.5. Also, no significant variation can be observed in the sinuosity index with time.

Table 11.4 Sinuosity Index (*P*) for different years in Lower Tapi river

*Reach No.	Reaches (km)	Sinuosity Index (*P*)			
		1981	**1990**	**2000**	**2010**
13	647-697	1.10	1.10	1.10	1.10
14	697-747	1.50	1.50	1.50	1.50
15	747-792	1.30	1.27	1.28	1.28

* Reach No. in continuation with the Middle Tapi river reaches

Table 11.4 shows the sinuosity index values of the Tapi river in its Lower reaches between Ukai Dam (CH: 647 km) and Arabian Sea (CH: 792 km). In reach 13, the sinuosity index value is the least, i.e. 1.10. The lower Tapi river in the reach from CH: 697 km (Kadod) to CH: 747 km (Surat city) can be classified as meandering channel. The lower Tapi river for the remaining reaches can be classified under sinuous category.



Fig 11.4 Straight reach between Ukai Dam (CH: 647 km) and Kadod (CH: 697 km)

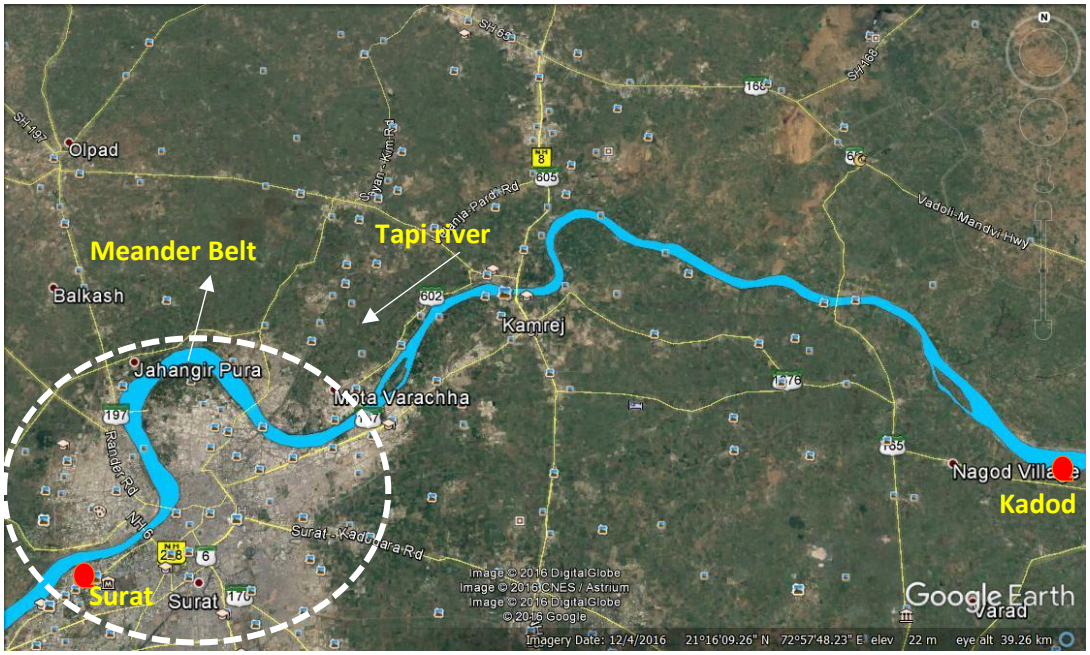


Fig 11.5 Meandering reach between Kadod (CH: 697 km) and Surat (CH: 747 km)

11.4.2 Meandering Parameters

As Reach 2 (CH: 50 km –CH: 100 km) and Reach 14 (CH: 697 km – 747 km) were identified as the meandering reaches in Tapi river, meandering parameters like Meander wavelength (λ_m), Meander amplitude (a_m), Meander belt width (B_m) and Radius of curvature (r_c) (Fig 11.6) were calculated for three meander bends, CH: 57.63 km- CH: 61.59 km (Upper Tapi river), CH: 71.41 km – CH: 77.49 km (Upper Tapi river) and CH: 697.00 km – 747.00 km (Lower Tapi river). The results are tabulated in Table 11.5.

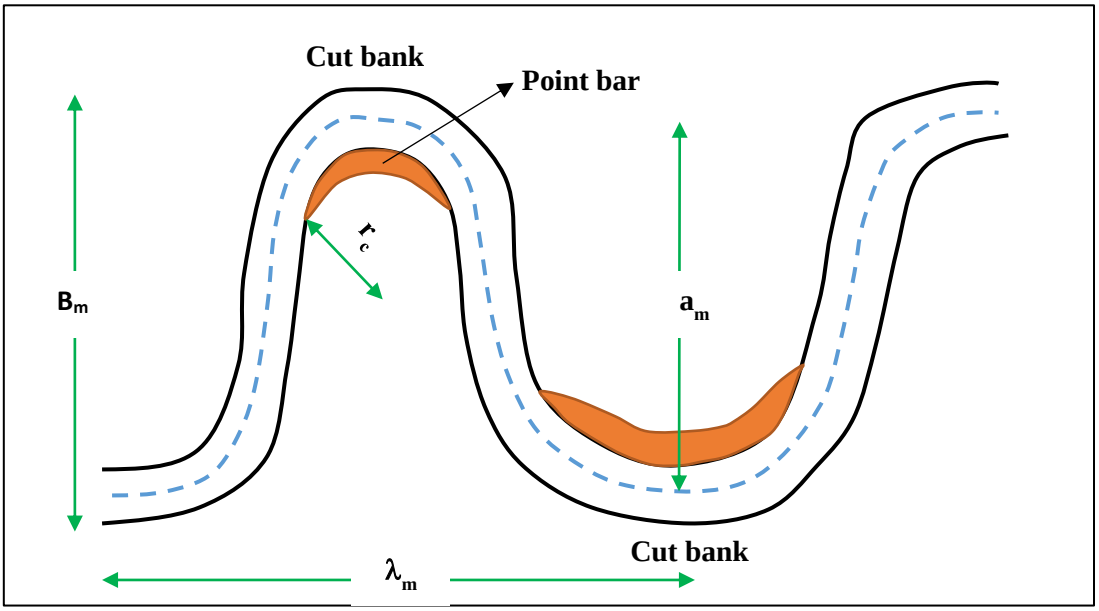


Fig 11.6 Diagram representing the calculation of the meandering parameters

Table 11.5 Meandering parameters for different years in Tapi river

Reach	1981				1990				2000				2010			
	λ_m	a_m	B_m	r_c	λ_m	a_m	B_m	r_c	λ_m	a_m	B_m	r_c	λ_m	a_m	B_m	r_c
CH: 57.63-CH: 61.59	1122*	1051	1440	317	1046	1079	1226	300	1108	1240	1403	299	1071	1181	1356	265
CH: 71.41-CH: 77.49	1491	1749	2130	419	1459	1748	2053	319	1466	1750	2015	344	1498	1792	2136	360
CH: 697.00-CH:747.00	10121	5558	5268	1216	9961	5370	5200	1097	9894	5360	5189	1088	9726	5191	5126	1062

*All values are in meters

From Table 11.5, it is clear that the meandering parameters of the meander bends that fall in Upper Tapi river do not follow any general pattern over the time period considered. However, for the meander bend that falls in the Lower Tapi river (CH: 697.00 km – 747.00 km), near Surat City, it is seen that a steady slow decrease in Meander wavelength (λ_m), Meander amplitude (a_m), Meander belt width (B_m) and Radius of curvature (r_c) are noted in Table 11.5. The bend near Surat City is sufficiently long with mean meandering amplitude 9925.5 m. The area is highly urbanized, and over the years, new constructions have emerged on both the banks of the Tapi river. Along with the reduction in radius of curvature, the possible reason for constriction of the meander bend is the anthropogenic activities in the form of flood plain encroachment.

11.4.3 Plan Form Index (*PFI*)

Plan Form Index (*PFI*) criteria was developed by Sharma (2004) to obtain the degree of braiding in the rivers. It reflects the fluvial landform with respect to a given water level and its lower value is indicative of higher degree of braiding. Accordingly, the *PFI* is defined 0-as:

$$PFI = \frac{\frac{T}{B} \times 100}{N} \qquad 11.2$$

where,

$T = T_1 + T_2$ = Flow top width

B = Overall flow width

N = Number of braided channels

The definition sketch of *PFI* is given in Fig 11.7.

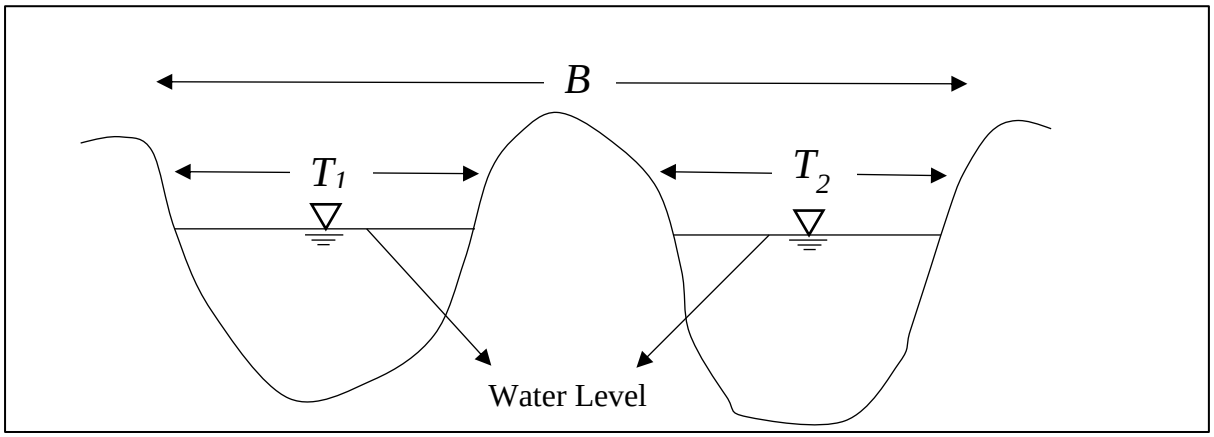


Fig 11.7 Definition sketch for Plan Form Index (*PFI*)

Plan Form Index represents the percentage of actual flow width per braided channel. For providing a broad range of classification of the braiding phenomenon, the following threshold values for ***PFI*** were proposed by Sharma (2004).

- Highly Braided: $PFI < 4$
- Moderately Braided: $19 > PFI > 4$
- Low Braided: $PFI > 19$

Table 11.6 Average *PFI* values for different years in Upper Tapi river

Reach No.	Reaches (km)	Average *PFI*			
		1981	**1990**	**2000**	**2010**
1	0-50	65.24	52.22	84.66	100
2	50-100	39.27	47.55	74.67	76.12
3	100-150	50.45	70.08	53.03	70.67
4	150-200	38.97	45.40	83.25	37.97
5	200-250	32.49	52.77	30.32	33.09
6	250-300	38.31	34.42	33.66	31.85
7	300-350	53.38	58.14	70.05	72.02

It can be observed from Table 11.6 that the Plan Form Index values are well beyond the threshold limit of low braided rivers in case of Upper Tapi river reaches. All the *PFI* values come under the category of 'Low Braided'. The river flows in single channel in most of its course in Upper Tapi river; however multiple channel formation is found in certain reaches, but for shorter lengths, not sufficient to form significant braids.

Table 11.7 Average *PFI* values for different years in Middle Tapi river

*Reach No.	Reaches (km)	Average *PFI*			
		1981	1990	2000	2010
8	350-400	33.12	22.16	24.53	22.68
9	400-450	46.51	31.46	28.10	64.63
10	450-500	52.31	39.49	22.42	64.18
11	500-550	39.44	36.26	54.77	100.00
12	550-581	70.45	51.76	36.21	72.59

* Reach No. in continuation with the Upper Tapi river reaches

Table 11.7 shows the PFI values for reaches 8-12 of Middle Tapi river. It can be seen that, except Reach 8, the average PFI values computed for all other reaches show quite high values, which do not produce significant braiding. While examining the course of Tapi river from Hatnur Dam to Ukai Reservoir, it can be seen that no major braiding pattern is seen anywhere. However, in Reach 8, between Vagdud (CH: 368.65 km) and Bhusawal (CH: 376.39 km), there's a stretch of Tapi river where the river flows forming multiple channels (Fig 11.8). This can be attributed to the considerable change in stream slope between these two locations, i.e., a stream slope of 1 in 317 has been computed (difference of 55 ft in 5320 m).

Table 11.8 Average *PFI* values for different years in Lower Tapi river

*Reach No.	Reaches (km)	Average *PFI*			
		1981	1990	2000	2010
13	647-697	39.23	21.58	23.84	13.64
14	697-747	26.46	24.26	24.64	14.12
15	747-792	17.15	20.51	19.58	6.42

* Reach No. in continuation with the Middle Tapi river reaches

The average PFI values of Lower Tapi river reaches show quite interesting values (Table 11.8), compared to those obtained for Upper Tapi river and Middle Tapi river. It can be observed that over the years, there has been a gradual transition of all the three reaches of Lower Tapi river from low braided state (PFI > 19) to moderately braided state (19 > PFI > 4). These values

clearly prove the reasonableness of using the Plan Form Index as the measure of braiding and closely obey the actual physical situation of the occurrence of braiding vividly portrayed in the satellite images. Fig 11.9 shows the braided reach between Khedpur Village (CH: 691.82 km) and Puna Village (CH: 696.41 km), which falls in Reach 14 of the Lower Tapi river. Fig 11.10 shows the braided reach between Umarsadi Village (CH: 707.62 km) and Kudashi Village (CH: 716.27 km), which falls in Reach 14 and Fig 11.11 shows the braided reach between Rundh Magdalla Village (CH: 776 km) and Arabian Sea (CH: 792.00 km), which falls in Reach 15 of Lower Tapi river.

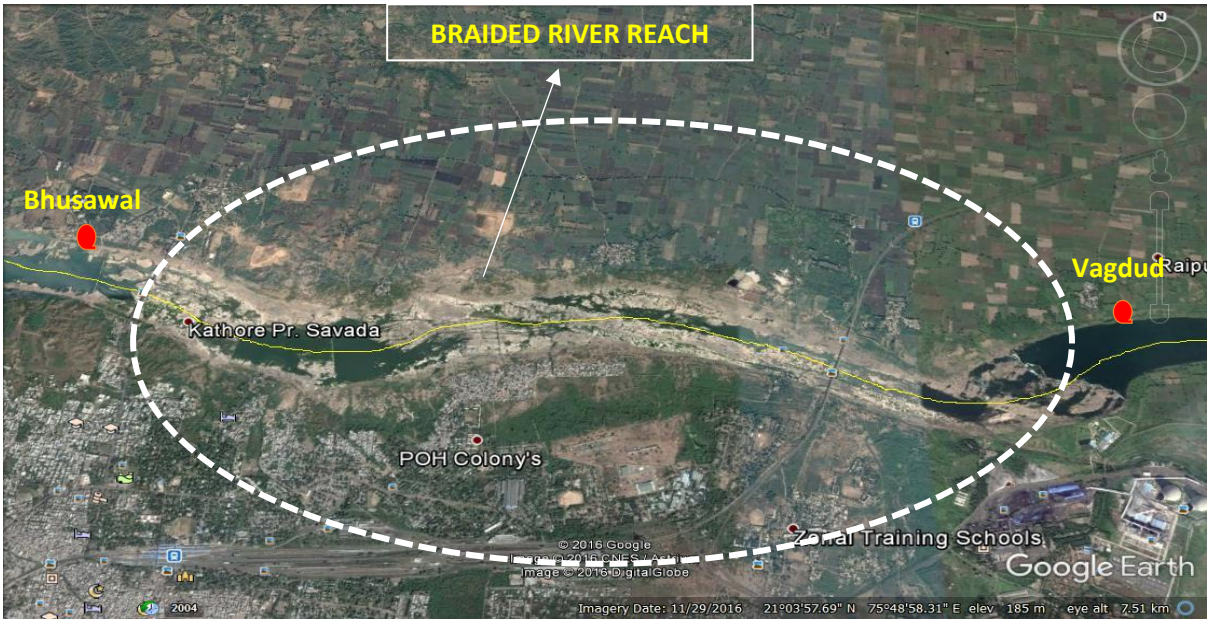


Fig 11.8 Braided reach in Middle Tapi river between Vagdud and Bhusawal

In all the three cases, it can be observed that the actual ground conditions match with that of the analysis performed. The degree of braiding is observed to increase with an increased number of channels over the years. This increase can be attributed to the increase in the sediments deposited in the Lower Tapi river, causing significant siltation in the River, reducing its carrying capacity. Significant reduction in *PFI* values are observed in Reach 15 which forms part of Tapi estuary System. It can be seen from Fig 11.11 that during 2000 and 2010, the river forms multiple channels at its confluence with Arabian Sea. This can probably be the indication of excessive sediment getting deposited at the river mouth, which if persist may cause threat to the channel carrying capacity, cause problems to navigation and affect the flora in the islands/mangroves78.

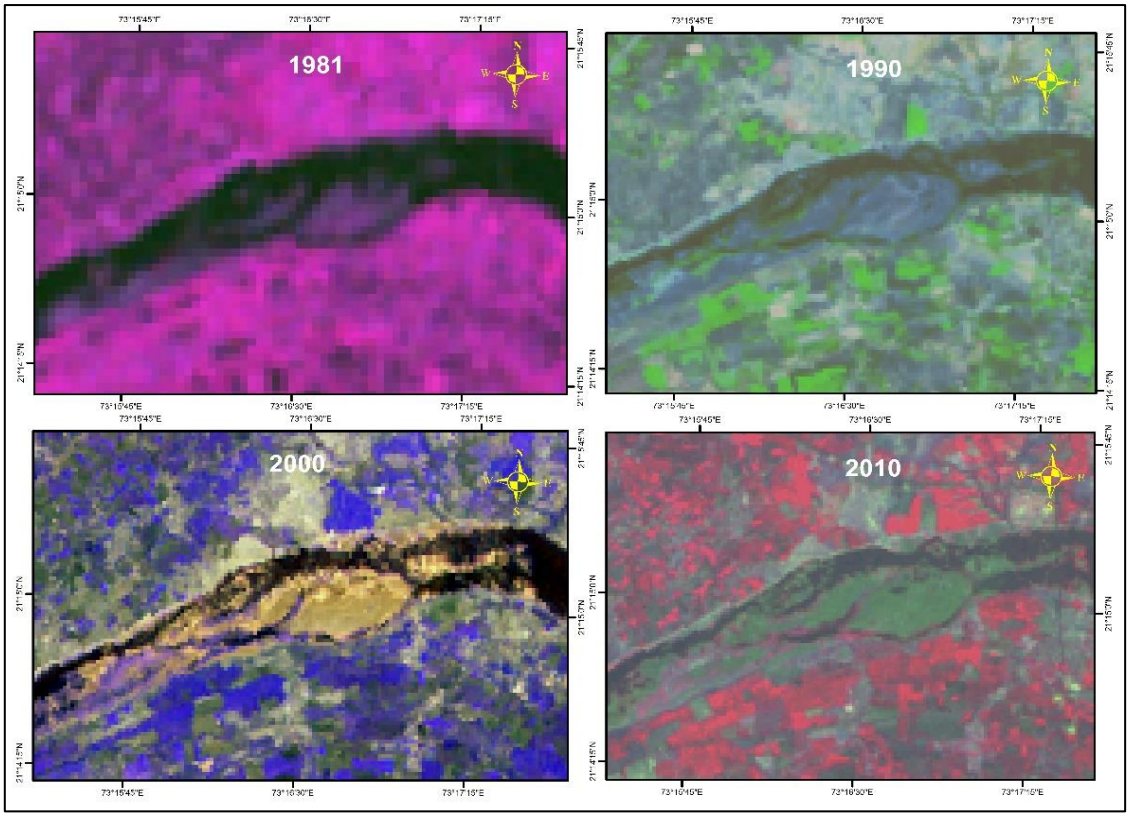


Fig 11.9 Braided reach in Lower Tapi river between Khedpur and Puna

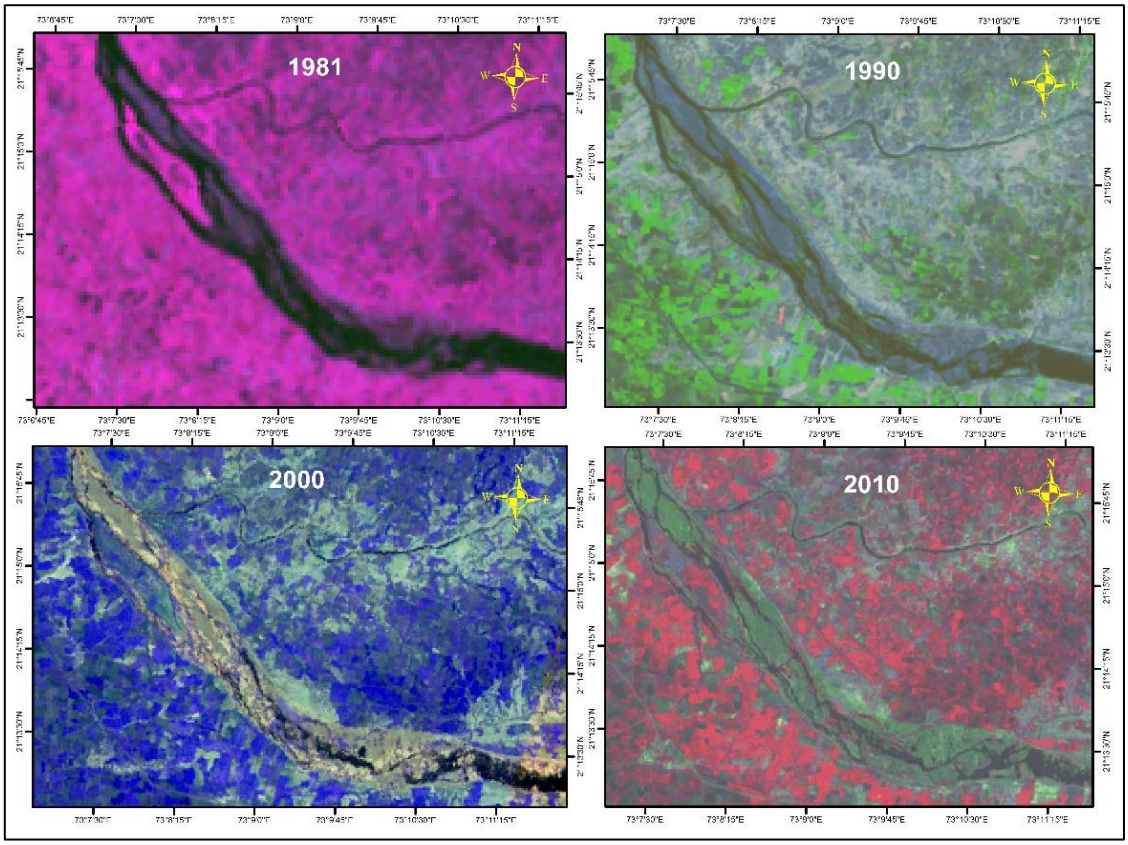


Fig 11.10 Braided reach in Lower Tapi river between Umarsadi and Kudashi

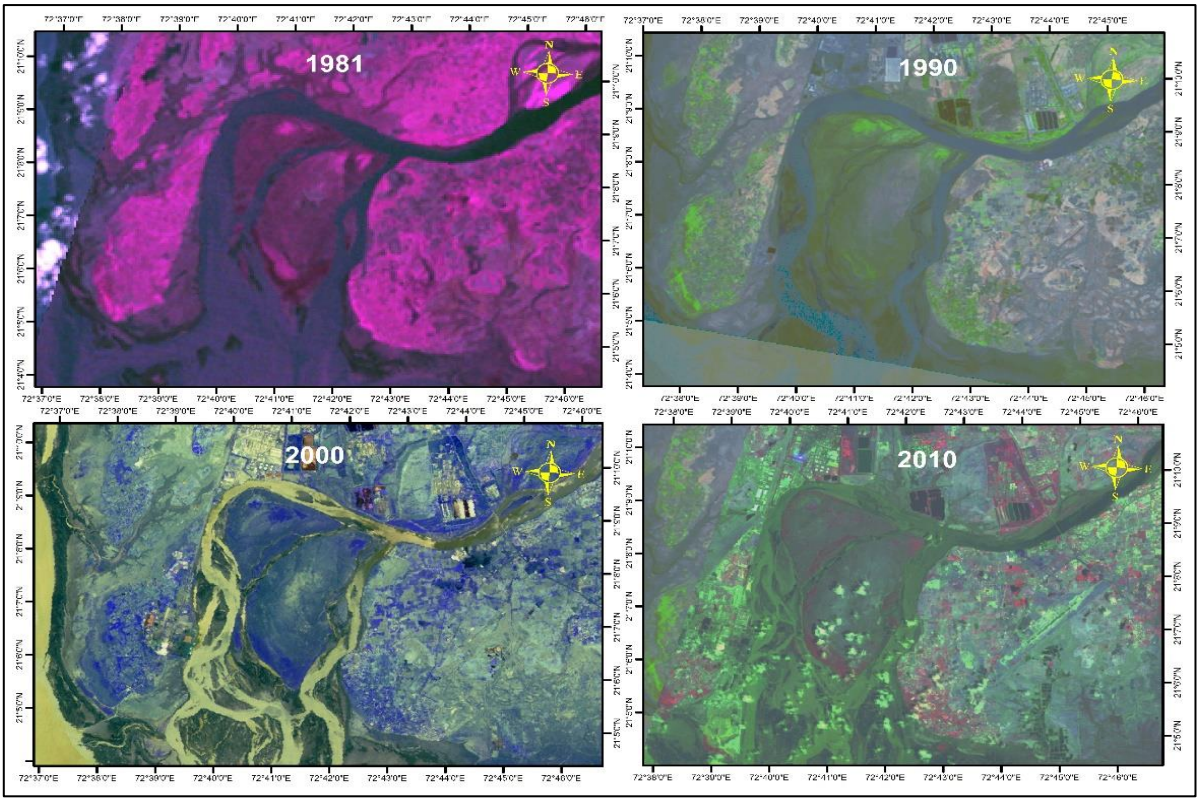


Fig 11.11 Braided reach in Lower Tapi river between Rundh Magdalla and Arabian Sea

11.5 RIVER BANK EROSION/ MIGRATION

The bank lines digitized on toposheets for base years ranging from 1971-1979 are taken as the reference for quantifying erosion and deposition areas, resulting from the migration of bank lines of Tapi river. Toposheets of different survey years had to be used due to non-availability of toposheets in a single year. For easy representation, the period 1971-1979 is designated as 'base year'. The bank lines were then overlaid on the respective bank lines digitized on satellite imagery, and the resulting bank migration length and erosion-deposition polygon areas were calculated using the 'calculate geometry' tool available in ArcGIS 10.4©. The results are as tabulated in Tables 11.9-11.14.

From Tables 11.9-11.14, it can be observed that the Right Bankline (RBL) of Tapi river invariably is gets eroded than corresponding deposition in almost all the reaches in Upper, Middle and Lower Tapi rivers. On the contrary, the left bank line migrates in such a way as to produce more deposited areas, compared to the eroded areas.

Table 11.9 Erosion and deposition areas due to migration of RBL in Upper Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
1	0-50	3.88	0.63	4.48	1.21	3.67	1.15	4.07	1.10
2	50-100	3.27	0.70	2.96	1.89	3.67	1.62	3.06	1.48
3	100-150	2.66	0.44	2.34	0.89	2.79	1.03	2.89	0.81
4	150-200	3.67	*0.32*	4.25	0.15	4.04	0.18	4.59	0.10
5	200-250	2.99	0.69	5.23	0.31	4.34	0.21	3.54	0.23
6	250-300	1.05	2.10	4.19	0.38	2.98	0.39	2.88	0.53
7	300-350	1.94	1.65	8.40	0.29	4.29	0.52	3.91	0.61
TOTAL		**19.46**	**6.53**	**31.85**	**5.12**	**25.78**	**5.10**	**24.94**	**4.86**

Table 11.10 Erosion and deposition areas due to migration of LBL in Upper Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
1	0-50	1.30	2.43	1.83	3.05	1.21	3.60	1.24	4.13
2	50-100	2.02	1.61	2.55	2.61	2.28	2.41	1.99	2.84
3	100-150	0.49	1.93	0.42	3.14	0.63	2.72	0.45	3.41
4	150-200	0.31	2.52	0.17	4.37	0.15	3.71	0.04	5.26
5	200-250	0.43	3.42	0.35	5.40	0.12	4.92	0.02	6.28
6	250-300	0.62	2.43	0.29	4.83	0.49	4.01	0.07	5.53
7	300-350	1.15	3.34	2.07	4.38	1.49	3.27	0.35	4.86
TOTAL		**6.32**	**17.68**	**7.68**	**27.78**	**6.37**	**24.64**	**4.16**	**32.31**

The erosion and deposition areas resulting due to the shifting of RBL and LBL in Upper Tapi river are shown in Tables 11.9 and 11.10 respectively. It can be seen that the RBL undergoes more erosion compared to LBL in all the years, viz., LBL undergoes more deposition compared to RBL in all the years. While analysing the reaches separately, in case of erosion, the RBL of Reach 1and Reach 7 shows maximum area loss during base year up to 2010. In reach 1 between CH: 0 km and CH: 50 km, the river passes through its youthful stage, where the velocity of flow is very high.

Reach 7 falls between CH: 300 km and CH: 350 km, just upstream of Hatnur dam. At chainage 300-350 km, just upstream of Hatnur reservoir, the apparent shifting of RBL is seen due to the presence of backwater and subsequent silting in the periphery of the reservoir after the construction of the dam in 1982. The erosion deposition areas for every 50-km length river reach for Tapi river are represented in Appendix A1-A4 (Upper Tapi river), Appendix B1-B4 (Middle Tapi river) and Appendix C1-C4 (Lower Tapi river).

Table 11.11 Erosion and deposition areas due to migration of RBL in Middle Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
8	350-400	1.23	0.37	2.57	0.89	1.92	0.89	2.07	1.09
9	400-450	1.95	0.16	3.09	0.53	3.05	0.37	2.07	0.61
10	450-500	1.12	1.13	1.22	2.22	1.30	1.56	0.73	1.53
11	500-550	1.87	0.29	1.56	0.72	1.33	0.97	1.91	0.39
12	550-581	2.03	0.06	1.82	0.16	1.99	0.37	2.73	0.16
TOTAL		**8.20**	**2.01**	**10.26**	**4.52**	**9.59**	**4.16**	**9.51**	**3.78**

Table 11.12 Erosion and deposition areas due to migration of LBL in Middle Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
8	350-400	0.04	0.54	0.40	3.32	0.52	2.49	0.53	3.08
9	400-450	1.64	2.52	0.47	2.82	0.47	2.70	0.34	2.65
10	450-500	1.28	1.01	1.31	1.58	0.81	1.82	1.05	0.61
11	500-550	0.84	1.26	0.74	1.94	0.43	2.19	0.52	1.54
12	550-581	0.04	1.17	0.00	2.91	0.03	3.48	0.02	2.63
TOTAL		**3.84**	**6.50**	**2.92**	**12.57**	**2.26**	**12.68**	**2.46**	**10.51**

Table 11.13 Erosion and deposition areas due to migration of RBL in Lower Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
13	647-697	3.27	0.13	4.37	0.03	3.61	0.07	3.32	0.08
14	697-747	2.84	0.15	2.87	0.49	2.44	0.17	2.26	0.32
15	747-792	13.98	0.33	6.53	1.77	6.65	2.11	5.93	2.59
TOTAL		**20.09**	**0.61**	**13.77**	**2.29**	**12.7**	**2.35**	**11.51**	**2.99**

Table 11.14 Erosion and deposition areas due to migration of LBL in Lower Tapi river

Reach No.	Reaches (km)	Erosion and Deposition areas in km^2							
		Base Year-1981		Base Year-1990		Base Year-2000		Base Year-2010	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
13	647-697	0	4.71	0	6.19	0	6.28	0.01	5.02
14	697-747	0.27	4.20	0.28	4.83	0.09	4.73	0.06	4.14
15	747-792	11.30	1.71	8.98	2.55	11.25	2.89	11.10	2.73
TOTAL		**11.57**	**10.62**	**9.26**	**13.57**	**11.34**	**13.90**	**11.17**	**11.89**

The erosion and deposition areas resulting due to the shifting of RBL and LBL in Middle Tapi river are shown in Tables 11.11 and 11.12 respectively. As observed in Upper Tapi river, the Middle Tapi river also shows prominent erosion in its right bank compared to left bank. Similarly, the left bank undergoes significant deposition in all the reaches. The results are in line with the observations made for the bank line migration in Middle Tapi river (Section 10.3.2). Reaches 8 (CH: 350 km-CH: 400 km), 9 (CH: 400 km-CH: 450 km) and 12 (CH: 550 km-CH: 581 km) undergoes maximum loss of area due to bankline migration causing erosion. Reach 7 falls just downstream of Hatnur Dam. The high erosion observed here may be due to the release of comparatively clearer water to the downstream side during monsoon period. As the bottom of stream at this location consists of hard rock stratum, the sediment carrying capacity of the stream is satisfied by eroding the either banks, and widening the same. Reach 12 falls just upstream of Ukai Reservoir. The probable cause of high erosion observed here may be the migration of right bank to

the northern side (widening) owing to siltation in the reservoir, and formation of new banklines due to infilling of the reservoir. It can be observed that the deposition areas also highest values in Reaches 8, 9 and 12. This shows that the positive migration (widening) of the right bank causing erosion is compensated by a negative migration (narrowing) of left bank causing deposition. The erosion deposition areas for every 50-km length river reach for Middle Tapi river are represented in Appendix B1 (base year to 1981), Appendix B2 (base year to 1990), Appendix B3 (base year to 2000) and Appendix B4 (base year to 2010) respectively. The erosion and deposition areas resulting due to the migration of RBL and LBL in Lower Tapi river are shown in Tables 11.13 and 11.14 respectively. It can be seen that Reach 15 (CH: 747 km-CH: 792 km) is the most critical regarding erosion in both RB and LB. The reach falls just upstream of Arabian Sea. Large positive shifting (widening) of both RB and LB have occurred in Reach 15, and this may be because of tidal action of the Arabian Sea. Deposition area is maximum in Reaches 13 (CH: 647 km-CH: 697 km) and 14 (CH: 697 km - CH: 747 km), which is found to be decreasing over the decades. The erosion deposition areas for every 50-km length river reach for Lower Tapi river are represented in Appendix C1 (base year to 1981), Appendix C2 (base year to 1990), Appendix C3 (base year to 2000) and Appendix C4 (base year to 2010) respectively.

11.6 ASSESSMENT OF VULNERABILITY IN TAPI BASIN IN CONTEXT TO RIVER BANK EROSION

The Tapi river has undergone erosion in varying magnitudes over the past 40 years as per the analysis reported in the preceding section. The basin, especially in the lower reaches of the Tapi river, is severely affected by floods, particularly during the monsoon season (June – September). Also, an extremely high volume of sediment is accumulated in the Tapi river, in upstream of Kakrapar weir as well as upstream of Hatnur Dam as per the studies carried out in present study. Between the base year and year 2010; total 63.75 km^2 of land area in Tapi basin has been lost due to bank erosion, averaging to 15.94 km^2 of land getting lost every decade. The average bank erosion due to the migration of right bank is estimated to be around 11.49 km^2/decade, whereas for the left bank, it comes around to be 4.45 km^2/decade. The estimated values are comparatively much lesser than that of highly dynamic rivers like Brahmaputra, where about 10.3 km^2 of land area is lost every year due to river bank erosion (Sharma et al., 2010). However, the erosion phenomena, even though in minor rates, can cause numerous social and economic consequences, including loss of agricultural land, loss of livelihood, loss of housing and other essential infrastructure like roads and railway lines along the river. In this

context, present study was aimed to link the past trend in bank erosion with possible potential hazard in the future by developing vulnerability indices along the river reach while taking into consideration the proximity of the erosion prone river banks to villages, urban centers and highways. Based on the proximity of villages, urban areas and highways to the eroded river banks (which have undergone an erosion of > 5000 m^2 during base year-2010), the grades have been assigned on a scale of 10. The details of assigned grades are included in Table 11.15.

Table 11.15 Grades assigned for different criteria considered in vulnerability assessment

Criteria	Distance (m) /shift (m)					Weightage assigned (W_i)
	<100	100-200	200-500	500-750	>750	
	Grade assigned on a scale of 10 (G_i)					
Villages and Urban areas	10	7.5	5	2.5	0	0.3
Highways	10	7.5	5	2.5	0	0.2
Positive shifting/ erosion	0	2.5	5	7.5	10	0.5

The vulnerability index is obtained by summing the grades multiplied by the respective weights assigned and dividing it by the total grade (10), .i.e,

$$\boldsymbol{VI = \frac{\sum_{i=1}^{n} G_i W_i}{10}}$$

Here, *n* is the number of criteria considered in the assessment of vulnerability, G_i is the grade assigned for i^{th} criteria and W_i is the weightage given to i^{th} criterion. The weights are assigned for each criterion based on their relative importance. In present study, rate of shifting has been assigned a maximum weightage of 0.5, followed by threat to villages and urban areas (0.3) and highways (0.2) (Table 11.15). This is assigned based on the fact that migration of bank lines causing erosion, not only causes destruction to settlements and infrastructure, but also results in loss of floodplain and agricultural land in the vicinity of bank lines. Based on the vulnerability index values calculated for each location, the locations are classified into different levels of vulnerability as included in Table 11.16).

Table 11.16 Levels of vulnerability

Vulnerability Index (VI)	Designation
>1.75	Highly Vulnerable
1.5-1.75	Vulnerable
1.25-1.5	Moderately Vulnerable
1-1.25	Less vulnerable
0.75-1	Very less vulnerable
< 0.75	Not vulnerable

The vulnerability index (VI) values were computed separately for Upper, Middle and Lower Tapi rivers. The proximity of erosion areas greater than 50000 m^2 (0.05 km^2) to villages/ urban areas were determined by measuring the distance between the centroid of the erosion polygon and the centroid of the adjoining/ nearby village/urban area. Also, the shortest distance between the centroid of erosion polygon and the state/national highways was measured using the measuring tool available in Google Earth Pro 7.3.0. These measured distances, along with the bankline shift (between base year and 2010), were used to calculate Vulnerability Index (VI) values. The results which shows the areas which are less vulnerable, moderately vulnerable and highly vulnerable are tabulated as follows.

Table 11.17 shows the vulnerability index values of Upper Tapi river reaches. The upstream course of the river passes through hilly gorges and confined rocky stratum and, hence, no locations are found to fall under the category of moderately vulnerable to high vulnerable classes. The locations of the Upper Tapi river fall under the category of less vulnerable to not vulnerable.

Compared to Upper Tapi river, the villages/ urban areas and State Highways in Middle Tapi river reaches are highly vulnerable to erosion (Table 11.18). The highest vulnerability is exhibited by erosion area E141, with a VI value of 1.75. This area falls on the right bank of Middle Tapi river, just downstream of Hatnur Dam, between CH: 350 km and CH: 372 km, where villages like Mangalwadi, Taskhede, Rangaon, Gahukhede, Raipur and Sudgaon are situated. Also, the right bank of the river has undergone an average shifting of 232 m (Grade 5) during base year-2010. The alarming rate of bank line migration, along with the huge erosion area (1005331 m^2) must be taken into consideration for controlling the possible threat to the villages. The erosion area E253 (691419 m^2) pose moderate vulnerability (VI=1.38) to villages Ubhad, Pisavar, Sadgavhan, Bhamsal, Hol, Nimbhora and Satola and to MH SH 4 which runs parallel to E256 at 562 m from its centroid. Villages Hatoda, Untavad, Pimlas, Gorasa, Amode Tarfe Talode, Kondraj and Gadid are vulnerable to erosion, under the erosion area E256 (1995872 m^2). The average shift during base year-2010 is 186 m. The erosion area extends a length of 17.5 km along the right bank.The Lower Tapi river has one highly vulnerable location and two moderately vulnerable location (Table 11.19). The highest vulnerability is posed by E263 (VI=2.00), which causes threat to villages like Ushked Khurd, Puna, Un, Kosadi, Umarsadi, Kamlapor and Khanjroli between CH: 695 km and CH: 711 km. The second highest vulnerability is exhibited by E288 (VI=1.33), which poses threat to villages like Mora, GSEG

Colony and Hazira and NH 6, that passes parallel to the eroded right bank. Similar observations were made during field visits conducted along Lower Tapi river reaches, where the right bank line of Tapi river was in high proximity to the road (NH 6). The average shift of the right bank was found to be around 530 m at this particular location (grade 7.5), which is significantly high. Immediate measures are required to arrest the further migration of banklines towards the road. The details are as tabulated in Table 11.19.

The vulnerability index proposed in present study, is for Tapi river only. The relative indices proposed for different reaches are meant to compare the critical areas along Tapi river only. Such indices should not be compared with vulnerability indices developed elsewhere.

11.7 PRIORITISATION OF LAND AREA LOST

Based on the analysis performed for computation of erosion-deposition areas for individual river reaches in Upper, Middle and Lower Tapi rivers, and the field recon trips conducted to specific locations in the Tapi river, critical areas are identified, where the land area is lost owing to erosion caused by widening of bank lines. The critical areas where the river has undergone significant narrowing down by depositing sediments have also been identified. These locations are marked separately for each decadal duration and are represented in Appendix A1 (base year to 1981), Appendix A2 (base year to 1990), Appendix A3 (base year to 2000) and Appendix A4 (base year to 2010) for Upper Tapi river reaches; Appendix B1 (base year to 1981), Appendix B2 (base year to 1990), Appendix B3 (base year to 2000) and Appendix B4 (base year to 2010) for Middle Tapi river reaches and Appendix C1 (base year to 1981), Appendix C2 (base year to 1990), Appendix C3 (base year to 2000) and Appendix C4 (base year to 2010) for Lower Tapi river reaches. The erosion and deposition areas greater than 50000 square meters (0.05 sq. km) are numbered tabulated in each of the figure. Also, the critical areas highlighted in respective figures were visited during the field trip.

Table 11.17 Vulnerability Index for Upper Tapi river

Erosion Polygon No.	Location	Villages/Urban areas	National/ State highways	Shift (m)	Vulnerability Index (VI)	Category
E10	CH: 23 km - CH: 28 km	Dohlan Iklahara	NA	133	0.5	Not vulnerable
E33	CH: 68 km - CH: 70 km	Khapa	NA	209	0.55	Not vulnerable
E88	CH: 189 km - CH: 200 km	Bhurbhur Batla Kalan Chakara Kasaikheda	NA	243	0.78	Very less vulnerable
E108	CH: 259 km - CH: 261 km	Daryapur Ryt	NA	212	0.55	Not vulnerable
E127	CH: 324 km - CH: 330 km	Ajanad Atwade Dodhe	NA	150	1.03	Less vulnerable
E130	CH: 333 km - CH: 336 km	Therode Dhurkhede	NA	208	0.78	Very less vulnerable
E139	CH: 340 km - CH: 350 km	Sulwadi Kolode	NA	331	0.85	Very less vulnerable

Table 11.18 Vulnerability Index for Middle Tapi river

Erosion Polygon No.	Location	Villages/Urban areas	National/ State highways	Shift (m)	Vulnerability Index (VI)	Category
E141	CH: 350 km to CH: 372 km	Mangalwadi Taskhede Rangaon Gahukhede Raipur Sudgaon	NA	232	1.75	Highly vulnerable due to proximity of many villages to the eroded bank line and relatively large shifting
E164	CH: 407 km - CH: 410 km	Shiragad Pungaon	NA	151	0.58	Not vulnerable
E178	CH: 439 km to CH: 441 km	Kurvel Tawase Khachane	NA	149	0.58	Not vulnerable
E185	CH: 451 km - CH: 453 km	Vichakhede Budhagaon Malkheda	NA	146	0.65	Not vulnerable
E215	CH: 497 km - CH: 499 km	Gidhade	NA	234	0.55	Not vulnerable
E231	CH: 522 km - CH: 522.5 km	Langhane Sahur	NA	36.8	0.6	Not vulnerable
E242	CH: 539 km - CH: 548 km	Vadhe Tembhe Biladi Bamkheda	NA	115	1.03	Less vulnerable
E243	CH: 548 km - CH: 551.5 km	Sasde Shelty	NA	144	0.73	Not vulnerable
E247	CH: 553 km - CH: 554 km	Khaparkhede Nashinde	NA	65.2	0.6	Not vulnerable
E251	CH: 560.5 km - CH: 562 km	Prakasha	MH SH-4	115	0.53	Not vulnerable
E253		Ubhad	MH SH-4	133	1.38	Moderately vulnerable

	CH: 565 km - CH: 573 km	Pisavar Sadgavhan Bhamsal Hol Nimbhora Satola				
E256	CH: 578.5 km - CH: 595 km	Hatoda Untavad Pimlas Gorasa Amode Tarfe Talode Kondraj Gadid	NA	186	1.63	Vulnerable

Table 11.19 Vulnerability Index for Lower Tapi river

Erosion Polygon No.	Location	Villages/Urban areas	National/ State highways	Shift (m)	Vulnerability Index (VI)	Category
E258	CH: 668 km - CH: 680 km	Limbi Sar Jamli Nindvada Bhatvada Mahudi Pipalvada	GJ SH 88	164	1.20	Less vulnerable
E262	CH: 695 km	Khedpur	GJ SH 65	159	0.53	Not vulnerable
E263	CH: 695 km - CH: 711 km	Ushked Khurd Puna Un Kosadi Umarsadi Kamlapor Khanjroli	NA	167	2.00	Highly vulnerable due to proximity of many villages to the eroded bank line

E266	CH: 719 km - CH: 727 km	Pipariya Kudashi Bodhan Ghala	NA	115	1.25	Moderately vulnerable
E270	CH: 735 km - CH: 736 km	Dhoran Pardi Choryasi	NA	53.25	0.6	Not vulnerable
E271	CH: 736 km - CH: 739 km	Amboli Kathor	NA	102	0.63	Not vulnerable
E275	CH: 755 km - CH: 760 km	Utran Variav Jahangir Pura	GJ SH 168	273	1.23	Less vulnerable
E277	CH: 760 km - CH: 771 km	Adajan	GJ SH 197	36.4	0.5	Not vulnerable
E286	CH: 788 km - Ch: 790 km	Dumas	Dumas Road	3048	0.9	Very less vulnerable
E288	CH: 783 km - CH: 790 km	Mora GSEG Colony Hazira	NH 6, Hazira	530 m	1.33	Moderately vulnerable

CHAPTER 12
DETAIL OF TYPICAL RIVER TRAINING WORKS PROPOSED FOR RESTORATION OF CRITICAL AND IMPORTANT REACHES

12.1 GENERAL

Riverbank erosion usually occurs in terms of surface erosion and mass failure which is predominantly influenced by the hydraulic characteristics of the flow as well as the composition of the bank materials. The main factors responsible for stability of river bank are: (1) composition of the bank materials; (2) magnitude of the flood discharge; (3) the angle at which the thalweg approaches the bank line; and (4) the variation of the water level (Nakagawa et al., 2013).

12.2 RESTORATION WORKS FOR IMPORTANT REACHES

The critical river reaches were identified based on their locations, i. e., upstream or downstream of a hydraulic structure or bridge, proximity to urban area, confluence of two rivers, meander bend in a river, etc. From the analyses carried out using satellite images and toposheets as well as field surveys, such reaches have been identified and the restoration works have been proposed for them as discussed in following subsections: -

12.2.1 Tapi Estuary System, Suvali Gam, Hazira (CH: 787.0 km)

Location Details: The Tapi estuary System is a part of the Gulf of Khambat in Suvali Gam, Hazira, Gujarat, located at India's west coast (Fig. 10.12). This area marks the end of Tapi river system where the river drains into Arabian Sea. The Hazira is an industrially important location in Surat Metropolitan Region which is a base for major industrial and shipping firms like Essar, KRIBHCO, Shell, Larsen & Toubro, NTPC, ONGC, GAIL, Gujarat State Petroleum Corporation, Ultra-Tech Cement and Reliance Industries.

Charecteristics and Existing Issues: The cited location experiences strong semidiurnal tides and the spring tides of amplitude greater than 5 m at the mouth of the estuary. The effect of the tide is maximum in and aound the estuary mouth and weakens away from the mouth. The fresh water discharge in the river is maximum during the monsoon period (July to September), while very low during the rest of the year. During the monsoon period, a complex coastal system with high

turbulence is formed here, and the region experiences tidal effect and high river flows. The field visit to this place has shown that, over the time, the estuary has been silted up at an alarming rate.



Fig 12.1 Location map of Tapi estuary system, Suvali Gam, Hazira

This area serves the navigational purpose for industrial firms like Essar, L&T and Reliance but it has been reported that owing to heavy siltation, the operation of ships is greatly restrictred (Ranganath et al., 2013). Owing to these effects, it was observed that the right bank of Tapi river has undergone an outward migration at a high rate leaving only about a 40 m distance between the river bank and the main road. Huge erosion has occurred in the right bank as well as the left bank. Even though bank protection works have been carried out here to arrest river migration, the erosion of the right bank is still progressive. The Tapi river forms three channels here, in between which two islands are located (Fig 12.1). These islands are valuable reserves of mangrove vegetation, which protect vulnerable coastlines from wave action and coastal erosion by holding the soil together. They also shield the inland areas during sea storms and minimize the damages. Due to the gradual outward migration of the river at this location, the mangrove cover has been observed to undergo depletion. It has been observed that at the right bank, there is considerable erosion where the bank is progressively shifting inside (Photo 12.1). The situation at one location is so alarming that the distance between road NH-6 and the river is hardly 2-4 m. This could threaten such an important route and thereby the operation and movement of man and materials.



Photo 12.1 The alarming proximity of right bank to the road NH-6 near Essar, Hazira

Protection measures: Gabions are wired mesh cages or baskets which are filled with stones, may serve the purpose of protecting earth embankments, lining channels, managing river/stream flow and protecting river banks or coast lines. The strength and effectiveness of gabions may increase with time in some cases, as silt and vegetation fill the interstitial voids and reinforce the structure. Groynes may be aligned either normal to the dominant flow direction or at an angle pointing upstream from the right bank at cited location. A groyne pointing upstream repells the river flow away from it and is known as repelling groyne. When a groyne of short length changes only direction of flow without repelling, it is known as deflecting groyne. It has been observed that a series of permeable spurs have been constructed on the right bank to protect it from erosion (Photo 12.2) and gabion structures are provided to protect the electric transmission towers against the action of river currents (Photo 12.3). Further, upon discussion with the officials of Essar Ltd., they conveyed that the company dumps the slag material on regular basis to protect the embankments. Eventhough the right bank is provided with bank protection works, the erosion is still observed at

high rate in upstream of existing bank protection. Hence, proper protection in the form of repelling gryones as well as deflecting gryones can be provided on both the banks for arresting erosion as per the provisions recommended in IS:8408-1994. Further, the islands in the middle of two river reaches which possess rich mangroves, must be protected given its ecological significance. The islands can be protected by constructing embankments and/or stepped/sloping gabions as per IS:14458 (Part-3)-1998. The locations and dimensions of the gryones as well as the embankments/gabions must be derived by conducting suitable physical scaled model studies.



Photo 12.2 Protection of right bank with permeable spurs

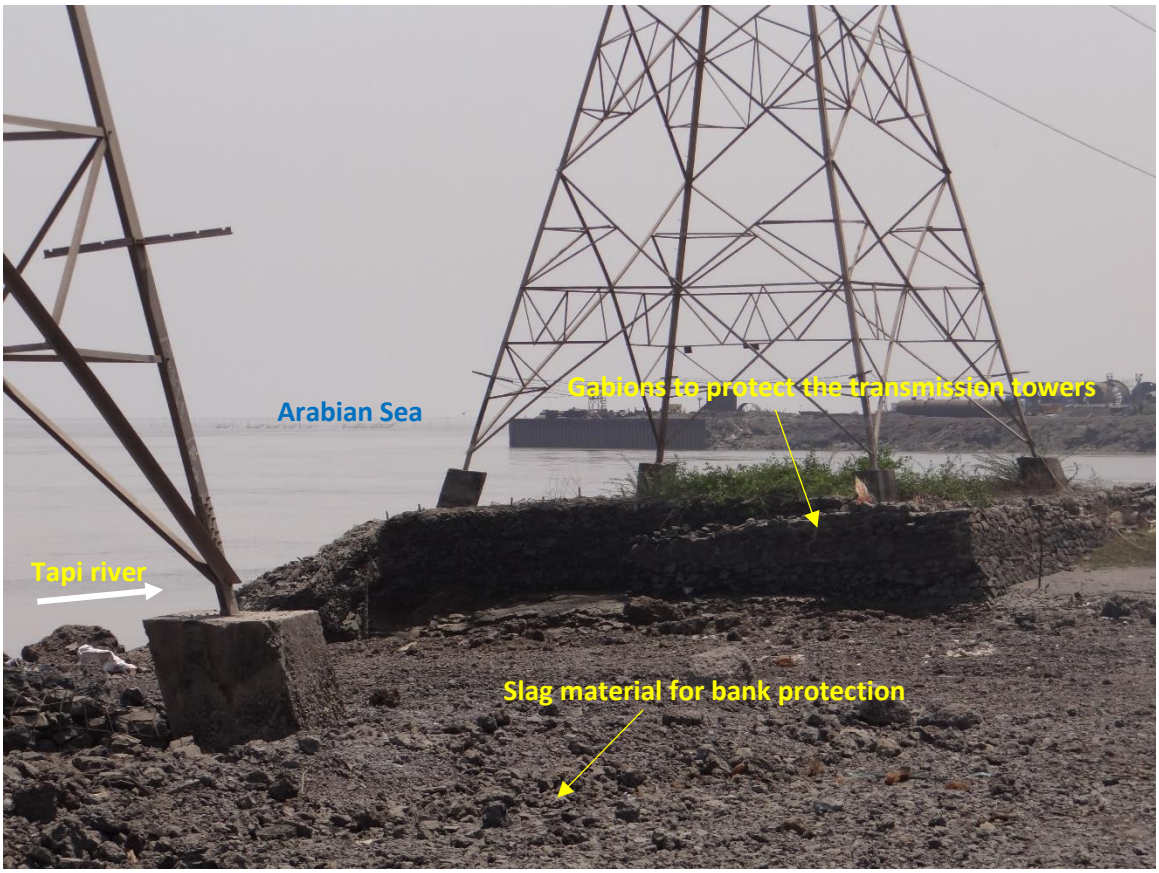


Photo 12.3 Gabions provided for protection of electric transmission towers

12.2.2 Kamrej and Kholvad Villages, Surat (CH: 736 km and 739 km)

Location Details: The Kamrej and Kholvad villages is located in Surat district in Gujarat state at Chainages 736 km and 739 km respectively, from the origin of the Tapi river (Fig. 12.2). A bridge is constructed across the Tapi river as a part of National Highway NH 8 (650 m upstream of Kholvad vilage), connecting Delhi and Mumbai. The width of river at this location is around 350-450 m.

Characteristics and Existing Issues: The banks at this location were observed to be alluvial in nature. The Kholvad village is located on a straight reach compared to Kamrej village, which is situated on the outer meander bend. It has been observed that the flow has been continuously hitting the outer bend, because of that there is severe bank cutting observed at the left bank.

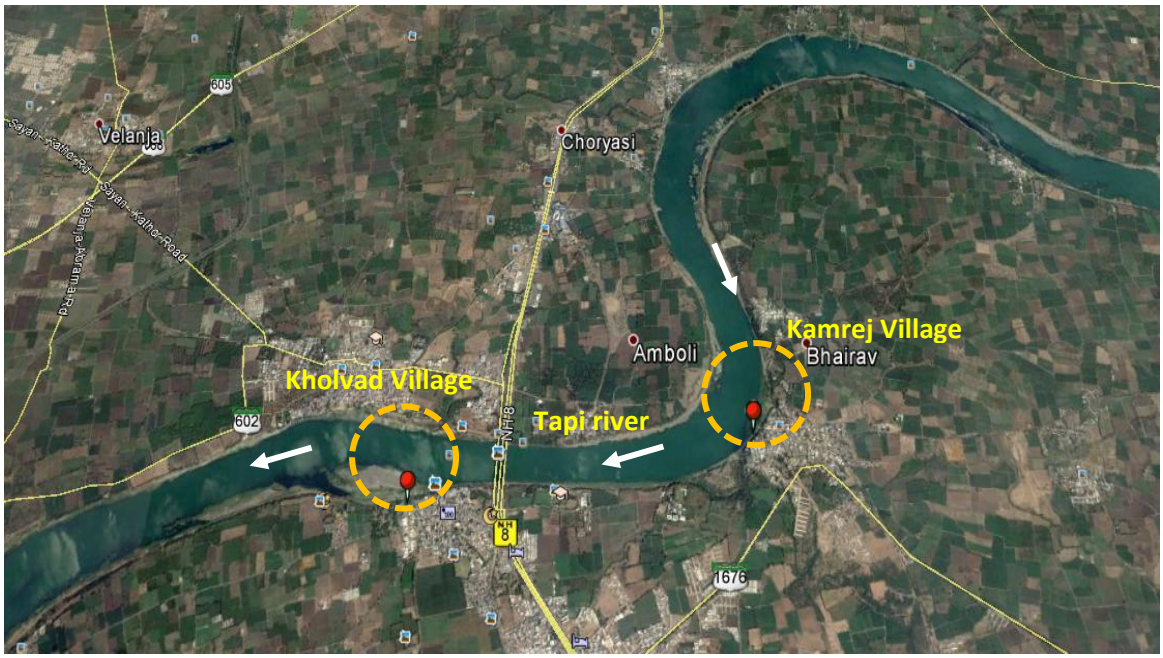


Fig. 12.2 Location map of Kamrej and Kholvad villages



Photo 12.4 Step gabions provided for bank protection near Kholvad village

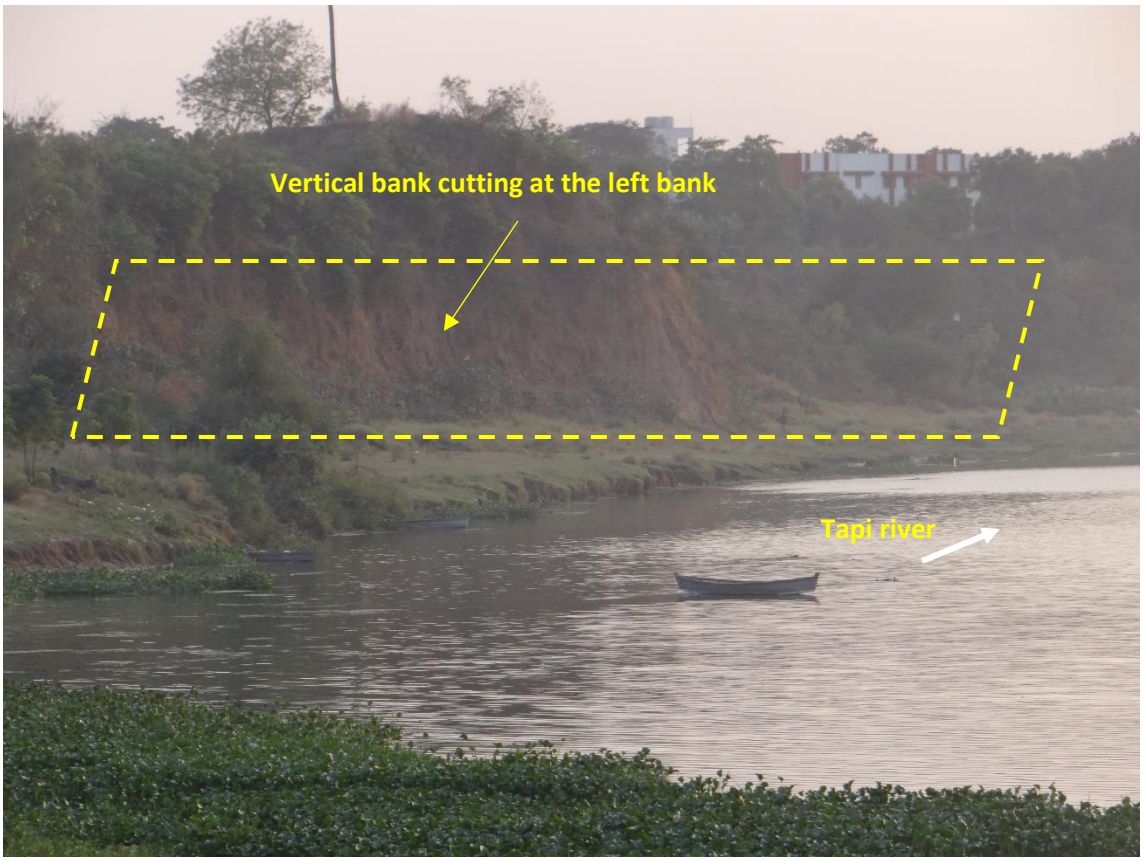


Photo 12.5 Vertical bank cutting on left bank near Kamrej village

Protection measures: The river banks at the meander bends where flow strikes directly must be protected by providing gryones or spurs at suitable locations. At this location, the repelling gryones can be provided in series to deflect the flow away and protect the banks. The groynes or spurs shall be designed as per IS 8408:1994 at the desired locations. Further, the location of gryones/spurs and their dimensions could be derived by conducting physical model studies.

12.2.3 Kavithe-Kukarmunda bridge, Gujarat (CH: 589.0 km)

Location Details: The Kavithe village is located in Nizar taluka of Tapi district in Gujarat state at a chainage 589 km from the origin of the Tapi river (Fig. 12.3). A bridge is constructed across the Tapi river as a part of Gujarat State Highway GJ SH 198, connecting Kavithe and Kukarmunda villages. The width of river at this location is around 400 m. An intake well as a part of lift irrigation scheme for Nizar taluka is constructed and operated under Gujarat Water Resources, Water Supply and Kalpsar Department, Government of Gujarat on the left bank of the river.



Fig. 12.3 Location map of Kavithe-Kukarmunda bridge site

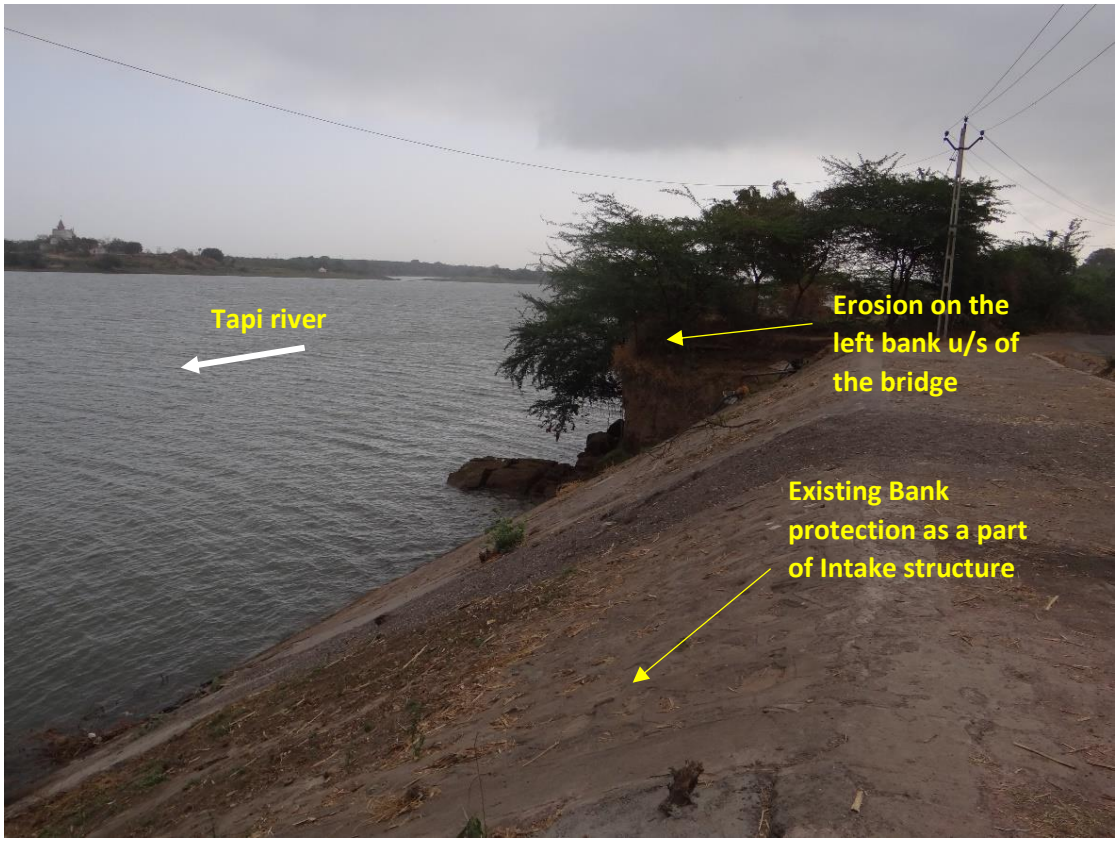


Photo 12.6 Erosion on left bank, upstream of Kavithe-Kukarmunda bridge

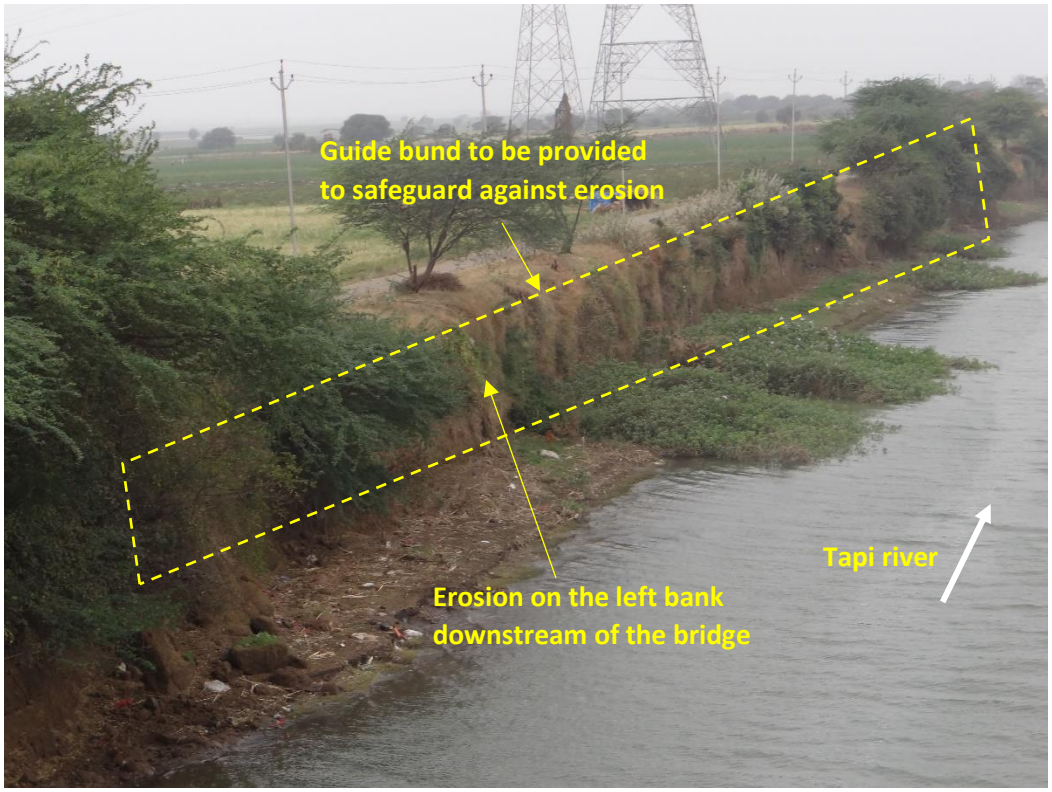


Photo 12.7 Erosion on left bank, downstream of Kavithe-Kukarmunda bridge

Characteristics and Existing Issues: The banks at this location were observed to be alluvial in nature. At this location, it was observed that vertical cutting and falling off of soil has happened in the left bank, upstream of the bridge (Photo 12.6). At the upstream portion, the bank protection is provided for a very short length of about 20-30 m for protecting the intake well. Moreover, vertical cutting has also been observed in further upstream and downstream of the bridge on the left bank and has therefore resulted in considerable erosion (Photo 12.7). The vertical cuts in the left bank, may be possibly due to cave in of banks while filling the Ukai reservoir and bridge afflux between the river banks.

Protection measures: To safeguard the bridge abutments, guide bunds need to be provided on the left bank till covering the effective length upstream and downstream of the bridge as per the guidelines laid in IRC-89:1997 and IS 10751:1994. However, in present situation there is no eminent threat to the bridge structure but there is a possibility that with passage of time, the bank cutting may cause the loss of private land on the left bank of the river. The design of guide bund must be done based on maximum discharge recorded at that site as well as the scour depth

considerations which are enumerated in IRC-89:1997. The river reach near the bridge in almost straight for about 2 km upstream and downstream, hence, provision of parallel guide bunds will be more suitable (see Fig. 12.4).

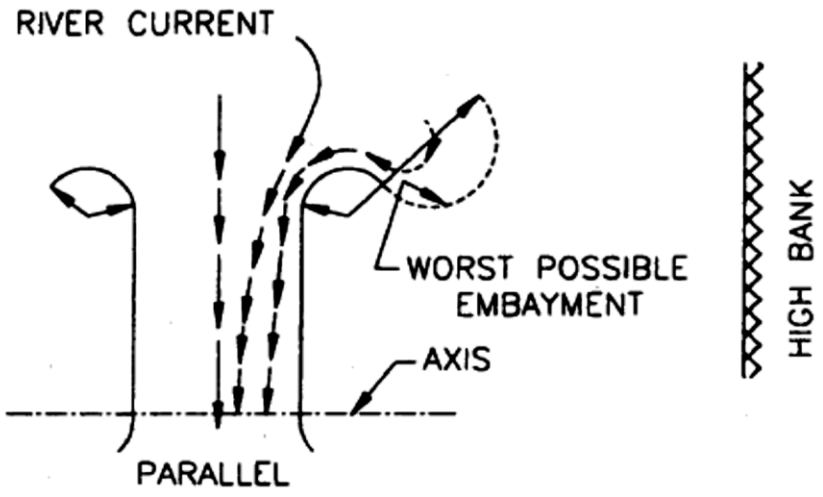


Fig. 12.4 Typical sketch of a parallel guide bund (IRC-89:1997)

Design Philosophy: For wide alluvial belt, the length of the guide bund should be decided from two important considerations, namely maximum obliquity of the current and the permissible limit to which main channel of the river can be allowed to flow near the approach embankment in the event river developing maximum embayment behind the guide bunds. The length of the guide bunds upstream is generally kept as 1.0 L to 1.5 L where no model studies are carried out. While, on the downstream side of the structure, the river tries to fan out to regain its natural width and a length equal to 0.2 L is generally found to be adequate (where L is the width of the river).

12.2.4 Sarangkheda bridge, Maharashtra (CH: 537.9 km)

Location Details: The Sarangkheda barrage across Tapi river and a road bridge is constructed 120 m downstream of the barrage which is a part of Maharashtra State Highway MH SH-1. A bridge is constructed 120 m downstream of the barrage which is a part of Maharashtra State Highway MH SH 1 (see Fig. 12.5). The width of river just upstream of the Sarangkheda barrage is around 480 m.

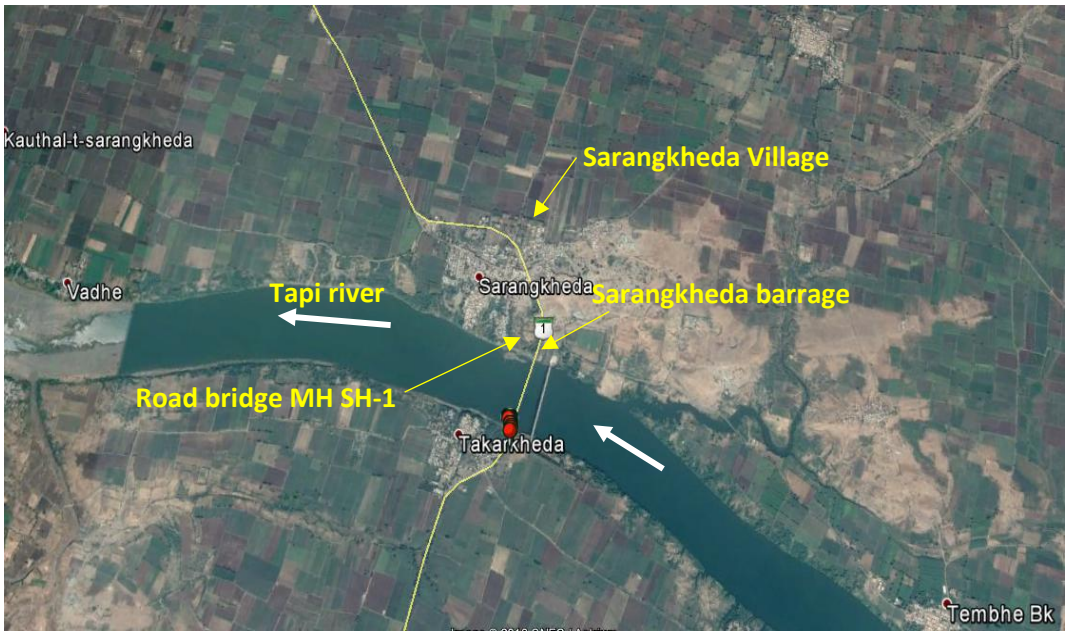


Fig. 12.5 Location map of Sarangkheda barrage and road bridge MH SH-1

Characteristics and Existing Issues: The barrage has a length of 484.5 m, height up to crest as 11 m with 26 spillway gates and design discharge of 50,529 m^3/s. The observed maximum flood discharge at Sarangkheda was 25,259 m^3/s with a HFL of 127.080 m during 08/08/2006. The banks were observed to be alluvial in nature and the river bed comprising of sand and gravels. It has been observed that considerable erosion has taken place on the left bank of the river, where the rip-rap protection below the bridge abutment was found to be damaged (Photo 12.8). The prime reason for damaging of rip-rap protection could be missing guide bunds between the barrage and the bridge. From Photo 12.9, it is visibly seen that portion between the barrage and bridge comprises of loose unstable banks and due to action of floods, the bank material gets washed away and this phenomenon further progresses downstream and thereby causes the erosion under the abutment.

Protection measures: To safeguard the bridge abutments, guide bund has to be provided on the left bank between the barrage and bridge as per the guidelines laid in IRC-89:1997 and IS 10751:1994. Also, the existing rip rap structure should be strengthened in addition to proposed changes. The guide bund should connect the guide wall of barrage and bridge abutment at the same level and extend downstream of the bridge in order to protect the loose soil from getting washed away during high floods.



Photo 12.8 Erosion observed underneath the abutment of road bridge (MH SH 1) on left bank



Photo 12.9 Cutting of left bank in the immediate downstream of Sarangkheda barrage

12.2.5 Mudawad, Maharashtra (CH: 478.0 km)

Location Details: This location marks the confluence of Panjara and Tapi rivers (Fig 12.6). The Panjara River is the left bank tributary of the Tapi river which originates near a small town of Pimpalner in Dhule district. The width of Tapi river at this location is around 350-420 m, while that of Panjara River is about 100-150 m with relatively steeper bed slope.

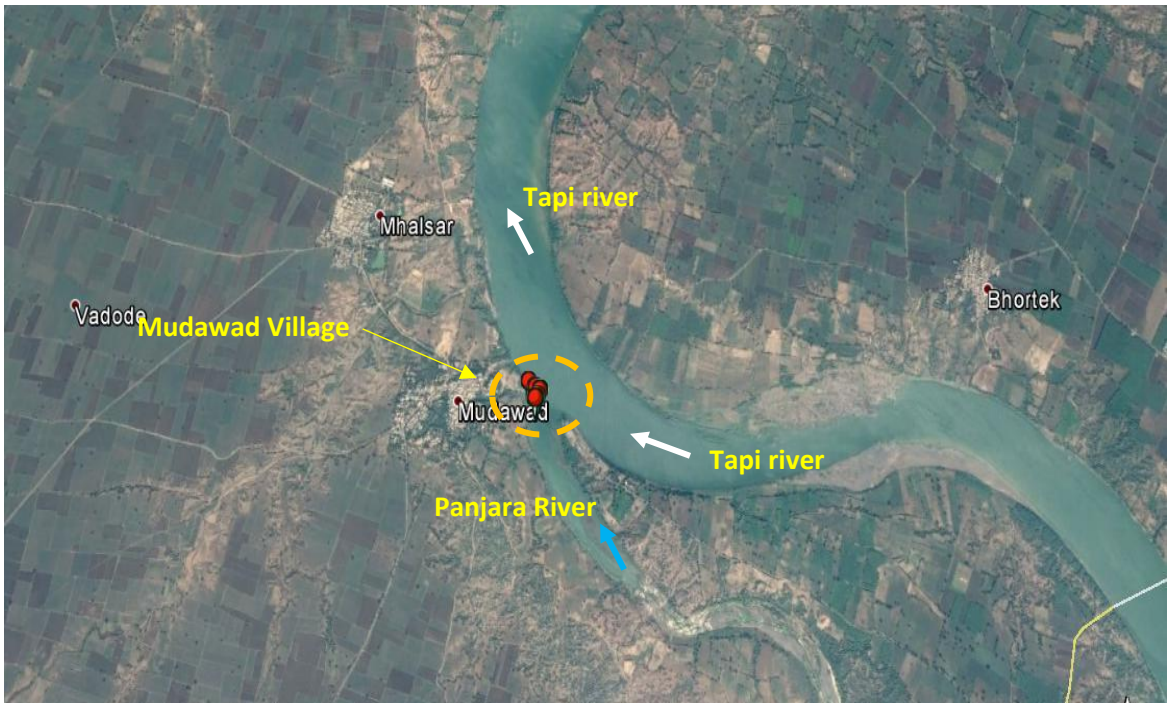


Fig. 12.6 Location map of Mudawad Village

Characteristics and Existing Issues: At this location, it has been observed that left bank of Tapi river and right bank of Panjhara River have undergone considerable erosion at the point of confluence, which has caused damage to the structure of Kapileshwar Mahadev Temple (Photo 12.10). The banks were observed to be alluvial in nature and the river bed was observed to be comprising of finer particles in case of Tapi river, while coarser particles in case of Panjara River. Two stream gauging sites are located upstream of Mudawad village on Tapi as well as Panjara Rivers, viz., Savkheda and Morane respectively. The maximum discharge observed at Savkheda on Tapi river and Morane on Panjara River have been observed to be 24,856 m^3/s and 645 m^3/s respectively. Further, the variation in mean annual discharge in both the rivers have been found to vary considerably.

Protection measures: To restrict further damages, these banks shall be strengthened by means of providing suitable bank stabilization structures such as guide bunds as per IRC-89:1997 and IS 10751:1994. It is therefore recommended to protect the banks at the confluence where considerable turbulence is created due to mixing of flow.



Photo 12.10 Erosion on the left bank of Tapi river and right bank of Panjara River at the point of confluence

12.2.6 Gangapuri, Jalod, Maharashtra (CH: 454.0 km)

Location Details: At this location, Budhgaon bridge is constructed across the Tapi river (Fig 12.7). The Gangapuri village is located in Dhule district of Maharashtra state at a chainage CH: 454.0 km from the origin of the Tapi river. The bank width of Tapi river at this location is about 350 m.

Characteristics and Existing Issues: At this location, silty bank material was found on the right bank whereas in left bank we could observe clayey deposits. The Tapi river has been observed to follow a sinuous path here, showing prominent erosion in the form of bank cutting along its left bank (Photo 12.11). The effect of secondary currents is clearly visible here, and a well developed

point bar has been formed on the right bank due to huge deposition of sediments. The erosion phenomenon if continues may pose threat to the bridge, which may result in bridge scouring.



Fig 12.7 Location map of Gangapuri, Jalod, Maharashtra



Photo 12.11 Erosion on left bank of the river

Protection measures: The river banks at the meander bends where flow strikes directly must be protected by providing gryones or spurs at suitable locations. The gryones or spurs function to reduce the concentration of flow at the point of attack, creating a slack flow for silting up the area in the vicinity and protecting the bank by keeping the flow away from it. The groynes or spurs shall be designed as per IS 8408:1994 at the desired locations (Fig. 12.8). The repelling gryones can be provided in series and can also be used in combination with other training measures also. Further, the location of gryones/spurs and their dimensions could be derived by conducting physical model studies.

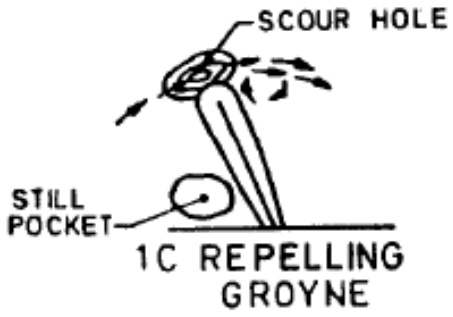


Fig. 12.8 Typical sketch of repelling gryone (IS 8408:1994)

12.2.7 Burhanpur Fort, Sanjaynagar, Madhya Pradesh (CH: 308.0 km)

Location Details: The Burhanpur Fort is located on the right bank of Tapi river (Fig 12.9). The location is popularly known as Rajghat. The Rajghat is situated on a meander bend so the width of the river at this location varies from 150-250 m. The river forms a meander bend here and at the outer bend, i.e., the right bank has been eroded.

Characteristics and Existing Issues: At this location, the river reach is alluvial, and the river follows a sinuous path. Significant erosion of RBL was observed near the fort (Photo 12.12). The part of the structure was also seen in damaged condition due to prevailing flow conditions in the river. Contrary to above, the left bank has been noticed to have significant deposition on the inner bend (LBL), see Fig 10.18.

Protection measures: At this location, the fort wall can be strengthened by constructing a gabion wall in the portion where the erosion is observed. Moreover, groynes or spurs can also be

constructed just upstream of the structure to minimize the erosion effect as per the guidelines laid in IS 8408:1994.

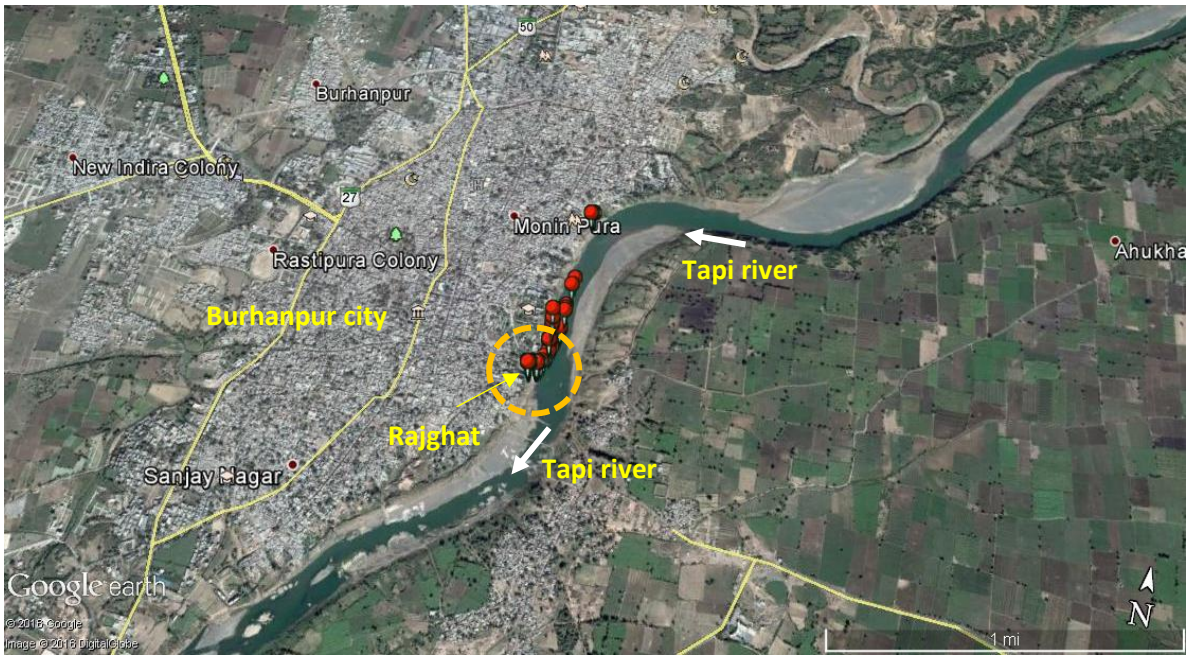


Fig 12.9 Location map of Rajghat and Najirighat in Burhanpur

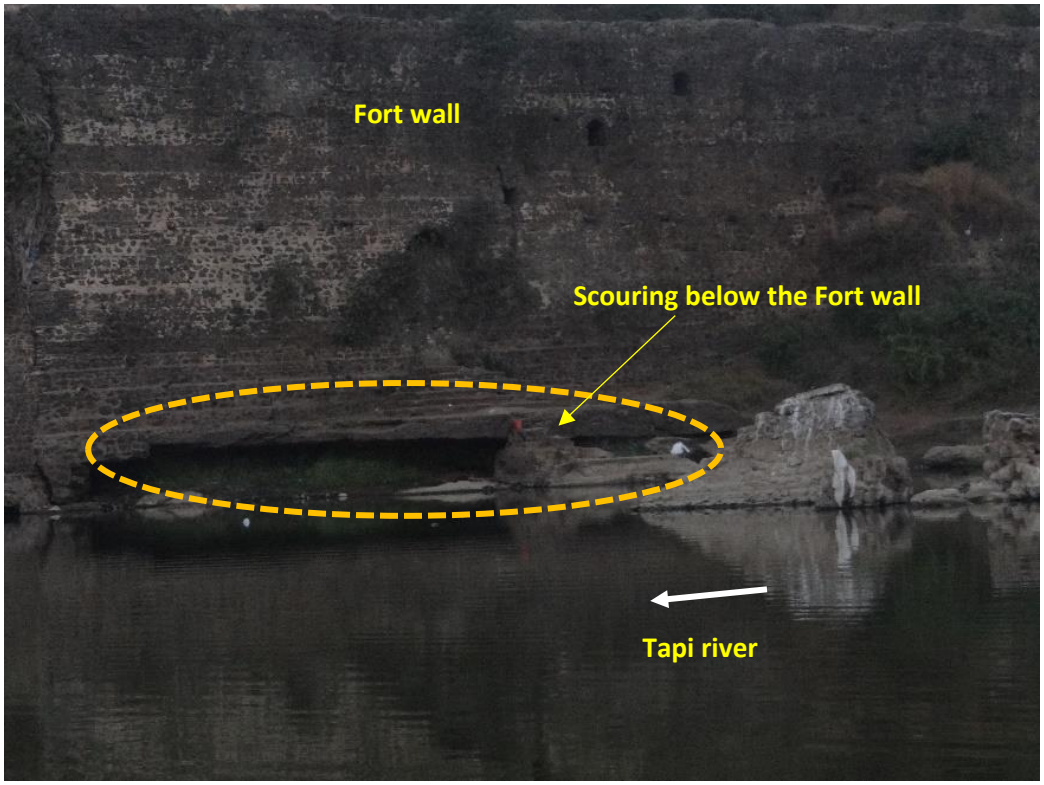


Photo 12.12 damaged portion of Fort wall near Rajghat in Burhanpur

Design Philosophy. As per IRC:89-1997, in a straight reach, the spacing is about three times the length of the spur. While in a curved reach, a spacing of 2 to 3.5 times the length of spur is recommended. Moreover, larger spacing (3 to 3.5 times) can be adopted for concave banks and smaller spacings (2 to 3 times) can be adopted for convex banks. Also, spurs are spaced further apart w.r.t. their length in a wide river than a narrower one.

The overall summary of the typical river training works proposed for Tapi river is shown in tabular form in Table 12.1.

Table 12.1 Details of the river training works proposed for restoration of critical river reaches

Sr No.	Chainage	Location	Suggested River Training works	Remarks
1	CH: 787 km	Tapi Estuary System, Suvali Gam, Hazira	1) Repelling gryones as well as deflecting gryones should be provided on both the banks for arresting erosion as per IS:8408-1994 2) The islands are to be protected by constructing embankments and/or stepped/sloping gabions as per IS:14458 (Part-3)-1998	The locations and dimensions of the gryones as well as the embankments/gabions must be derived by conducting suitable physical scaled model studies
2	CH: 736 km and 739 km	Kamrej and Kholvad Villages, Surat	The river banks at the meander bends where flow strikes directly must be protected by gryones or spurs at suitable locations as per IS 8408:1994	The locations and dimensions of the gryones and spurs must be derived by conducting suitable physical scaled model studies
3	CH: 587.0 km	Kavithe-Kukarmunda bridge, Nizar	1) Guide bunds on the left bank till covering effective length upstream and downstream of the bridge as per the guidelines laid in IRC-89:1997 and IS 10751:1994 to safeguard the bridge abutments .	1) The design of guide bund must be done on the basis of maximum discharge recorded at that site as well as the scour depth considerations which are enumerated in IRC-89:1997 2) The river reach near the bridge in almost straight for about 2 km upstream and downstream, hence, provision of parallel guide bunds would be more appropriate
4	CH: 537.9 km	Sarangkheda bridge, Maharashtra	1) Guide bund to be provided on the left bank between the barrage and bridge as per the guidelines laid in IRC-89:1997 and IS 10751:1994	Guide bund should connect the guide wall of barrage and bridge abutment at the same level and extend downstream

			2) Existing rip rap structure should be strengthened	of the bridge in order to protect the loose soil from getting washed away during high flood
5	CH: 478.0 km	Mudawad, Maharashtra	Protect the banks at the confluence where considerable turbulence is created due to mixing of flow by means of providing suitable bank stabilization structures such as guide bunds as per IRC-89:1997	---
6	CH: 454.0 km	Gangapuri, Jalod, Maharashtra	The river banks at the meander bends where flow strikes directly must be protected by gryones or spurs at suitable locations as per IS 8408:1994	The locations and dimensions of the gryones and spurs must be derived by conducting suitable physical scaled model studies
7	CH: 308.0 km	Burhanpur Fort, Sanjaynagar, Madhya Pradesh	1) Fort wall to be strengthened by constructing a gabion wall in the portion where the erosion is observed 2) Gryones or spurs to be constructed just upstream of the structure to minimize the erosion effect as per the guidelines laid in IS 8408:1994.	---

12.3 DETAILS OF LOCATIONS WITH EXCESSIVE SEDIMENT DEPOSITION

The details of the river banks which have undergone excessive deposition have already been incorporated in Volume-II of this report as Appendix A1 (base year to 1981), Appendix A2 (base year to 1990), Appendix A3 (base year to 2000) and Appendix A4 (base year to 2010) for Upper Tapi river reaches, Appendix B1 (base year to 1981), Appendix B2 (base year to 1990), Appendix B3 (base year to 2000) and Appendix B4 (base year to 2010) for Middle Tapi river reaches and Appendix C1 (base year to 1981), Appendix C2 (base year to 1990), Appendix C3 (base year to 2000) and Appendix C4 (base year to 2010) for Lower Tapi river reaches. Also, the most recent cross-sectional details of various locations in Upper, Middle and Lower Tapi rivers were used to obtain the bed level variations during 2015-2017. Using these analyses and the field visit investigations, the probable river reaches from where such sediments can be desilted/dredged for construction purposes and other activities have been identified and tabulated separately for Upper, Middle and Lower Tapi rivers (wrt. base year-2010) in Tables 12.2-12.4. Also, the locations of prevailing sand mining activities are highlighted. However, detailed prior investigation must be carried out, before planning the desilting/dredging activities at these locations which may affect the river, its adjoining flood plain, the aquatic habitats and the inhabitants in nearby villages/ urban areas. Also, the legal authenticity of the existing sand mining activities be investigated.

Table 12.2 Details of locations with excessive sediment deposition in Upper Tapi river

Location	Nearby village / hydraulic structure	Deposition polygon no.	Area (m^2)	Remarks
CH:253.33 km	Melchuka	D110	1338509	Significant deposition on the inner bend (LB)
CH: 312.17 km	Burhanpur	D119	3919583	Significant deposition on the inner bend (LB)
CH: 320 km	Sirsoda	D124	2638722	Deposition on the left bank

Table 12.3 Details of locations with excessive sediment deposition in Middle Tapi river

Location	Nearby village / hydraulic structure	Deposition polygon no.	Area (m^2)	Remarks
CH: 350 km	Upstream of Hatnur dam	NIL	NIL	As per the study carried out by Maharashtra Engineering Research Institute (MERI) during 2007-2008, observed rate of sedimentation = 2.374 ha.m/100 sq.km/year which is five times the rate adopted while designing, i.e., 0.451 Ha.m/100 sq.km/year
CH: 380 km - CH: 390 km	Between Aklud Village and Bhalshiva Village	NIL	NIL	Significant amount of sediment deposits visible within the active channel of Tapi river
CH: 418.5 km	Pimpri Village	D170	231484	Significant deposition on the right bank (RB)
CH: 454 km	Gangapuri, Jalod	D184	500014	Sand mining activities obserevd on the left bank in the downstream of the Budhgaon bridge
CH: 460 km - CH: 470 km	Between Vitner Village and Piloda Village	NIL	NIL	Significant amount of sediment deposits visible within the active channel of Tapi river
CH: 498 km - CH: 510 km	Between Sulwade barrage and Achhi Village	NIL	NIL	Significant amount of sediment deposits visible within the active channel of Tapi river
CH: 544 km	Biladi Bamkheda Village	D239	570240	Sand mining activity observed at the left bank at about 500 m upstream of the site
CH: 561 km	Downstream of Prakasha barrage	D249	979733	Significant deposition on the right bank (LB) downstream of Prakasha barrage
CH: 581 km	Upstream of Ukai dam	D253	961631	Significant deposition on the right bank (LB) upstream of the Ukai dam for a length of about 13 km

Table 12.4 Details of locations with excessive sediment deposition in Lower Tapi river

Location	Nearby village / hydraulic structure	Deposition polygon no.	Area (m^2)	Remarks
CH: 662.28 km	Ukai Village	NIL	NIL	A rise in bed level with a maximum rise of 10 m obtained during 2015-2017, see Section 10.9.3
CH: 705.0 km	Umarsadi Haripura bridge Site, Mandvi	NIL	NIL	Excessive sand mining taking place at both right bank and left bank of the river
CH: 721 km	Bodhan Village	NIL	NIL	Excessive sand mining taking place at left bank of the river
CH: 730 km	Ghala Village	NIL	NIL	Sand mining activities observed at right bank of the river (Similar observations made while analyzing bed level variations in Lower Tapi river, see Sections 10.9.3 and 10.9.4)
CH: 780 km - CH: 792 km	Hazira Region	NIL	NIL	As per the braiding pattern, the PFI values observed to be increasing over the decades, indicating deposition of sediments. Dredging activities may be carried out for removing the excess sediments

12.4 DETAILS OF EXISTING BRIDGES IN TAPI RIVER

Before carrying out any river restoration activities, dredging or desilting activities or construction of a new hydraulic structure, it is important to know the locations and details of the existing bridges that lie on the river and the possible effects of such activities on the bridges. Tables 12.5-12.7 give the details of the existing bridges on Upper, Middle and Lower Tapi rivers respectively. The bridge details were obtained from Surat Municipal Corporation (SMC) and Surat Irrigation Circle (SIC) for bridges that fall in Gujarat State, Public Works Division, Nashik and Tapi Irrigation Development Corporation (TIDC), Jalgaon for bridges that fall in Maharashtra State and Public Works Department (PWD), Madhya Pradesh for bridges that fall in Madhya Pradesh State. The details of such bridges are also marked in Volume-II of this report as Appendix A1 (base year to 1981), Appendix A2 (base year to 1990), Appendix A3 (base year to 2000) and Appendix A4 (base year to 2010) for Upper Tapi river reaches, Appendix B1 (base year to 1981), Appendix B2 (base year to 1990), Appendix B3 (base year to 2000) and Appendix B4 (base year to 2010) for Middle Tapi river reaches and Appendix C1 (base year to 1981), Appendix C2 (base year to 1990), Appendix C3 (base year to 2000) and Appendix C4 (base year to 2010) for Lower Tapi river reaches.

Table 12.5 Details of existing bridges in Lower Tapi river

Name	Location	Year of construction	State	Length (m)	Width (m)	Width of the Tapi river (m)	No. of span	Span length (m)	Type of bridge	Remarks
Hindustan bridge	CH: 669 km	---	Gujarat	342.25		300	8	5 No. of 42.50 m, 1 No. of 42.95 m and 1 No. of 43.90 m	High level bridge	---
Mandvi bridge	CH: 695 km	---	Gujarat	550		River flows in multiple channels along a rocky bed stratum	14	12 No.s of 48.00 m	High level bridge	---
Umarsadi Haripura bridge	CH: 689.7 km	---	Gujarat	---	---	River flows in multiple channels along a rocky bed stratum	59	6	---	---
Bodhan Flyover	CH: 721 km	---	Gujarat	---	---	230			---	---
Kholvad bridge	CH: 739 km	---	Gujarat	---	---	250	11	38	---	---
Savjibhai Korat bridge	CH: 748 km	2001	Gujarat	544.6	21.5	490	13	11 No. of 42 m each and 2 No. of 41.3 m each at the ends	High level bridge	---

Utran-Kapodara bridge	CH: 750 km	---	Gujarat		---	530	---	---	---	---
Railway bridge No. 452	CH: 751 km	1915	Gujarat	572.3	12.23	490	10	57	High level bridge	---
Amroli bridge	CH: 757 km	1982	Gujarat	607.32	---	510	12	50.61	---	---
Dabholi Jahangirpura bridge	CH: 761 km	---	Gujarat		---	945	---	---	---	---
Morarji Desai Setu (weir cum causeway)	CH: 763 km	1995	Gujarat	580	10	580	16 (gated portion)	6.2	Causeway cum weir	---
Nehru bridge	CH: 765 km	1966	Gujarat	603.5	11.56	150	13	10 No. of 50.6 m, 2 No. of 44.50 m and 1 No. of 8.50 m	High level bridge	---
Swami Vivekanand bridge	CH: 766 km	1996	Gujarat	625	19.52	190	25	25	Submersible bridge	---
Sardar Patel bridge	CH: 767 km	1991	Gujarat	700	22.4	170	14	50	High level bridge	---
ONGC bridge	CH: 775 km	1984	Gujarat	900	---	470	18	50	---	---

Table 12.6 Details of existing bridges in Middle Tapi river

Name	Location	Year of construction	State	Length (m)	Width (m)	Width of the Tapi river (m)	No. of span	Span length (m)	Type of bridge	Remarks
Hatnur bridge	CH: 351 km	2000	Maharashtra	480	NA	320	20	NA	NA	Protection wall has been proposed by the dam authority inorder to safeguard the banks
bridge near Bhusawal	CH: 376.39 km	1961 and 2007-08	Maharashtra	597.1	8.3	River flows in multiple channels along a rocky bed stratum	29	20.6	High Level submersible	Good condition bridge
bridge near Vidgaon	CH: 406.14 km	1961 and 2007-08	Maharashtra	390	8.3	140	5	20.6	High Level	Well foundation is exposed at pier-1, pier-2 and pier-3; Increased floral growth observed adjacent to the bridge abutments
bridge near Savkheda	CH: 442.93 km	1961 and 2007-08	Maharashtra	417.6	8.3	260	9	46.4	High Level	Twin well foundation is exposed and possibility of scouring at Pier-1 to pier-7; Silt accumulation and undergrowth observed in Span-

										1, span-8 and span-9
Budhgaon bridge	CH: 454 km	2010	Maharashtra	560	10	350	14	40	High Level	Bank protection works have been provided for a length of 0.62 km towards Jalod Village (left bank) and 1.23 km towards Budhgaon Village (right bank)
Tapi bridge near Sukwad	CH: 496 km	1933	Maharashtra	336	10	440	28	12	High Level	Vegaetation growth on the superstructure
bridge near Sarangkheda	CH: 537.9 km	1957	Maharashtra	513	7	480	11	46.64	High Level	Scouring is observed in Abutment-1
bridge near Prakasha	CH: 561 km	1961 and 2007-08	Maharashtra	594.74	8	540	39	15.25	High Level submersible	Spalling of concrete and steel exposed at side wall of abutment-2; Erosion of concrete surafce and scouring observed ta pier-3, pier-4, pier-6 and pier-12; Vegetation growth observed at pier-12 and pier-17
Kavithe-Kukarmunda bridge	CH: 589 km	---	Gujarat	---	---	380	---	---	High Level	---

Table 12.7 Details of existing bridges in Upper Tapi river

Name	Location	Year of construction	State	Length (m)	Width (m)	Width of the Tapi river (m)	No. of span	Span length (m)	Type of bridge	Remarks
Khandwa-Dedtalai Road bridge	CH: 235 km	1992	Madhya Pradesh		---	180	9	7 No. of 41.50 m and 2 No. of 17.25 m	High Level	---
Majrod Kalan-Daryapur Road bridge	CH: 260 km	Under construction	Madhya Pradesh	285	---	220	---	---	---	---
Nepanagar-Ambada Road bridge	CH: 288.50 km	Under construction	Madhya Pradesh	263.53	---	300	16	16 No. of 16.47 m	---	---
Zainabad-Rajghat Road bridge	CH: 308.71 km	Under construction	Madhya Pradesh	240	---	240	16	16 No. of 15 m	Submersible	---
Indore-Ichchapur Road bridge	CH: 311 km		Madhya Pradesh		---	280	---	---	---	---
Hatnur-Bhatkheda Road bridge	CH: 317.21 km	1985	Madhya Pradesh	210	---	200	12	12 No. of 17.50 m	Submersible	---
Pimprinadu bridge	CH: 338 km	2001	Maharashtra	250	NA	240	5	---	---	Gabion wall is provided for bank protection

CHAPTER 13
FLOOD AFFECTED AREA

13.1 INTRODUCTION

The reconnaissance survey undertaken for the whole stretch of Tapi river and interaction with concern stake-holders revealed that lower Tapi river is much more prone to the flood vis-à-vis Middle and Upper Tapi river. The Ukai project is the largest multipurpose project and its dam site is located across the lower Tapi river near Ukai village of Fort-Songadh taluka in Tapi district of Gujarat. The Surat city, located about 85 km downstream of the Ukai dam is highly flood prone area. The catchment area of the Tapi river up to Ukai is 62,225 km^2. The dam site is located about 23 km upstream of the Kakrapar weir. The dam comprises a 4,927m long earth-cum-masonry dam. The top bund level of earthen and masonry dam is located at 80.77 m and 68.68 m respectively above the lowest foundation level. The reservoir has a live storage capacity of 0.71 M ha-m at FRL 105.156 m. Historical records indicate that larger river floods have occurred in the Surat city during years 1727, 1776,1782, 1829, 1837, 1872, 1944, 1959, 1968,1970, 1994, 1998 and 2006 (Kale and Hire, 2004). The flood of year 1968 in the Tapi river, with a peak discharge of 42,500 m^3s^{-1}, was the highest in the last century (Timbadiya et al. 2015). The major floods in the Lower Tapi river in the last five decades are tabulated in Table 13.1.

Table 13.1 Major floods in the Lower Tapi river in last five decades

Sr. No.	Year	Peak Discharge (m^3s^{-1})	Water level (m) at Nehru bridge, Surat
1	1968	42500	12.08
2	1994	14384	10.10
3	1998	19815	11.40
4	2006	25780	12.40

The lower Tapi river has faced the major flood in the recent past in year 1994, 1998 and 2006 after construction of the Ukai dam. The peak outflow from Ukai dam in year 1998 and 2006 is, 19815 m^3s^{-1} and 25780 m^3s^{-1} respectively. The flow carrying capacity of Tapi river at Surat city has been reduced with time due to unprecedented development in the floodplain and silting of river bed due to tidal currents and accumulation of sediments in the storage of Singapore weir cum

causeway in the city. Sharma (2012) also highlighted the reduction in the capacity of Tapi River in Surat city due to encroachment in the flood plains and silting in the Singapore weir. The city has total population of 4,461,026 (as per census in year 2011); and is distributed into its seven zones (area wise) as shown in Fig 13.1.

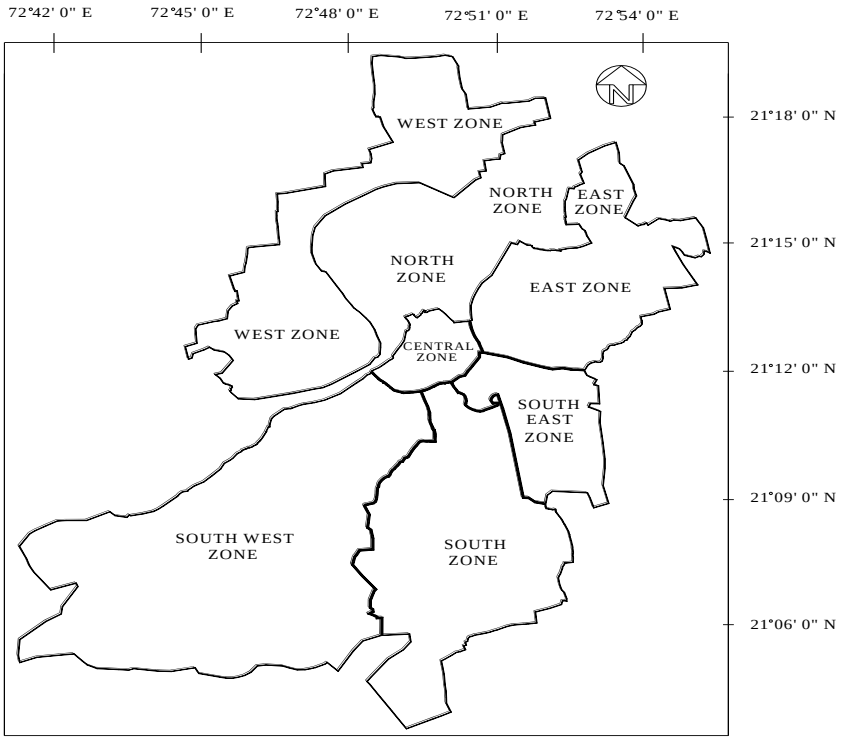


Fig. 13.1 Zone wise distribution of Surat city excluding outskirt rural area (Source: Timbadiya et al. 2015)

Table 13.2. Zone-wise Urban Area in Surat City

Sr. No.	Name of zone	Area (km^2)
1	Central Zone	08.18
2	North Zone	36.363
3	East Zone	37.525
4	South East Zone	19.492
5	South Zone	61.764
6	South-west Zone	111.912
7	West Zone	51.29
	Total	**326.515**

Distributed maximum water depths at location, during flood of year 2006 were marked by Surat Municipal Corporation (SMC) in all the zones of the Surat City. The markings were based on the debris marks on the walls and the communication with residents of particular locality. The photographs of the maximum water level marks in the city were captured and few selected photographs are shown in Photo 13.1 to 13.3 as reference.



Photo 13.1 Maximum water level during flood of 2006 at Pragna vidhyalaya in North zone



Photo 13.2 Maximum water level during flood of 2006 at Pandol in North zone



Photo 13.3 Maximum water level during flood of 2006 at Variavi Bazar in Central zone



Photo 13.4 Maximum water level during flood of 2006 at Athwagate in West zone

13.2 DATA ANALYSIS AND INTERPRETATION

The 1D-2D coupled hydrodynamic model for lower Tapi river and Surat city including its outskirt area was developed by Timbadiya et al. (2014). The said model was used to simulate flood of year 1998 and 2006. The data used in the said study and other output are shown subsequently.

13.2.1 The flood of year 2006

The outflow from the Ukai dam during the flood of year 2006 is shown in the Fig. 13.2

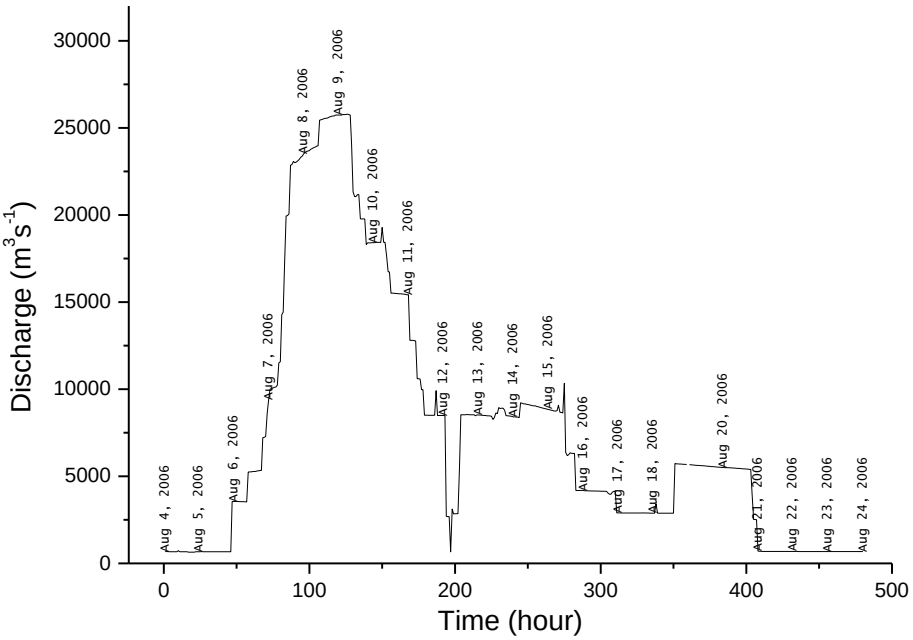


Fig. 13.2 Flow hydrograph of Ukai during flood of year 2006 (Timbadiya et al. 2014)

Total about 80% of the area of the Surat city was affected due to the flood during year 2006. The releases from Ukai reservoir as depicted in Fig 13.2 was used as upstream boundary condition for simulation of flood of year 2006 by Timbadiya et al. (2014).

13.2.2 Tidal levels during flood of year 2006

The selection of boundary conditions depends on the availability of data and the physical situations of the model area. For unsteady state simulation, hourly discharge hydrograph and hourly water level hydrograph are invariably being considered as upstream and downstream boundary conditions respectively. Accordingly, hourly discharge hydrograph at Ukai dam and hourly spring

tidal levels in the sea were considered as upstream and downstream boundary conditions respectively for simulation of flood for year 2006 as shown in Fig. 13.3.

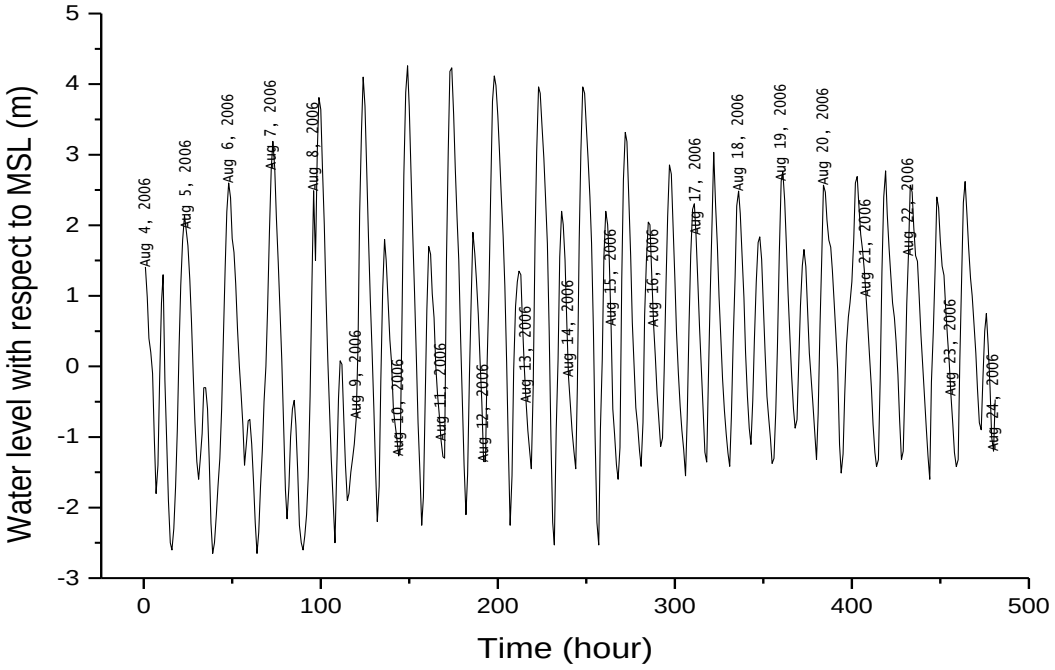


Fig. 13.3 Tidal level (downstream boundary condition) during flood of year 2006

13.3 RESULTS AND DISCUSSIONS

The key results of simulation of flood of year 2006 is included in following paragraphs:

13.3.1 Hydraulic Properties of the flood in the River and Floodplain

Various hydraulic properties of flow generated through simulation of flood of year 2006 using foregoing hydrodynamic model and tabulated in Table 13.3. It is apparent that Flood of year 2006 was nearly horizontal under subcritical condition. After going through entire simulation results, it is found that hydraulic jump was formed at the downstream of Kakrapar weir, may be due to excessive sloped channel, and submergence condition was arrived at Singapore weir for the highest discharge.

Table 13.3 Hydraulic properties of flood in lower Tapi river (Source: Timbadiya et al. 2015)

SN	Stations	Velocity (m/s)	Froude No.	Energy level Slope (10^{-4})	Water level Slope (10^{-4})	Bed shear stress (N/m^2)
		Max	Max	Max	Max	Max
1	Kakrapar weir	3.10	0.29	2.3	2.6	34.86
2	Mandavi bridge	3.67	0.33	3.6	1.3	50.28
3	Ghala	3.51	0.28	3.5	4.3	43.76
4	Singanpur weir	2.64	0.24	1.4	1.7	26.73
5	Surat city (Nehru bridge)	3.14	0.47	4.5	3.3	40.14

Various hydraulic properties of flow, generated through simulation of flood of year 2006 using foregoing model, for the floodplain (Surat city) are tabulated in Table 13.4.

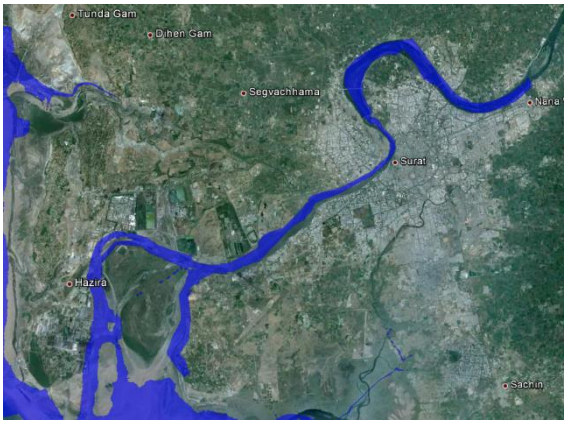
Table 13.4 Wave hydraulic for flood of year 2006 on floodplain (Surat City)
(Source: Timbadiya et al. 2015)

Sr. No.	Properties	Unit	Max.
1	Water depth	meter	6.06*
2	Flow flux in x direction	$m^3/s/m$	9.74
3	Flow flux in y direction	$m^3/s/m$	28.02
4	u-velocity	m/s	2.80
5	v-velocity	m/s	3.65

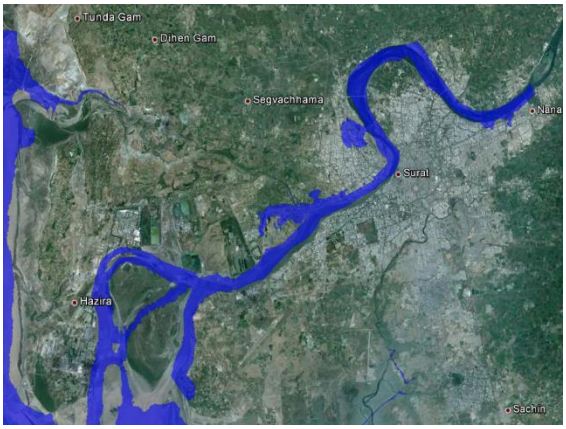
* Depth of water in city area, urban area

The simulated water depth in the floodplain, clearly indicates that the building up to two storied (up to height 6m) were under submergence during the flood of year 2006. The highest simulated depth of the flood is in the North zone having a value of 6.03 m, can be ascertain in Photo 13.1. The West Zone and North zone were highly affected due to the flood of the year 2006 followed by the Central Zone. The higher values of fluxes in x and y direction may be due to the entering of the flood water into the floodplains from either bank of the river. The high velocity, as simulated for the floodplain, may be the main reason for major damages during the flood of year 2006. The aforesaid simulation model is helpful in quantifying the water depth in all the zones, stream power for a given flood situation, spread of the flood over the time and development of stage-discharge

curve along the river. The temporal variation of the inundation depths during flood of year 2006 is shown in the Fig. 13.4.



Date: 06-08-2006 at Time 06:00:00 having Ukai discharge: 3,546 m^3s^{-1}



Date: 07-08-2006 at Time 12:00:00 having Ukai discharge: 19,974 m^3s^{-1}



Date: 07-08-2006 at Time 18:00:00 having Ukai discharge: 23,038 m^3s^{-1}



Date: 08-08-2006 at Time 06:00:00 having Ukai discharge: 23,876 m^3s^{-1}



Date: 08-08-2006 at Time 18:00:00 having Ukai discharge: 25,662 m^3s^{-1}



Date: 08-08-2006 at Time 24:00:00 having Ukai discharge: 25,770 m^3s^{-1}

Fig. 13.4 Temporal changes in areal extent of the flood

13.3.2 Prediction of Rating Curves in the Lower Tapi river

Various hydraulic properties of flow were generated for the study reach through simulation of flood of year 2006 using the developed model and tabulated in the Table 13.3. The levels with respect to the mean sea level are marked at different gauging stations and control structures along the lower Tapi river. Accordingly, discharge and water level (stage) have been considered as dependent and independent variable respectively for the development of the stage-discharge curve (rating curve) through hydrodynamic simulation undertaken in the present study. Mosley and McKerchar (1993) presented the general form of the rating curve equation as

$$\boldsymbol{Q = C(h + a)^N} \qquad \textbf{13.1}$$

where Q=discharge in m^3s^{-1}; C and N are constants; h=stage (free surface elevation) in meter and a = stage at which discharge is zero. The rating curves have been derived using log-log regression relationships for simulated values at Kakrapar weir, Mandvi bridge, Ghala village, Singanpur weir and Nehru bridge (Surat City).

13.3.3 Rating Curves using 1D-2D Coupled Approach

The computed rating curves at various gauging stations were derived from simulation of 1D-2D integrated hydrodynamic model as shown graphically in Fig. 13.5. Right/Left bank-full depth and bed level from msl at which discharge is **zero (a)**, at respective locations can be worked out from Fig. 13.6. It may be seen that, at Nehru bridge (Surat City) gauging station, the bed level is lower than msl. Similar rating curves can also be prepared at any chosen station along the study reach from the developed model by Timbadiya et al. (2015).

The rating curves, so developed, may be useful in computation of water levels along the lower Tapi river for discharges of different return periods. Apart from using the rating curves for the levee design, river front development and design of side channel structure, they can be useful to develop flood inundation maps which may guide the flood protection agency for development of evacuation plan during the process of flood mitigation.

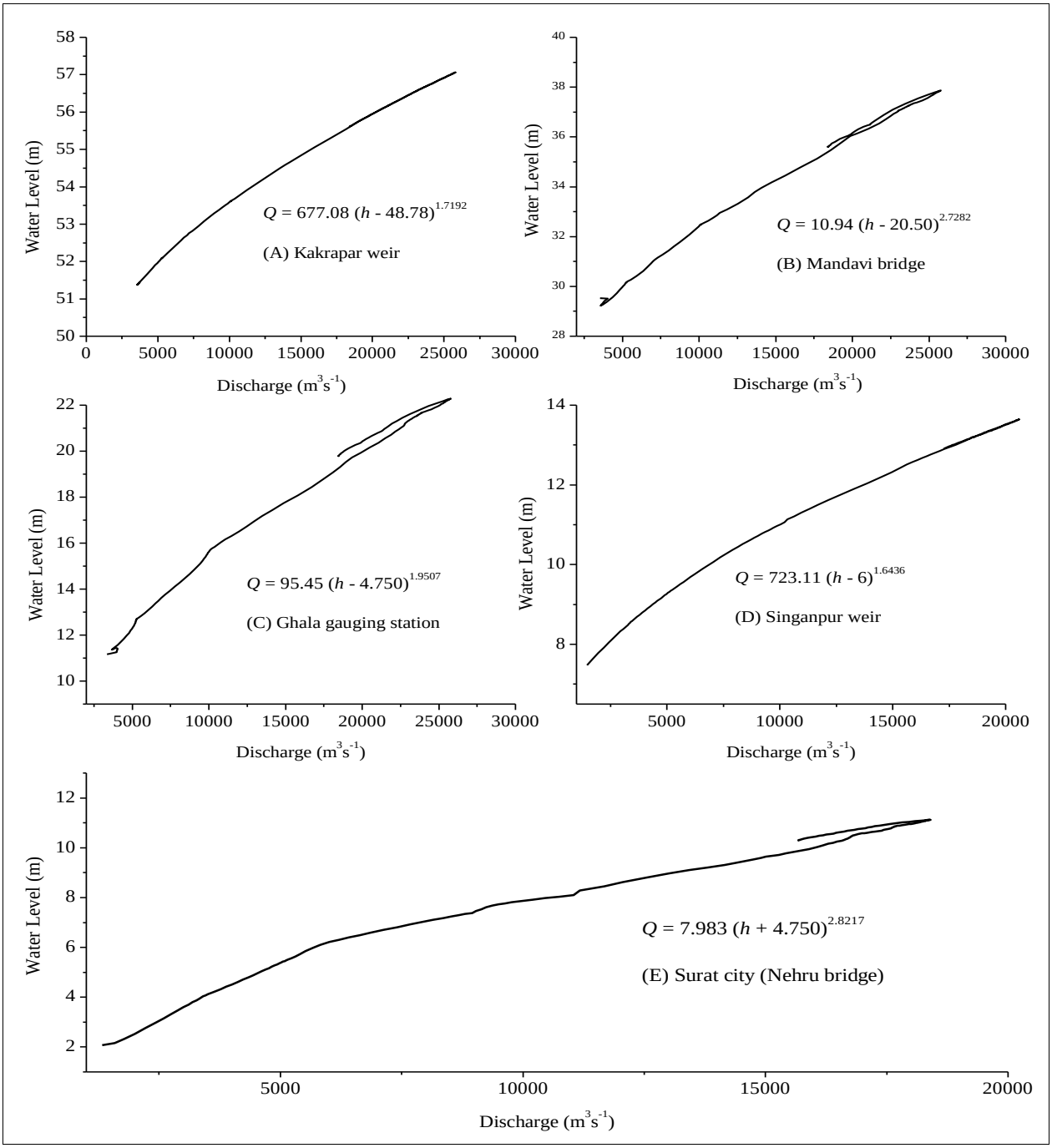


Fig. 13.5 Rating curve (Q-h relationship) along the lower Tapi river using 1D-2D coupled model (Source: Timbadiya et al., 2015)

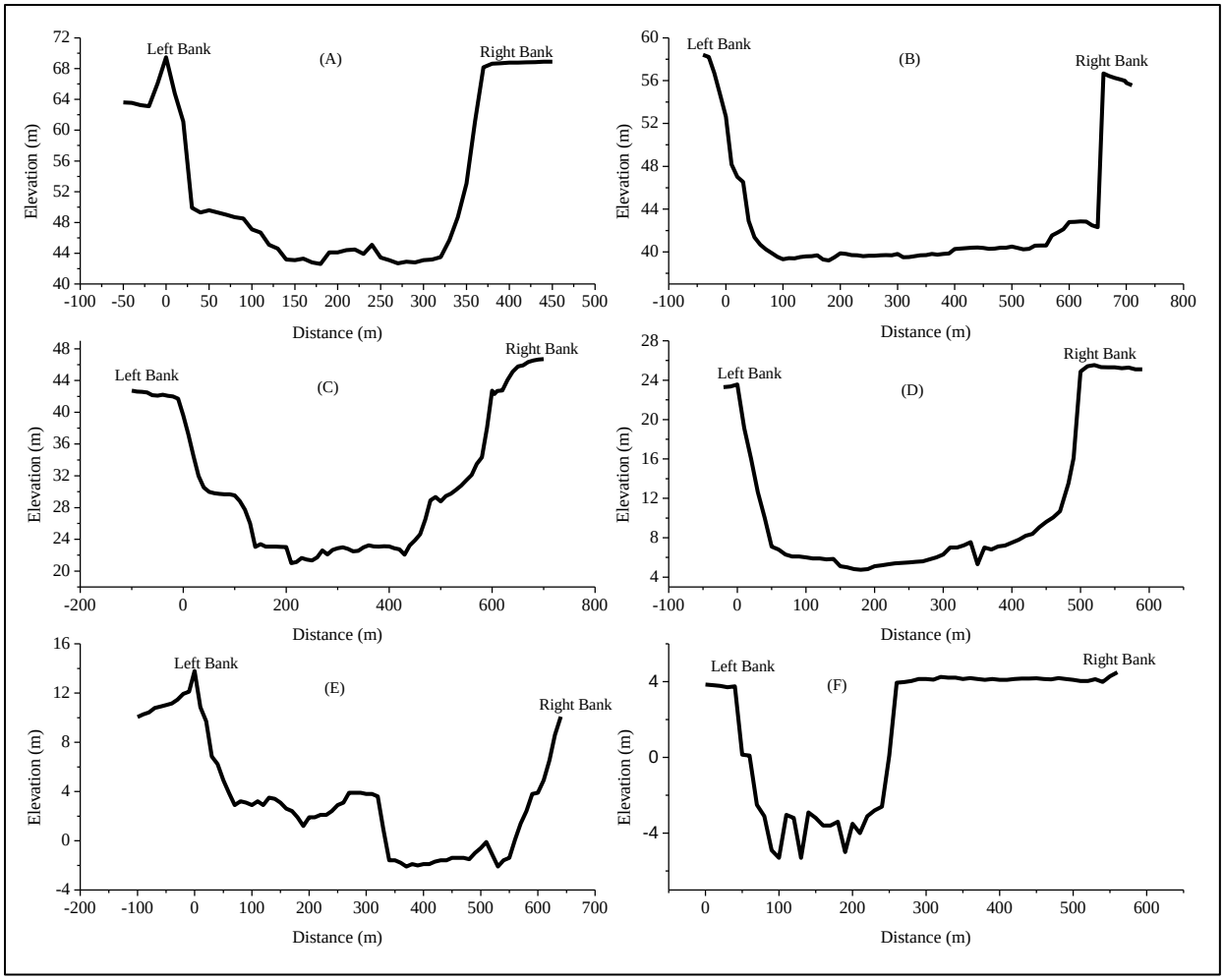


Fig. 13.6 Cross sections of lower Tapi river at (A) Ukai dam (B) Kakrapar weir (C) Mandvi bridge (D) Ghala Village (E) Singapore weir (F) Nehru bridge (Surat city) (Source: Timbadiya et al., 2015)

13.4 CONCLUDING REMARKS

During the flood the stream power of the river increases significantly which intensify the morphological changes in the river. Kale (2007) reported that peak unit stream power at Ghala station on the Tapi river for flood of year 1968 was 290 Wm^{-2}. The peak unit stream power for the flood of year 2006 for the same station, computed based on simulated hydraulic quantities as shown in Table 13.3, has been found to be 93.67 Wm^{-2} which is less than Magilligan's (1992) critical unit stream power (300 Wm^{-2}) associate with major morphological adjustment in gentle gradient alluvial channel in humid and semi-humid region. The discharge carrying capacity of the lower Tapi river in the upstream and downstream of the Singapore weir has decreased significantly

in the recent past due to unprecedented floodplain encroachment and silting of river due to tidal waves and creation of storage of Singanpore weir in its upstream.

Due to significant reduction of carrying capacity of Tapi river in Surat city, the floods in the city may become highly critical, particularly when the Ukai reservoir is full at the end of the monsoon, and any severe storm comes in the upper catchment of Ukai reservoir. For efficient management of flood in Surat city, effective early warning system is the need of the hour, which should be developed by considering the integration of inflow into Ukai reservoir, simulation of flow in Ukai reservoir and hydrodynamic flood in the lower reaches of Ukai reservoir.

CHAPTER 14
RESULTS AND DISCUSSIONS

14.1 INTRODUCTION

The objectives of the present study have been addressed while including the relevant details in Chapters 2 to 13. This chapter provides the summary of the results derived from the analysis of hydrological data, land use changes, reconnaissance survey, river morphology, stream bank erosion analysis, proposed restoration of critical and important river reaches, and flood affected areas for the Upper, Middle and Lower Tapi river. The brief description on above account are included in following paragraphs: -

14.2 UPPER TAPI RIVER

a) The lengths of right bank line (RBL) and left bank line (LBL) of the Upper Tapi river for period under consideration varies between 352 to 355 km and 351 to 354 km respectively. The RBL predominantly shows positive migration towards northern direction (+ve shift: widening), while LBL shows negative shift (migration to right side, narrowing) with respect to the base year under consideration (1971-1979). The shifts of RBL and LBL are opposite in nature, i.e., erosion on the right bank is compensated by corresponding deposition on left bank. The erosion and deposition areas resulting due to the migration of RBL and LBL in Upper Tapi river shows that the RBL undergoes more erosion compared to LBL in all the years, vis-a-vis., LBL undergoes more deposition compared to RBL in all the years. The RBL of Reach 1 (Ch. 0 to 50 km) and Reach 6 (CH. 300 to 350 km) shows maximum area loss during base year up to 2010 in the Upper Tapi river. In Reach 1, the river passes through its youthful stage, where the velocity of flow is very high. The Reach 6 falls just upstream of Hatnur dam. Field investigations revealed that migrations of right bankline and left bankline are due to infilling of Hatnur reservoir, and creation of afflux in the upstream of the reservoir (Figs 10.3 and 10.4)

b) The banks of Tapi river have been observed to be erosion resistant, and no major long-term threats along the upper river reaches are noticed. At Chainage 308.0 km (Burhanpur Fort), the significant erosion was observed during the field visit near the fort. To protect the Burhanpur Fort (Ch. 308 km) from erosion, the gabion wall may be constructed. Moreover,

groynes or spurs can also be planned in upstream of the structure to minimize the erosion effect as per the guidelines laid in IS 8408:1994 (Photos 9.85-9.87).

c) In Upper Tapi river, the sinuosity values are within the limit of threshold meandering (Sinuosity < 1.5) except in reach 2, which extends between Tipnapur village (CH: 50 km) and Dokya village (CH: 100 km) in Madhya Pradesh. The moderately high value of sinuosity in this reach can be attributed to the Tapi river following meandering path through confined bedrock reaches of Upper Tapi Gorge between Tipnapur village and Teska. Also, the minor increase in sinuosity index values are reported with time in reaches 2 (CH: 50 to 100 km), 5 (CH: 200 to 250 km) and 7 (CH: 300 to 350 km). This is an indication that the river trying to dissipate its excess energy by following curved paths, which may not accelerate the bank erosion rate as the banks are consisting of resistant rocks. The river flows in single channel in most of its course in Upper Tapi river; however multiple channel formation is found in certain reaches, but for short lengths, not sufficient to form significant braids.

d) Total number of the rainy days in the Upper Tapi basin is showing a decreasing trend. Out of 24 rain gauge stations, 12 depicts the increasing trend of total annual rainfall, and the rest are showing decreasing trend. Mean annual maximum flow discharge at stations Dedtalai and Burhanpur stream gauging stations are 4191.3 $m^3 s^{-1}$ and 7598.5 $m^3 s^{-1}$ respectively. The 2.5-year return period flood at Dedtalai and Burhanpur are 4443 $m^3 s^{-1}$ and 8079.1 $m^3 s^{-1}$ respectively. The average runoff coefficient (runoff/ rainfall) at Hatnur dam is 0.21. At Burhanpur station, the decreasing trends in sediment transport rate are observed during the monsoon months. The construction of new minor hydraulic structures in the Upper Tapi Basin may be the reason for the decreasing trends in suspended sediment transport rates at the outlet of the Upper Tapi river (Table 6.7).

e) In the Upper Tapi basin, the forest cover has been found to reduce from 59.40% to 49.56% during 1990-2010. In contrast to it, the agricultural land has been found to increase by 13.64% from 15.79% in 1990 to 29.43% year 2010. This increase in agricultural land is at the expense of the forest cover and fallow land in the sub-basin. The increase in built-up area (1.28%) is not observed to be significant when compared with the rest of the classes. The water bodies are observed to be expanding, and the scrub lands are observed to be declining during 1990-2010 by 0.35% and 0.80% respectively (Table 8.3).

f) The analysis of cross-sections before and after the occurrence of floods in 1994 and 2006 reveals that the cross-sections of the Upper Tapi river were not altered significantly, except at Dedtalai stream gauging station in 1994, where the right bank was observed to get eroded (Fig 10.27).

g) The observed rate of sedimentation in Hatnur Reservoir was 2.374 ha-m/100 sq.km/year, which is about five times the rate adopted in planning of the reservoir, i.e., 0.451 ha-m/100 sq.km/year (Annual Research Report, MERI, 2007-2008). Also, the average annual sediment erosion rates from Burhanpur and Yerli sub-catchments were observed to be 5.839 t/ha and 3.98 t/ha respectively (Fig 10.20). Excessive deposited sediments into the Hatnur Reservoir can be used for construction of flood protection measures along the river or other construction purposes near the structure.

h) Invariably, the reaches of Upper Tapi river possess hilly gorges and confines rock stratum, and the river has been observed to be in stable state only. The river reach at Burhanpur fort is required to be intervened as per the suggestions given in Sub-section 12.2.7 for the safety of the fort in near future.

i) The water quality in the said reach fall in the 'C' grade as per CPCB criteria (TOI Report, 2017).

14.3 MIDDLE TAPI RIVER

a) The lengths of RBL and LBL of the Middle Tapi river for period under consideration varies between 234 to 256 km and 236 to 257 km respectively from the analyses of satellite imagery and SoI toposheets undertaken for different period (Table 10.1). The RBL shows positive migration (erosion) in most of the chainages. The maximum positive shifts in LBL and RBL are observed just the downstream of Hatnur Dam at CH: 350 km. The LBL, invariably shows negative shift (deposition) along Middle Tapi river reaches (Table 10.3). The larger width of the channel just downstream of Hatnur Reservoir could be due to erosion of either banks resulting from release of relatively clear water from the reservoir during the monsoon (Fig 10.10). The Middle Tapi river also shows prominent erosion in its right bank compared to left bank. Similarly, the left bank undergoes significant deposition in all the reaches. Reaches 8 (CH: 350-CH: 400), 9 (CH: 400-CH: 450) and 12 (CH: 550-CH: 581) undergoes maximum loss of area due to the eroding bankline (Table

11.11). Reach 8 falls just downstream of Hatnur Dam. Reach 12 falls just upstream of Ukai Reservoir. The probable cause of high erosion observed at Reach 12 may be the migration of right bank to the northern side (widening) owing to afflux in the reservoir. It can be observed that the deposition areas are also nearing highest values in Reaches 8, 9 and 12 (Table 11.12). This shows that the positive migration (widening) of the right bank causing erosion might get compensated by a negative migration (narrowing) of left bank causing deposition.

b) At Ch. 589 km (Kavithe-Kukurmunda bridge), Ch. 478 km (Mudawad), Ch. 454 (Gangapuri, Jalod) are found highly active and significant erosion were observed. At Gangapuri, Jalod, Maharashtra (CH: 454.0 km), repelling groynes may be constructed to arrest the erosion of the left bank (Photo 12.11). At, Mudawad, Maharashtra (CH: 478.0 km) (Photo 12.11), the bank stabilization structure such as guide bund may be constructed at the confluence to reduce/arrest erosion. At Sarangkheda bridge, Maharashtra (CH: 537.9 km) (Photos 12.8-12.9), to safe guard the bridge abutment, the guide bund is required to be provided on left bank between barrage and bridge as per the IS: 10751:1994. At Kavithe-Kukarmunda bridge, Gujarat (CH: 589.0 km) (Photo 12.6), to protect the left bank and safe guard the bridge abutment, the guide bunds are to be provided.

c) The values of sinuosity show that the river follows sinuous course throughout its translational path. Although occasional bends are present in the Middle Tapi river, no prominent meander reaches are found in the said reach, and the values of sinuosity varies from 1.10 to 1.30 (Table 11.3). The PFI values for reaches 8-12 (CH: 350 to 581 km) of Middle Tapi river is not showing significant braiding (Table 11.7). While examining the course of Middle Tapi river from Hatnur Dam to Ukai Reservoir, no major braiding pattern is seen anywhere. However, in Reach 8, between Vagdud (CH: 368.65 km) and Bhusawal (CH: 376.39 km), there is a stretch of Tapi river where the river flows in multiple channels. This can be attributed to the considerable change in stream slope between these two locations, i.e., a stream slope of approximately 1 in 317.

d) In the Middle Tapi basin, out of total 28 rainguage stations, 14 raingauge stations reflect increasing trend in the number of rainy days. Total annual rainfall is decreasing at 14 raingauge stations in the basin. Mean annual maximum flow discharge at Savkheda, Gidhade and Sarangkheda stations were observed to be 8720.9 $m^3 s^{-1}$, 8733.1 $m^3 s^{-1}$ and

8886.4 $m^3 s^{-1}$ respectively. The 2.5-year return period floods at Savkheda, Gidhade and Sarangkheda are 9159.4 $m^3 s^{-1}$, 9159.4 $m^3 s^{-1}$ and 9352 $m^3 s^{-1}$ respectively during the study period. The average runoff coefficient at Ukai dam (at the outlet of Middle Tapi river) is 0.18. It can be observed that, in the recent decade, i.e., 2000-2010, there has been an increase in the sediment transport rate in all months except in September month (Table 6.17). The Tapi river flows through alluvial plains as it enters its middle reaches. The increase in sediment transport rates may be attributed to the enhanced agricultural activities in the basin. The increase in sediment transport rates in Middle Tapi river in recent years, may accelerate the sediment deposition in Ukai reservoir (reservoir at the tail end of Middle Tapi river). The watershed areas of Middle Tapi river are required to be managed to reduce the excessive silt entry into the river.

e) It can be observed that agricultural land and fallow land together occupy more than 60% of the total area of the sub-basin. This can be attributed to the abundancy of alluvial soil in the sub-basin, which makes it perfect for cultivation and human occupancy. The second predominant land-use class is the forest cover, which can be seen on the northern as well as north-western part of the sub-basin. The land-use classes like built-up area, water and scrub land occupy comparatively less percentage area in the sub-basin. As reported in case of Upper Tapi river, there is continuous increase in agricultural area in the Middle Tapi river toos. On the other hand, there is a decrease in forest, fallow and scrub lands, as reported in the sub-basin (Fig 8.4a-8.4f)

f) Series of barrages/minor storage structures are coming up along the reaches of Middle Tapi river which may store the entire flow during the lean period. Under such circumstances, the riparian rights of water sharing states is required to be clearly identified to avoid further complication regarding water availability in future.

g) The villages/ urban areas and State Highways in Middle Tapi river reaches are relatively more vulnerable to erosion vis-à-vis river reaches in Upper Tapi river. The locations of Middle Tapi river fall under the category of highly vulnerable to not vulnerable as per the classification proposed in present study.

h) The water quality in the said reach fall in the ‘C’ grade as per CPCB criteria (TOI Report, 2017).

14.4 LOWER TAPI RIVER

a) The length of RBL and LBL of the Lower Tapi river for period under consideration varies between 131 km to 136 km and 122 km to 126 km respectively, as observed while analyzing SoI toposheets and Satellite imagery for different durations. There is no significant migration observed in both banks except at last chainage, i.e., CH: 792 km. The larger shifting/migration of RBL and LBL at this location have occurred due to combined effects of tidal currents in the Arabian Sea and main flow from Tapi river.

b) At CH: 787 km (Tapi Estuary Suvali gam), CH: 750 km (Utran-Kapodara bridge), CH. 735 km (near old magistrate office) the river is found to be found active and significant erosions are observed. At Tapi Estuary System, Suvali Gam, Hazira (CH: 787.0 km), to protect the banks, the provision of gabions is recommended. The series of permeable spurs in the right bank are required to be constructed just upstream of existing spurs to protect the adjacent road (NH-8) (Section 12.2.1 of report). At Kamrej and Kholvad villages, Surat (CH: 736 km and 739 km), the groynes or spurs at suitable locations are required to be constructed to arrest further erosion at inner bend (Section 12.2.2 of report). The physical model study is recommended before implementation and planning the layouts of aforesaid corrective measures.

c) The Lower Tapi river, generally, falls in the category of sinuous river as sinuosity is in the range of 1.10 to 1.50. In the reach (CH: 697-747 km), the value of sinuosity has been found to reach threshold value of meandering river. While observing the computed values of plan form index (PFI), it is seen that the last reach (CH: 747-792 km) of the river, falls under the category of braided river (Tables 11.4 and 11.8).

d) Most of the rain gauge stations in the Lower Tapi river shows increasing trend in total annual rainfall. Out of 11 rain gauge station, total 9 stations depict, increasing trend in number of rainy days. The Lower Tapi Basin falls within the zone of severe rainstorms, and heavy rainfall spells have been observed in the recent past. As per historical records, Tapi river has experienced large floods in the years 1727, 1776, 1782, 1829, 1837, 1872, 1944, 1959, 1968, 1970, 1994, 1998 and 2006. The lower reaches of the Tapi river, especially the Surat City has faced maximum destruction due to the havoc caused by severe floods. The Surat city on the bank of the lower Tapi river was highly affected by recent floods, in the years 1994, 1998 and 2006. The Surat flood of year 2006, alone had caused direct damages to the time of Rs. 21,000 crores.

The carrying capacity of the Tapi river in the Surat city has been found to get reduced drastically which is the prime reason for flooding in the Lower Tapi river. A flood of magnitude 42,500 m^3s^{-1} had produced a water level of 12.08 m at Nehru bridge in the year 1968. On the other hand, a discharge of magnitude 25,780 m^3s^{-1} produced a water level of 12.40 m in the year 2006. This clearly indicates the reduction in capacity of river channel at Surat city due to unprecedented development in its flood plain and rise in the bed levels due to tidal currents and afflux of Singanpore weir constructed within the Surat city during year 1995. Provisioning of 'Early warning system' for flood forecasting in the Surat city is essentially required while accounting the inflow prediction model for Ukai reservoir, reservoir simulation and hydrodynamic modelling downstream of the Ukai reservoir.

e) The agricultural land in Lower Tapi river has been increased by 8.74% during 1990-2010. The forest areas are observed to be declining while agricultural and built-up land are increasing in aforementioned duration. There has been a decrease of 6.09% in forest area in the sub-basin during 1990-2010. There has been a transition of fallow land into cultivable land in the basin. The waterbodies were observed to be expanding and the scrub lands are observed to be declining (Table 8.5).

f) Excessive siltation upstream and downstream of Singanpore weir, is responsible for reduction in the capacity of the river in the city (Section 10.9.4). The planning for desilting of sediments in the upstream and downstream of Singanpore weir can be undertaken and desilted sediments can be used for construction of river training works in the Lower Tapi river and coastal protection works using the geo-bags and geo-tubes. The systematic study on possible morphological changes due to desilting of the river bed is required to be undertaken before planning such major desilting exercises.

g) While analyzing the variation in cross-sectional geometry of Ghala stream gauging station that falls in Lower Tapi river, it was observed that the river bed adjacent to the right bank has undergone local scouring, during 1989-2004, over a length of 130 m. Such erosion in the stream gauging site could be due to ongoing sand mining activity in the vicinity of the site. The possible changes in water rating curves are required time to time to account aforesaid morphological changes.

h) The vulnerability of Lower Tapi river ranges from highly vulnerable to not vulnerable. The villages like Ushked Khurd, Puna, Unn, Kosadi, Umarsadi and Kamlapor, which falls in Surat

District of Gujarat, fall under highly vulnerable category due to their proximity with the eroded bankline.

i) The water quality in the river at Surat city (stations Varachha, Rander, Weir Cum Causeway) is relatively impaired compare to other upstream station. Although, the Tapi river water was categorized as 'C' grade, the water quality of the river has deteriorated to 'D' and 'E' grades within the city limits. Also, on the upstream of the Singapore weir, thick layer of water hyacinth was noticed which substantially depleted the dissolved oxygen (DO), which may be responsible for the presence of the odor in water (TOI Report, 2017).

14.5 FURTHER STUDY / INVESTIGATIONS RECOMMENDED

1) The morphological study reported for Lower Tapi river indicated that, carrying capacity of the river in Surat city has drastically been reduced due to extensive development in the coastal urban floodplain and siltation in the bed of Tapi river. The following actions are suggested with reference to morphology/flooding of Lower Tapi river: -
    i) The Surat city is highly susceptible to flooding as and when severe storms come in the catchment of Ukai reservoir, particularly in the end of the monsoon, when the reservoir is at FRL (full reservoir level). Under such condition, entire inflow into the reservoir has to be passed in the downstream of the reservoir, and massive loss to the life and property is expected in the Surat city. Keeping in view, the susceptibility of Surat city to flooding, it is the need of the hour to develop 'Early warning System' for the Surat city while accounting real time information of inflow into the Ukai reservoir, reservoir simulation, controlled releases from the reservoir in the downstream channel and provide advance information to the people in the city to be prepared against the flooding.
    ii) Two-dimensional hydrodynamic model for inundation of Urban Surat centre is required to be developed while considering releases from Ukai reservoir and sea tidal levels on upstream and downstream boundary conditions respectively. Such model may be useful in identifying various risk zones in the city, which in turn may be useful in controlling the development in the urban flood plain.
    iii) The possibility of using the silted sediments, particularly in the river bed in Surat city, for the construction of flood protection measures along the river/coastal protection

works, and other construction purposes, be explored by the Surat Municipal Corporation in consultation with Narmada, Water Resources, Water Supply and Kalpsar Department; and Road and Building Departments respectively. The sediments silted in the downstream of Singanpore weir may not be suitable for construction purposes due to the presence of excessive salt content.

2) The quality of water in the Tapi river, particularly in the Surat city, need to be addressed at the earliest while identifying the possible causes for the degraded water quality in the urban areas, and implement possible measures to restore the healthy condition of the river.
3) The critical erosion prone areas identified along the Tapi river, are required to be noted by the concerned State agencies. The identified critical areas need to be studied individually, and possible curative measures are to be adopted to avoid aggravating the situations further. The contents presented in Chapter 9- Chapter 12 need to be referred.
4) The alarming siltation rate has been reported in the Hatnur reservoir. The previous studies have indicated that Burhanpur catchment is more fragile to erosion vis-à-vis Purna sub-catchment. The specific study for identifying critical erosion prone areas of Burhanpur and Purna sub-catchments need to be undertaken for providing possible soil conservation measures, and reducing the silting into the Hatnur reservoir. The Hatnur reservoir, being a minor storage structure, the possibility of desilting of the deposited sediments and its usage be explored by the State Govt. agencies.

CHAPTER 15
WORKSHOP REPORT

Name of Program (Workshop)	**Morphological Study of Tapi River using Remote Sensing Technique**
Date	July 21, 2017
Organizing Department	Civil Engineering Department (CED)
Name of Coordinator (s)	Dr. P.L. Patel, Professor, CED, SVNIT-Surat Dr. P V Timbadiya, Assistant Professor, CED, SVNIT-Surat
Category of Program	Workshop
Venue & Time	Conference Hall, SVNIT Guest House, 10:00 AM to 5:30 PM
Sponsored by	Central Water Commission (CWC), Ministry of Water Resources, River Development & Ganga Rejuvenation, New Delhi
Objective of Program	The objective of the workshop is to disseminate the results of the study carried out by SVNIT-Surat on "Morphological Study of Tapi River using Remote Sensing Technique." The participation of the stakeholders and their suggestions were requested during the workshop to improve the usefulness of the work in management of Tapi River, including operation of hydraulic structures and extreme flood events along the river

The copy of Information Brochure of the Workshop is enclosed in Annexure-I.

The workshop was inaugurated by Chief Guest Shri. Ajay K Sinha, Director, Morphology, CWC, New Delhi and Dr. S R Gandhi, Director, SVNIT Surat. The participants were welcomed by Prof. P L Patel, Principal Investigator and Professor, Civil Engineering Department. He also briefed about Morphology Project and its significance on management of rivers and related hydraulic structures. The Chief Guest in his address, appreciated the work carried out by the team of SVNIT on Morphology project in a timely manner, and fulfilling the objectives specified in the Memorandum of Understanding (MoU). Prof. S R Gandhi, in his Presidential address, shared his experiences on morphology of Lower Tapi River while working for a project of Larsen and Toubro (L&T), Hazira, Surat. He shared the effect of dredging on

morphological behavior of Tapi River at Hazira, Surat. At the end of the inaugural function, Dr. P V Timbadiya (Assistant Professor& Co-PI) has presented the Vote of Thanks to all eminent experts and stakeholders for their participation in the event. The details of dignitaries on dais during inaugural session is included in **Photo 15.1**.



Photo 15.1 : Inaugural Session (Left to Right): *Dr. P L Patel (Professor, CED and PI), Dr. S R Gandhi (Director, SVNIT Surat), Shri. Ajay K Sinha (Director, Morphology, CWC), Dr. J E M Macwan (Head, CED, SVNIT Surat) and Dr. P V Timbadiya (Asst. Professor, CED and Co-PI)*

Total of 52 participants attended the workshop. Details of the participants are enclosed in **Annexure-II**, including their Mail ID's and contact numbers.

A group photograph of participants taken during the workshop is enclosed as **Photo 15.2**.



Photo 15.2 Group Photo of Workshop - 2017

The deliberation during the workshop included six presentations by the team of SVNIT, Surat. The schedule of the workshop is included in **Annexure-III**. **A panel discussion** was held at the end of the workshop under the Chairmanship of Shri. M P Singh, Chief Engineer, CWC, NTBO, Gandhinagar. The details of other Panelists are included in Annexure-III.

During the presentations, extensive deliberations were initiated on each sub-theme of the workshop. The presentations were followed by a Panel Discussion wherein the experts on and off the dais presented their views to refine the work undertaken on morphology, and possible implementation of the findings by the state agencies/ stakeholders. The minutes of the workshop including the suggestions of the participants and panelists are included in Annexure-IV. The event was concluded with appreciation to the organizing team for their untiring efforts in organizing the workshop. During the Valedictory function, certificate of participation and group photographs were distributed by Shri M.P. Singh, Chief Engineer, NTBO, CWC and Dr. G L Asawa, Retd. Professor, IIT-Roorkee. The glimpses of the certification distribution is shown in **Photo 15.3**.





Photo 15.3 Certificate and workshop group photo distribution to the participants by *Shri. M.P Singh and Dr. G.L Asawa (Retd. Professor, IIT Roorkee)*

Further, reply to the comments receved from Morphology and Climate Change Directorate, CWC, New Delhi (Letter No. 4/19/2012/SVNIT/Morpho/659-60 dated 20/06/2017) along with the compliance of Minutes of foregoing workshop (Letter No. 4/19/2012/SVNIT/Morpho/1173-80 dated 04/09/2017) is enclosed in Annexure V and Annexure VI respectively. Also, the reply to the letter from Member (RM), Central Water Commission (CWC), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India (Letter no. 4/19/2012/Morpho/1200-1201 dated Sep. 7, 2017) is enclosed in Annexure VII.

Annexure-I

One Day Workshop

on

Morphological Study of Tapi River using Remote Sensing Technique

July 21, 2017

Sponsored by
Central Water Commission, New Delhi

Coordinators
Dr. P L Patel
Dr. P V Timbadiya

Call for participation

Organized by
Centre of Excellence on
"Water Resources and Flood Management",
Civil Engineering Department
Sardar Vallabhbhai National Institute of Technology, Surat-395007.

About Central Water Commission (CWC)

It is a premier Technical Organization of India in the field of Water Resources and is presently functioning as an attached office of the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. The Commission is entrusted with the general responsibilities of initiating, coordinating and furthering in consultation of the State Governments concerned, schemes for control, conservation and utilization of water resources throughout the country, for purpose of Flood Control, Irrigation, Navigation, Drinking Water Supply and Water Power Development. It also undertakes the investigations, construction and execution of any such schemes as required.

The Central Water Commission (CWC) is headed by a Chairman, with the status of Ex-Officio Secretary to the Government of India. The work of the Commission is divided among 3 wings namely, Designs and Research (D&R) Wing, River Management (RM) Wing and Water Planning and Projects (WP&P) Wing. Each wing is placed under the charge of a full-time Member with the status of Ex-Officio Additional Secretary to the Government of India and comprising of number of Organizations responsible for the disposal of tasks and duties falling within their assigned scope of functions.

Directorate of Morphology

Directorate of Morphology is functioning under the office of Chief Engineer (P&D), CWC, New Delhi. They have initiated the morphological studies of few major rivers of the country by entrusting the responsibilities to the leading institutions like IITS and NITs. They have assigned the task of "Morphological Study of Tapi River using Remote Sensing Technique" to SVNIT-Surat.

About the Institute

The institute was initially established as Sardar Vallabhbhai Regional College of Engineering & Technology in 1961, and was upgraded to National Institute of Technology (SVNIT) in 2002. The SVNIT, at present, is one of the prestigious engineering institutions of the country, and has contributed many outstanding engineers in India and abroad. At present, the Institute runs six Undergraduate, and seventeen Postgraduate programmes, three MSc integrated programmes and Ph.D. programmes in all disciplines of Engineering and Applied Sciences. Special attention is being given in developing the culture of interdisciplinary and collaborative research. The institute has an excellent placement record with a number of top-ranking companies visiting the campus every year.

About the Department

The Department of Civil Engineering came into existence in the year 1961. The department has 27 faculty members with specialization in various themes of Civil Engineering. The department has been running one UG programme in Civil Engineering, four PG programmes (Water Resources Engineering, Environmental Engineering, Urban Planning, and Transportation Engineering & Planning) and the research programmes leading to Ph.D. degree in different areas of specializations.

About Centre of Excellence (CoE)

The Water Resources Engineering section of the department had full-fledged facilities for UG/PG and PhD programmes under the leadership of eight dedicated faculty members. The section has taken lead to establish Centre of Excellence (CoE) on 'Water Resources and Flood Management being funded from World Bank under TEQIP-II. The CoE aims to develop excellent computational and experimental facilities in the area of Hydraulics and Water Resources; develop Early Warning System for flooding in Surat city; and organize short term training programmes, workshops and conferences on thematic areas to the academicians and practitioners in the field.

About Computational Hydraulics Laboratory (CHL)

The Water Resources Engineering section of the department had full-fledged Computational Hydraulic Laboratory with following professional softwares:

1) Bentley Storm CAD V8i
2) Bentley Sewer GEMs V8i
3) Bentley Water GEMs V8i
4) MIKE 11/MIKE 11 GIS/MIKE 11 FF
5) MIKE FLOOD, MIKE SHE, MIKE URBAN
6) River CAD Professional (HEC-RAS)
7) HEC-2, HEC-HMS Professional
8) Arc GIS 10
9) ERDAS IMAGINE 10
10) STATISTICA 10
11) MATLAB 2014a

First page of the brochure

About Surat

The Surat city, situated on the bank of river Tapi, is highly ranked industrial city of the country with a network of flyovers and clean wide roads. It is well known worldwide for textiles, Zari and Diamond industries. Several large scale industries and establishment are located in the city. The city is situated on the main western railway route between Vadodara and Mumbai. The institute is located at Ichchhanath on Surat-Dumas road at a distance of about 10 km from the Surat railway station.

Workshop Objectives

The objective of the workshop is to disseminate the results of the study carried out by SVNIT-Surat on "Morphological Study of Tapi River using Remote Sensing Technique." The participation of the stakeholders and their suggestions during the workshop would improve the usefulness of the work.

Workshop Deliberations

The topics of deliberations in the workshop would be as follows:

1) **Description of Tapi basin including key morphological issues in Tapi River**
2) **Morphological study of Tapi River using Remote Sensing: Objectives and detailed scope of work**
3) **Trend of climatic and land use-land cover parameters in the basin including pattern of runoff and sediment yield, and flood frequency analyses**
4) **River Morphology: Shifting of bank lines and hydraulic geometric relationships**
5) **Stream bank erosion analysis including planform of the river**
6) **Identification of critical reaches including outcomes of field visits**
7) **Panel Discussion**

Registration of Participants

The workshop is open to engineering professionals, field engineers, working in the different departments (Govt./Non-govt.) related to Water Resources, Irrigation, Flood management, River engineering and other stake holders related with Tapi river. The participants/stake holders desirous for attending the workshop has to make their own arrangements for accommodation and travel.

The number of participants for the programme is limited to 50.

Speakers

The outcome of the Morphological study of Tapi River using Remote Sensing Technique will be deliberated among the faculty members of SVNIT-Surat and invited expert participants from the leading organisations. The valuable inputs from the stakeholders are expected during the workshop.

Important Dates

The completed filled-in registration form will be sent as an e-mail attachment to **praful.timbadiya@gmail.com** on or before **July 15, 2017.** The registration form should contain the signature of the Head of the department with seal.

The list of selected applicants will be informed through E-mail and displayed on the institute website by **July 16, 2017.** The registration is compulsory for participation in the workshop.

Venue

Conference Room,
Institute Guest House (Sardar Vallabhbhai Patel Bhavan),
SVNIT Surat - 395007.

Contacts

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S.V. National Institute of Technology-Surat
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(M) +91-9904003857
Email: plpatel@ced.svnit.ac.in

Registration Form

One Day Workshop

on

Morphological Study of Tapi River using Remote Sensing Technique

July 21, 2017

Name:_____
Gender (M/F):_____Age:_____
Designation:
_____
Organization:_____
_____
_____
Qualification:_____
Experience:_____
Address for correspondence:_____
_____
_____
_____
Phone: (O)_____(R)_____
Mobile: _____
Email:
Accommodation required: Yes/No

Date:_____
Place:_____

Signature of Participant

Signature of Head of the
institution/company/department with Seal

Second page of the brochure

Annexure-II: List of Participants of the workshop

Sr. No.	Name of the Participant	Designation	Name of Department	Mail ID	Contact Number
1	Shri Manish Vasawa	Assistant Engineer	Ukai Dvision-1, Ukai	seuccukai52@gmail.com	02624-233254
2	Shri Priyank Patel	Assistant Engineer	B-1, Sub-Division, Ukai Division-1, Ukai	seuccukai52@gmail.com	02624-233254
3	Shri Bhavin Gamit	Assistant Engineer	B-1, Sub-Division, Ukai Division-1, Ukai	seuccukai52@gmail.com	02624-233254
4	Shri Jigar Jariwala	Assistant Engineer	Ukai Dvision-1, Ukai	seuccukai52@gmail.com	02624-233254
5	Shri Prashant Bharti	Assistant Engineer	Vyara Irrigation Sub division, ULBMC & Inv. Division-2, Valod	seuccukai52@gmail.com	02626-222090
6	Shri Mayur Bhavsar	Assistant Engineer	Ver-2 Project division, Vyara	seuccukai52@gmail.com	02626-222090
7	Shri Parth Sarkar	Assistant Engineer	Ukai Circle (Civil), Ukai	seuccukai52@gmail.com	02624-233254
8	Shri Rajesh Govind Patil	Executive Engineer	Lower Tapi Project Division, Amalner	rgpatil11@gmail.com	7720093437
9	Shri Devendra K Madankar	Assistant Engineer	Hydrology Project Division, Amaravati	dev.indra.madankar@gmail.com	8956847247
10	Shri Prashant Ramesh More	Executive Engineer	Jalgaon Medium Project Division No.2, Jalgaon	prmore53@gmail.com	2572235752
11	Shri Tushar Prabhakar Chinawalkar	Executive Engineer	Lift Irrigation Construction Division, Jalgaon	gitu1622mosu@yahoo.com	9422772626
12	Shri Satish Pandharinath Kale	Executive Engineer	Waghur Dam Division, Jalgaon	spkakejal@gmail.com	9422275566
13	Shri Rajiv Bhajiyawala	Assistant Engineer	Surat Irrigation Circle, Surat	sesicsurat@gmail.com	9909666733
14	Shri Dixit Patel	Assistant Engineer	Ambica Division, Navsari	sesicsurat@gmail.com	9727390879
15	Shri Ashish Bariya	Assistant Engineer	Surat Canal Division, Surat	sesicsurat@gmail.com	9925845027
16	Shri Prakash Patel	Assistant Engineer	Kakrapar Right Bank Canal Division, Surat	sesicsurat@gmail.com	9374733466
17	Shri Bhargav Kothiya	Assistant Engineer	Drainage Division, Navsari	sesicsurat@gmail.com	9427948707
18	Shri Chintan Mistry	Assistant Engineer	Drainage Division, Navsari	sesicsurat@gmail.com	9879076560
19	Shri R S Visave	Executive Engineer	Jalgaon Irrigation Department, TIDC, Jalgaon	tidcjal@gmail.com	9422181259
20	Shri K T Suryavanshi	Executive Engineer	Dhule Irrigation Department, TIDC, Dhule	tidcjal@gmail.com	9421448789
21	Shri S C Ahire	Executive Engineer	Small Irrigation Department, TIDC, Dhule	tidcjal@gmail.com	9850748897
22	Shri R S Badgujar	Executive Engineer	Dhule Medium Irrigation Department, TIDC, Dhule	tidcjal@gmail.com	9422289330
23	Dr. Nehal Shah	Assistant Professor	Shree Ram Krishan Institute of Computer Science and Applied Sciences, Surat	shahnehal29@gmail.com	9825240430

24	Shri Ajay Kumar Sinha	Director	Morphology, Central Water Commission, New Delhi	dirmorpho-cwc@nic.in	9560444535
25	Ms. Shobika Singh	Assistant Director	Assistant Director, Morphology	shobhika.singh05@gmail.com	8130986942
26	Shri M P Singh	Chief Engineer	Narmada Tapi Basin Organization, Central Water Commission-Gandhinagar	centbo-cwc@nic.in	079-23246115
27	Shri Kushagra Sharma	Superintending Engineer (Co.)	Narmada Tapi Basin Organization, Central Water Commission-Gandhinagar	secogandhinagar-cwc@nic.in	079-23246115
28	Shri K K Rao	AD-II	Narmada Tapi Basin Organization, Central Water Commission-Gandhinagar	secogandhinagar-cwc@nic.in	079-23246115
29	Shri M W Paunikar	Director, M & A	Central Water Commission, Vadodara	dirmongnagar-cwc@nic.in	079-23244882
30	Dr. U P Gupta	Executive Engineer	Tapi Division, Central Water Commission, Surat	tapi_exern@yahoo.com	0261-2904006
31	Dr. G L Asawa	Retired Professor	Indian Institure of Technology-Roorkee	gl.asawa46@gmail.com	9837082933
32	Dr. P G Agnithotri	Associate Professor	CED, SVNIT-Surat	pga@ced.svnit.ac.in	9924207781
33	Shri Tushar J Shah	Assistant Engineer	Kalpsar Department, Gandhinagar		9825464761
34	Shri Naresh R Patel	Assistant Engineer	Kalpsar Department, Gandhinagar		9825383559
35	Shri Pramod R Bendale	Deputy Executive Engineer	Jalgaon Irrigation Department, TIDC, Jalgaon	tidcjal@gmail.com	0257 222 1290
36	Shri M V Baviskar	Assistant Engineer	Tapi Division, CWC-Surat	tapi_exern@yahoo.com	261 247 8569
37	Shri S.C. Vasava	Deputy Engineer	Hydraulic Department, Surat Municipal Corporation	itman@suratmunicipal.org	261 2423750
38	Shri N V Choudhri	Deputy Engineer	Hydraulic Department, Surat Municipal Corporation	itman@suratmunicipal.org	261 2423750
40	Shri Viraj Loliyana	Research Scholar	SVNIT-Surat	viraj_nishi@yahoo.com	7779090415
41	Priyank J Sharma	Research Scholar	SVNIT-Surat	pjs230688@gmail.com	9898838823
42	Ms. Resmi S.R.	Research Scholar	SVNIT-Surat	iiresmii@gmail.com	9537632196
43	Mr. P. Laxminarayana	Research Scholar	SVNIT-Surat	laxmiraagini@gmail.com	8499033154
44	Mr. Nishant Sourabh	Research Scholar	SVNIT-Surat	ns90tnau@gmail.com	9624820932
45	Ms. Rupal Waghwala	Research Scholar	SVNIT-Surat		
46	Ms. Navya Chandu	PG-Scholar	SVNIT-Surat	nav.nav93@gmail.com	9924778523
47	Ms. Suhani Chaudhri	PG-Scholar	SVNIT-Surat	suhanichoudhary3@gmail.com	9983959529
48	Mr. Shubham Jibhakate	PG-Scholar	SVNIT-Surat	shubhamjibhakate1771@gmail.com	7083844021

49	Mr. Saurabh Tanpure	PG-Scholar	SVNIT-Surat	tanpuress@gmail.com	9028195031
50	Mr. Lalit Gehlot	PG-Scholar	SVNIT-Surat	gehlot.lalit1994@gmail.com	8446559345
51	Mr. Vishal Kuchawaha	PG-Scholar	SVNIT-Surat	vishalkachhwaha09@gmail.com	8764035090
52	Mr. Mahesh Sitari	PG-Scholar	SVNIT-Surat	mahesh.sitari@gmail.com	8374992899

Annexure-III: Schedule of Workshop on 'Morphological Study of Tapi River using Remote Sensing Technique'

Time	Description	Presenter
10.00-10.30 am	Inaugural Session	-
10.30 – 11.00 am	High Tea	
11.00 – 11.45 am	Topic 1: Description of Tapi basin including key morphological issues in Tapi River	Dr. P L Patel, Professor and PI
11.45 am – 12.00 pm	Topic 2: Morphological study of Tapi River using Remote Sensing: Objectives and detailed scope of work	Dr. P L Patel, Professor and PI
12.00 – 12.30 pm	Topic 3: Trend of climatic and land use-land cover parameters in the basin including pattern of runoff and sediment yield, and flood frequency analyses	Dr. P L Patel, Professor and PI
12.30 – 1.30 pm	Topic 4: River Morphology: Shifting of bank lines and hydraulic geometric relationships	Dr. P V Timbadiya, Asst. Professor and Co-PI
1.30 – 2.30 pm	Lunch	-
2.30 – 3.30 pm	Topic 5: Stream bank erosion analysis including planform of the river	Ms. Resmi S.R., Research Scholar
3.30 – 3.45 pm	Tea	-
3.45 – 4.45 pm	Topic 6: Identification of critical reaches including outcomes of field visits	Mr. Priyank.J. Sharma, Research Scholar
4.45 – 5.30 pm	Panel Discussion	**Panelists:** Shri. M.P Singh, Chief Engineer (Narmada Tapi Basin Organization, CWC-Gandhinagar)- Chairman Dr. P.L Patel (Professor and PI), Dr. U.P Gupta (Executive Engineer, Tapi Division, CWC-Surat), Shri. Satish P Kale (Executive Engineer, Waghur Dam Division, Jalgaon) Shri. Tushar J Shah (Asst. Engineer, Kalpsar Department, Gandhinagar)

Annexure-IV: Minutes of the one-day workshop on 'Morphological Study of Tapi River using Remote Sensing Technique'

1. The annual reservoir sedimentation rate reported by previous studies at Hatnur Reservoir has been found alarming at 1.8% (Ladhe et al., 2008). Similar figures were also reported by Prabhat Chandra (2016). The sediment inflow into Hatnur Reservoir from Tapi River as well as Purna River has been recommended to be compared, with already carried out study on the same such as Hatnur Reservoir Sedimentation by Maharashtra Engineering Research Institute (MERI). The actual sediment inflow contributions from Burhanpur and Yerli sub-catchments are to be clearly highlighted. Such findings may help watershed management authority to provision suitable soil conservation measures in respective sub-catchments.

2. While calculating the sinuosity index, SVNIT, Surat has approximated the thalweg line as the river centre line due to non-availability of cross-section at small intervals over a continuous period of time. CWC has agreed to provide SVNIT, Surat, surveyed cross-sections for the last 7 years, so that the variation in sinuosity index can be computed for this period. Also, these cross-sections can be used to identify the possible changes in the longitudinal profile of the river over the time period under consideration.

3. Locations of hydraulic structures are to be marked on the map and their possible effect on the morphology of Tapi River be quantified.

4. In the study, it has been observed that, right bank of Tapi River shows a northward migration (erosion), in majority of its reaches, resulting in erosion on the right bank and deposition on the left bank. During the interactive session, it was discussed by Shri Tushar Prabhakar Chinawalkar, Executive Engineer, Lift Irrigation Construction Division, Jalgaon that, the right bank of Tapi River is invariably occupied with prominent alluvial strata of soil, with high ground water table, while the left bank is geologically more stable reach. Thus, distinct geological characteristics of right bank (alluvial), vis-à-vis rocky left bank could be the possible cause of erosion of right bank and hence, shifting in northern direction.

5. The water quality grades, at the city limits of Lower Tapi River has been observed to fall under 'D' and 'E' grades. The situation prevailing requires to be attended and the possible

remedial measures are to be adopted and implemented by the Surat Municipal Corporation (SMC). Also, due to scarcity of minimal environmental flows in the river during lean period, water quality is adversely affected, especially, d/s of Kakrapar weir. The due attention of state agencies is required to maintain healthy condition of the river.

6. Sand mining activities are observed in various reaches of Tapi River, especially in the Middle and Lower Reaches of the river. Such kind of activities should be regulated, and prevented in the vicinity of hydraulic structures in order to avoid the possible threat to the structures. Also, such activities should be strictly prohibited near the HO sites, because it would alter the complete hydrology of the location and hence would result in erroneous observations.

7. During discussion with participants, it came to notice that several multiple bridges adjacent to each other along Tapi River were constructed in the past. The final report should include as one of the recommendations that State Agencies, municipalities etc. must take into account, the effects of interference of such parallel adjacent bridges while their execution in future.

8. The morphological study clearly highlighted the aggravating flooding situations in Lower Tapi River, due to severe reduction in carrying capacity of Tapi River in the Surat City. The experts clearly felt the need for development of 'Early Warning System' of Surat City while giving due consideration to inflow into Ukai Reservoir, reservoir operation and hydrodynamic modelling of Lower Tapi River. Further detailed investigation is needed for identifying if such reduction in capacity.

9. The findings of the present study be circulated amongst all the stakeholders, including the relevant state agencies. These findings will provide basic information about the behavior of Tapi River, and will be useful to the agencies/authorities who may carry out future development projects. The details of left and right banks erosion/deposition areas would help state agencies to prioritize their action for restoration of river in future.

10. Shri. M W Paunikar, Director, M & A, CWC, Vadodara, shared that failure of Chandora Dam in Upper Tapi River was due to faulty operation of spillway gates due to heavy rainfall in the past. The draft Morphology Report be corrected accordingly.

11. The Middle Tapi River, at the confluence of main Tapi River and Girna River be inspected to see the possible morphological changes at the same location. Such suggestion was given by CWC and State Govt. Agencies.

12. One of the participant has raise the concern of the issue of mangrove growth at Dumas beach. The growth may be due to construction of shore line protection work carried out in the recent past to save the village and temple. Further study is required to ascertain the reason for such growth. It is noted that, the area does not fall in the river boundary.

13. In future, detailed sedimentation studies must be included while planning new hydraulic structures in Tapi River to assess possible morphological changes likely to come during the operation of hydraulic structures.

14. Dr. G L Asawa, Retd. Professor, IIT Roorkee suggested that State Govt. Agencies should take up new projects in an integrated manner to study the possible effects in upstream and downstream reaches of Tapi River.



Photo 15.4 Presentations by Dr. P L Patel, Dr. P V Timbadiya, Ms. Resmi S R and Mr. Priyank J Sharma



Photo 15.5 Interactive session with field experts

Annexure-V: Reply to the comments received from Morphology and Climate Change Directorate on Draft Final Report (Letter No. 4/19/2012/SVNIT/Morpho/659-60 dated 20/06/2017)

Sr. No.	Comment	Reply
1 (i)	Decadal Changes have been observed in the Land use/Land cover pattern, however, the same should be analyzed for impact of changes in land cover on river morphology.	The impact of land use land cover changes in the basin on the morphology of Tapi River has been discussed in **Section 8.5 of Chapter 8 (Page No. 106 – 108).**
1 (ii)	Vulnerability index for different reaches may be evolved & prioritized along with causative factors detail for the erosion may be worked out.	The river reaches of Upper, Middle and Lower Tapi Rivers have been prioritized based on the erosivity of their respective banklines, i.e., the areas of erosion and deposition > 0.05 km^2, and presented in **Appendix A1 – C4.** Also, **Vulnerability Index** has been formulated based on the proximity of eroded reaches of Tapi River to the village/urban areas, national/state highways, and the positive shifting (erosion) of the bank lines in the period base year – 2010. The same was calculated for Upper, Middle and Lower Tapi River reaches separately and is presented in **Section 11.6 of Chapter 11 (Page No. 250 – 257)**.
1 (iii)	Graphical plots on A0 size showing the comparison of delineated different river courses should be arranged in a separate volume in Final Report. The maps showing the details of Erosion/Deposition are not clear. Proper representation of the same should be done on A0 plots as well.	The delineated river reaches have been represented in A0 size, as a separate volume in **Appendix A1-A4; B1-B4 and C1-C4.** The plots include, the active river channel, areas occupied by sand, rocks and islands, eroded and deposited banks, banklines of the base year (toposheets), district boundary, state boundary, villages, towns, barrages, dams, HO sites and bridges.
1 (iv)	Plan form Index and Sinuosity Ratio has been calculated in the report. However, other details like meander wavelength, radius of curvature, amplitude, no of bends for different RDs, average radius of curvature for each segment of river defined etc. should also be provided. Based on this channel pattern analysis, proper interpretation to be given.	The meandering reaches of the river have been identified using the threshold values of sinuosity index (P) and meandering parameters like Meander wavelength (λ_m), Meander amplitude (A_m), Meander belt width (B_m) and Radius of curvature (r_c) have been computed and presented in Table 11.5 of Chapter 11. The detailed representation is given in **Section 11.4.2 of Chapter 11 (Page No. 240 – 241)**.
1 (v)	The future river channel dimensions need to be evaluated based on the available cross-section detail for vulnerable/critical reaches of the rivers.	Based on the available cross-sections of Upper, Middle and Lower Tapi River, we have already identified the critical locations based on excessive aggradation and degradation. Also, detailed study has been

		carried out for the bed level variations in Lower Tapi River between Ghala stream gauging station and the Arabian Sea. (**Section 10.9.4, Figs. 10.35 and 10.36**).
1 (vi)	The channel profile be developed for river reach under consideration. The proper interpretation w.r.t. bed formations, aggradation, degradation etc. to be made part of final report.	The longitudinal profiles for Upper Tapi, Middle Tapi and Lower Tapi Rivers have been developed using relevant softwares using the available cross-section data of years 2015 and 2017 (**Section 10.9, Figs. 10.22, 10.27 and 10.31**). Also, the variations in the reduced level of Thalweg line from Mean Sea Level (MSL) and river chainage have been plotted graphically and proper interpretation of the aggrading and degrading reaches are presented using the aforesaid figures.
1 (vii)	Aggradation/River bed rising aspect also to be considered while identifying the critical reaches.	The aspect of aggradation and degradation are discussed in **Sections 10.9.1 – 10.9.3**, by means of cross-sectional data at various locations along the Tapi River (see Fig.10.22, Fig.10.27 and Fig.10.31 for Upper, Middle and Lower Tapi river respectively). Also, the sedimentation issues in Lower Tapi River has been analyzed in detail, by making use of contours at 2.5 m interval. The river reaches under threat have been identified and duly mentioned (Section 10.9.4, Figs.10.35 and 10.36).
1 (viii)	Existing Embankments along with their impact on river and its morphology should also be discussed in the main report.	The levees which are constructed for flood protection in Lower Tapi River, have ben already mapped and presented in **Fig 4.3 (Chapter 4)**. The possible morphological effect of such levees is discussed in Section 4.2.
1 (ix)	Pre- and Post-monsoon cross-sections of a particular gauging station for different years of study to be plotted for comparison and observing the change with time. Further, by, studying the plotted cross-sections inferences regarding aggradation and degradation in the Tapi river to be drawn.	The pre- and post-monsoon cross-sections at various stream gauging sites have been superimposed, on a decadal basis as well for flood years and presented in Section **10.9.1 – 10.9.3 of Chapter 10**. The observations made regarding local bed level rising and scouring have been reported (**Figs. 10.26, 10.30 and 10.34**).

2 (i)	A brief description of river valley projects which are under construction and planned with figures of water utilization for different purposes.	A brief description on the water resources projects along the Tapi River (Upper Tapi (Hathnur) Irrigation Project, Ukai Project, Kakrapar Irrigation Project and Ukai Hydroelectric Project) have been reported in **Section 3.3 of Chapter 3**. Also, the details of the Lower Tapi Dam in Padalse Village, which is under construction has been given. The existing water resources projects along Tapi River have been labelled and presented in **Fig 4.4 (Chapter 4).**
2 (ii)	Fluvial geomorphology -It should also contain information in terms of identifying abandoned/moribandh/ seasonally active spill channels/ meander scrolls/ oxbow lakes etc.	The fluvial geomorphology of the River has been analyzed with the help of hydraulic geometry equations and unit stream power produced by the peak flows in the River at various stream gauging stations. The results are presented in Section 6.5, Chapter 6. However, abandoned/moribandh/seasonally active spill channels/ meander scrolls/oxbow lakes, were not observed in the reach of Tapi River.
3 (i)	A lot of images are incorporated in the draft report. Some extraneous images may be deleted in the final report.	The photographs presented in the report which are extremely relevant, and give idea about the conditions of the site, behaviour of the river, river bed and the respective banks along Tapi River, are included. However, the photographs pertaining to the tributaries of Tapi River have been deleted.
3 (ii)	The details of the typical river training works proposed for restoration of critical and important reaches to be given in tabular form indicating the name of place, length of reach etc.	The details of the typical river training works proposed for restoration of critical and important reaches have been tabulated in the format specified in **Table 12.1 of Chapter 12.**

Annexure-VI: Reply to the comments on Minutes of the one-day workshop on 'Morphological Study of Tapi River using Remote Sensing Technique (Letter No. 4/19/2012/SVNIT/Morpho/1173-80 dated 04/09/2017)

Sr. No.	Comment	Reply
1)	The sediment inflow contributions at Hatnur Reservoir from Tapi as well as Purna River needs to be clearly highlighted.	The sediment inflow contributions at Hatnur Reservoir from Tapi and Purna Rivers have been analyzed by comparing the observed annual sediment yield (t/ha) at Yerli stream gauging station (Purna basin) and Burhanpur stream gauging station (Tapi basin). The previous studies that have carried out in the same context, i.e., Ladhe et al., 2008 and Prabhat Chandra (2016), have been made use of to evaluate the same (**Section 10.8.2, Chapter 10)**.
2)	The exact locations of sand mining activities may be also should be brought out. So that the actual impact on the morphological aspects are to be ascertained and to be incorporated in the final report. If there is negligible effect of sand mining on river morphology, the quantifiable reasons for the same may be elaborated and incorporate in final report. If there is any success story of sand mining that also needs to be elaborated.	The exact locations of existing sand mining, identified during the field visits and ascertain from Google Earth imagery are discussed in detail in **Chapter 9**. Also, existing sand mining sites along with the sites that exhibit excessive bank deposition are tabulated and highlighted in **Tables 12.2 -12.4 of Chapter 12**. The possible locations for desilting of excessive deposited sediments in Hatnur Reservoir is highlighted in Chapter 10, Section 10.8. Also, the possible locations for desilting of excessive deposited/ aggraded sediments in Lower Tapi River are included in Section 10.9.3.
3)	Cross- section of river needs to be superimposed to ascertain the aggradations of river, if any.	The pre- and post-monsoon cross-sections at various stream gauging sites have been superimposed, on a decadal basis as well for flood years and presented in Section **10.9.1 – 10.9.3 of Chapter 10**. The observations made regarding local bed level rising and scouring have been reported.
4)	How much length of rivers has already been protected by river training work on both banks, this need to be shown on separate map.	The levees which are constructed for flood protection in Lower Tapi River, have ben already mapped and presented in **Fig 4.3 (Chapter 4)**.
5)	A workshop/ seminar was held in NWA, Pune on Surat Flooding. The proceedings of Workshop/Seminar may be obtained from NWA, Pune.	The NWA Pune was approached for getting the proceedings of Training Program on **Flood Disaster Management** during 30 April – 4 May 2012. The presentation made by Shri Aditya Sharma, SE (C), CWC on

		Ukai Flood – A case study was noted for its possible compliance in the report. Accordingly, the findings of above presentation are included in **Chapter 13, Section 13.1.**
6)	Sediments deposition reach have been marked in the reports. CSRM & CWPRS may be requested to identify the probable reaches from where such sediments can be desilted /dredged for construction works/ other purposes	The probable river reaches from where excessive sediments can be desilted/dredged for construction purposes and other activities have been identified and tabulated separately for Upper, Middle and Lower Tapi Rivers (wrt. base year-2010) in **Tables 12.2-12.4 of Chapter 12**. The possible locations for desilting of excessive deposited sediments in Hatnur Reservoir is highlighted in Chapter 10, Section 10.8. Also, the possible locations for desilting of excessive deposited/ aggraded sediments in Lower Tapi River are included in Section 10.9.3. Apart from consulting local organizations, the consulting originations like CSRM & CWPRS, are required to be consulted for identifying the exact locations of desilting sites, quantum of desilting and their possible future morphological effects, before taking the final decision on the same.

Annexure-VII: Reply to the Letter from Member (RM), Central Water Commission (CWC), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India
(Letter no. 4/19/2012/Morpho/1200-1201 dated Sep. 7, 2017)

In current morphological report, the river stretches, wherein excessive sediment depositions in the river bed are present, are identified. Such stretches are mainly in the upstream and downstream of Singapore weir in the lower Tapi River, and excessive sediments being in the lower Tapi River. Such excessive deposited sediments can be excavated, and put in the forms of geo-bags and geo-tubes for provisioning flood protection measures along lower Tapi River, and protection of coastal area from coastal floods. It is worth noting that major coast lines of Gujarat state are becoming more vulnerable due to rise in sea level under changing climatic conditions across the globe. The detailed globally accepted design criteria can be assessed from www.tessilbrenta.com/en/stopwave

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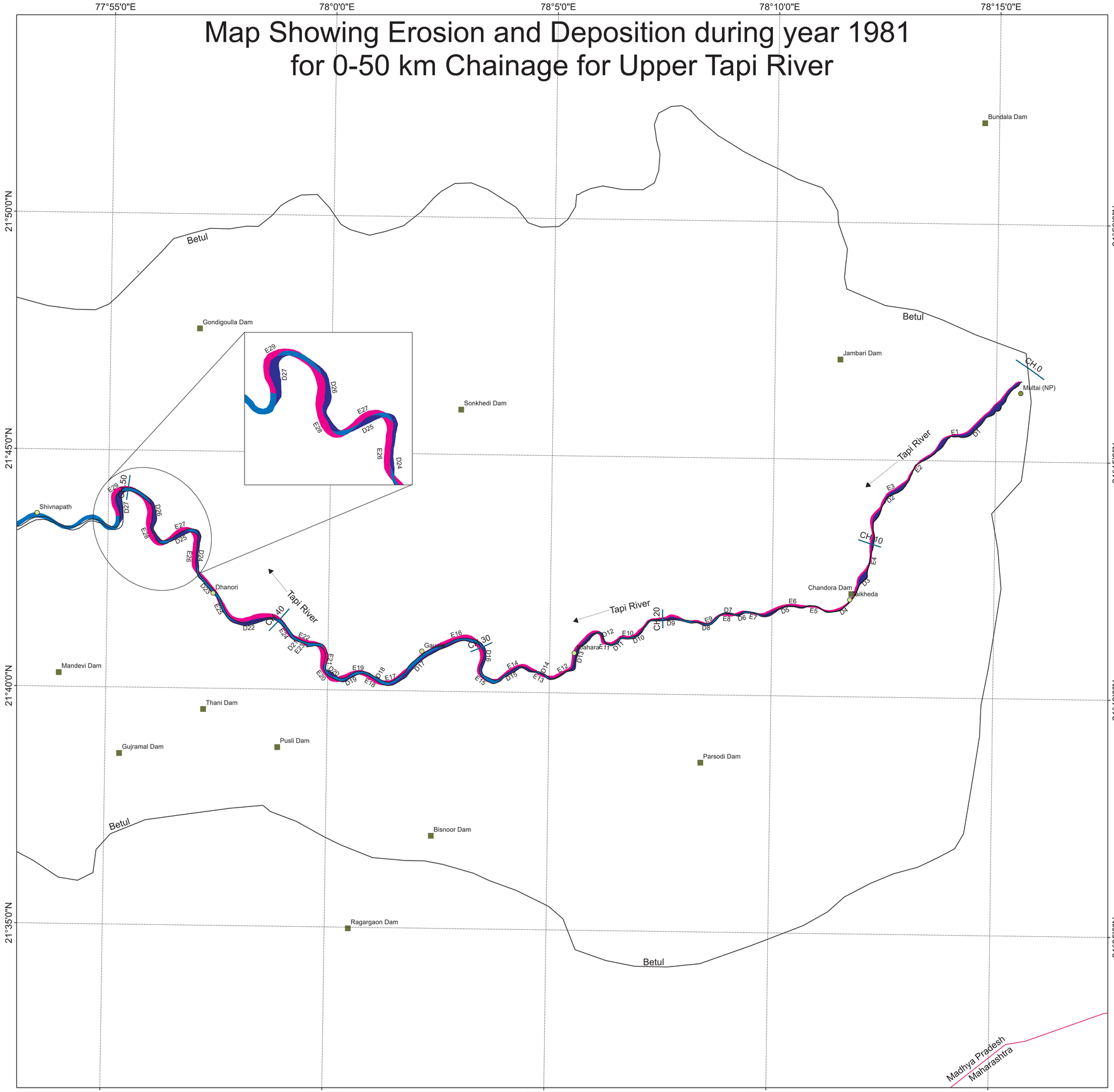
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Map Showing Erosion and Deposition during year 1981 for 0-50 km Chainage for Upper Tapi River



Appendix: A1(Ch. 0 to 50 km, Reach 1)

N

Legend

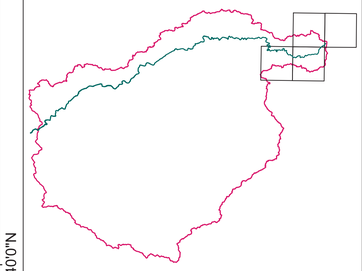
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

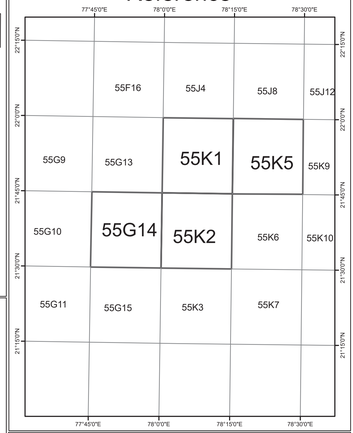
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E1	730187
E3	745222
E6	196544
E9	53390
E10	246279
E12	347533
E14	151914
E16	213053
E17	67422
E19	88017
E21	70006
E22	574221
E27	121295
E29	267767

LBL

Location	Area(sqm)
E2	9959
E4	17403
E5	26175
E7	9781
E8	34802
E11	42285
E13	24033
E15	161409
E18	81791
E20	215184
E23	9973
E24	31812
E25	16920
E26	235944
E28	380699

RBL

Location	Area(sqm)
D7	17093
D12	15925
D14	10681
D16	101406
D18	6727
D20	39100
D24	162977
D26	271186

LBL

Location	Area(sqm)
D1	565923
D2	261469
D3	120909
D4	22136
D5	106432
D6	22369
D8	27585
D9	68389
D10	36752
D11	11779
D13	236803
D15	100270
D17	258792
D19	28875
D21	5425
D22	195347
D23	24874
D25	90549
D27	241289

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/1/2017

Map Showing Erosion and Deposition during year 1981 for 50 -100 km Chainage for Upper Tapi River

77°40'0"E 77°45'0"E 77°50'0"E 77°55'0"E 78°0'0"E

21°55'0"N 21°50'0"N 21°45'0"N 21°40'0"N

Betul

Tapi River

Siyakundal Barrage

Teska Bridge

Layabarni

Tapi River

Gondigoulla Dam

Mandha

Tapi River

Shivnapath

Betul

Dhanora

Mandevi Dam

Thani Dam

Gujramal Dam

Pusli Dam

Betul

CH 100 CH 90 CH 80 CH 70 CH 60 CH 50 CH 40

D49 D48 D47 D46 D45 D44 D43 D42 D41 D40 D39 D38 D37 D36 D35 D34 D33 D32 D31 D30 D29 D28

E52 E53 E50 E5 E49 E47 E46 E45 E44 E43 E42 E41 E40 E39 E38 E37 E36 E35 E34 E33 E32 E31

Appendix: A1(Ch.50 to100 km,Reach 2)

N

Legend

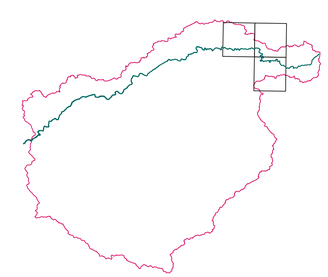
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

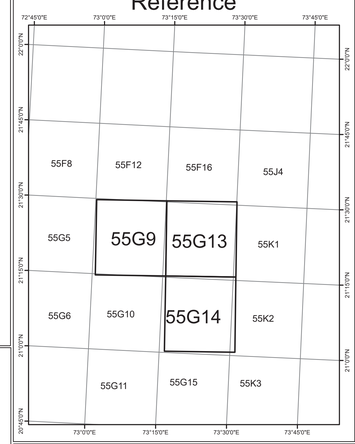
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E30	74905
E32	210658
E34	268713
E35	263790
E37	640908
E40	382780
E42	32513
E44	113546
E46	38154
E47	190504
E49	15161
E52	1037947

RBL

Location	Area(sqm)
D32	67684
D35	15658
D37	59645
D39	42952
D40	33117
D41	5074
D43	5998
D44	182267
D45	285737

LBL

Location	Area(sqm)
E31	36648
E33	36016
E36	191967
E38	213375
E39	76153
E41	154217
E43	117207
E45	281507
E48	847188
E50	14997
E51	20020
E53	23850

LBL

Location	Area(sqm)
D28	36634
D29	91683
D30	134651
D31	178966
D33	27208
D34	160158
D36	126250
D38	8309
D42	198704
D46	29100
D47	67801
D48	126082
D49	272116
D50	152527

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Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/2/2017

Map Showing Erosion and Deposition during year 1981 for 100 -150 km Chainage for Upper Tapi River

Appendix:A1(Ch.100 to150 km,Reach3)

77°20'0"E 77°25'0"E 77°30'0"E 77°35'0"E 77°40'0"E

21°55'0"N 21°50'0"N 21°45'0"N 21°40'0"N

East Nimar
Betul

Betul

Tapi River

Dabida

Utara

Gorkhidhana

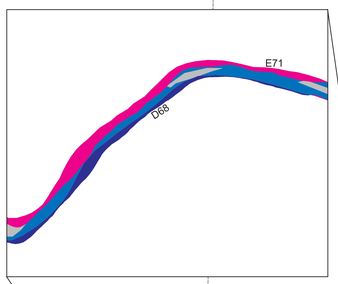
Siyakundal Barrage

Betwa Barrage

Betul
Amrawati

Madhya Pradesh
Maharashtra

CH 160 CH 150 CH 140 CH 130 CH 120 CH 110 CH 100





Legend

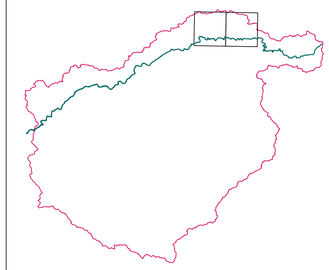
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

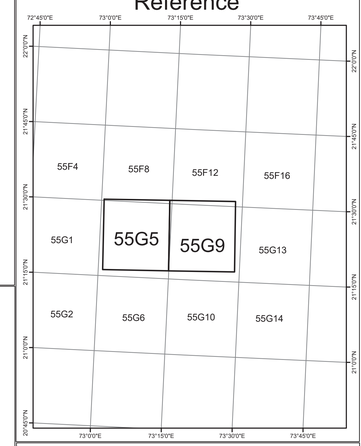
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E54	391609
E56	137221
E58	264823
E59	45112
E61	40301
E63	376938
E66	196659
E68	30836
E70	8121
E71	547856
E74	193870
E75	148211
E77	276001

RBL

Location	Area(sqm)
D52	43692
D54	66165
D59	13584
D64	11302
D66	29868
D70	27034
D73	13997
D75	95550
D77	12297
D78	16139
D80	101490

LBL

Location	Area(sqm)
E55	33636
E57	62884
E60	25068
E62	53613
E64	16288
E65	72368
E67	6390
E69	23844
E72	6643
E73	5726
E76	48261
E78	23688
E79	77468
E80	14904
E81	6699

LBL

Location	Area(sqm)
D51	285860
D53	102172
D55	98317
D56	12824
D57	63124
D58	23988
D60	137221
D61	8564
D62	16599
D63	20727
D65	90225
D67	42491
D68	295067
D69	15878
D71	10026
D72	185860
D74	196297
D76	280696
D79	25610
D81	11512

Prepared for

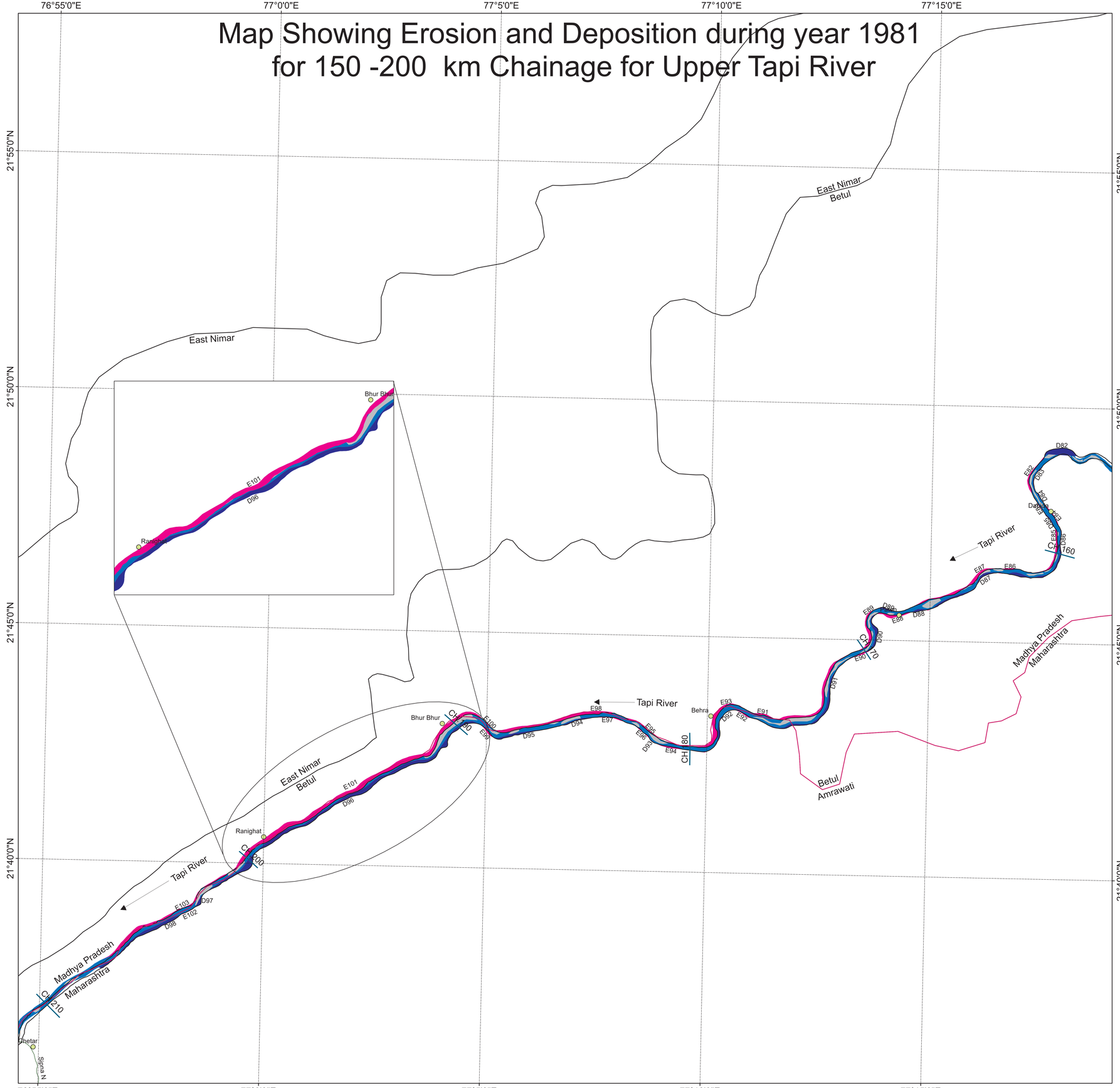
Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/3/2017

Map Showing Erosion and Deposition during year 1981 for 150 -200 km Chainage for Upper Tapi River



Appendix:A1(Ch.150 to200 km,Reach4)

Legend

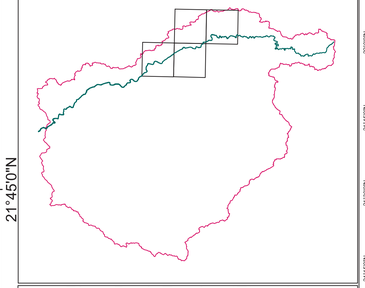
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

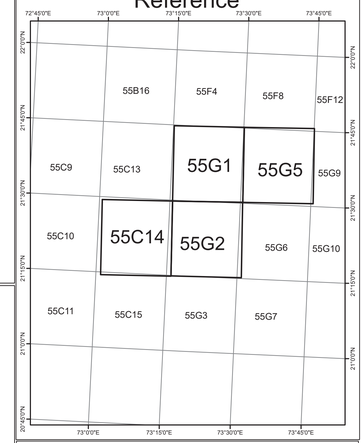
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E82	71802
E83	8530
E85	117144
E86	23355
E87	207607
E89	465372
E91	38478
E93	294743
E95	44703
E98	426257
E100	12422
E101	1625208
E103	334557

RBL

Location	Area(sqm)
D82	246735
D85	19470
D89	30745

LBL

Location	Area(sqm)
E84	27761
E88	85716
E90	29140
E92	21787
E94	51669
E96	16455
E97	26673
E99	28973
E102	8539

LBL

Location	Area(sqm)
D83	24022
D84	11718
D86	176376
D87	144388
D88	33693
D90	109553
D91	231462
D92	63519
D93	5356
D94	45377
D95	108294
D96	1229858
D97	37664
D98	298603

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/4/2017

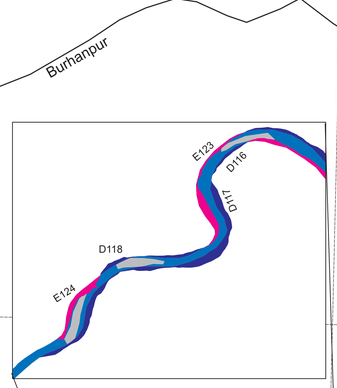
Map Showing Erosion and Deposition during year 1981 for 200 - 250 km Chainage for Upper Tapi River

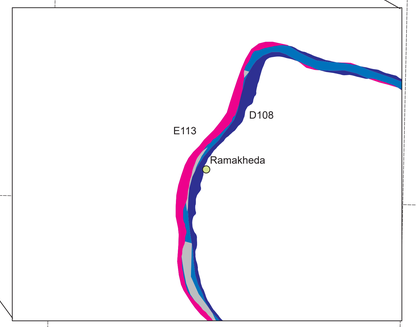
Appendix:A1(Ch.200 to250 km,Reach5)

76°35'0"E 76°40'0"E 76°45'0"E 76°50'0"E 76°55'0"E

21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N

East Nimar
Burhanpur
Tapi River
Ramakheda
CH:230
Dharni
Sipna N
Mandwa Dam
Jutpani Dam
Khari Dam
Gaolandoh Dam
Sadrabadi Dam
Dedtalai
Bhakri Bhorabhi
Khandwa-Dedtalai Rd
Dangurla
CH:250
Majrodkla
Majrod Kalan-Daryapur Road Bridge
Burhanpur
Amrawati
Madhya Pradesh
Maharashtra
East Nimar
Betul
Chetar
CH:210





Legend

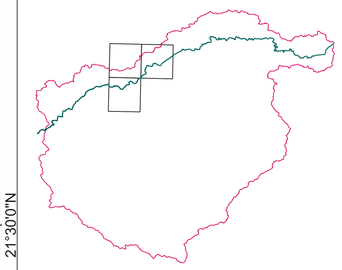
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

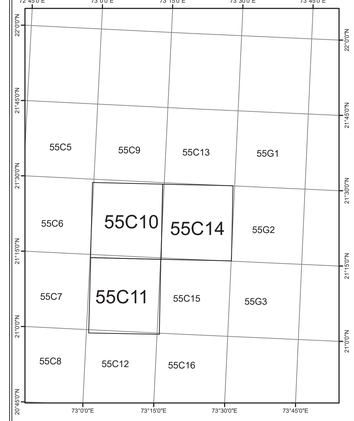
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B1	CH: 235 km	Khandwa-Dedtalai Rd	7 No. of 41.50 m and 2 No. of 17.25 m	8	1992
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E104	916005
E106	7479
E107	157689
E108	150830
E111	5589
E113	1070337
E115	65105
E116	26632
E118	19267
E119	44040
E120	104660
E123	246943
E124	167280

LBL

Location	Area(sqm)
E105	13505
E109	13550
E110	17299
E112	14091
E114	37592
E117	12081
E121	115343
E122	198649

RBL

Location	Area(sqm)
D101	9010
D103	11196
D104	68250
D107	48167
D109	32696
D111	119534
D115	279305
D118	118872

LBL

Location	Area(sqm)
D99	533814
D100	13742
D102	454188
D105	7393
D106	55545
D108	1019257
D110	290081
D112	24357
D113	186460
D114	86165
D116	54605
D117	688881

Prepared for

Central Water Commission
New Delhi

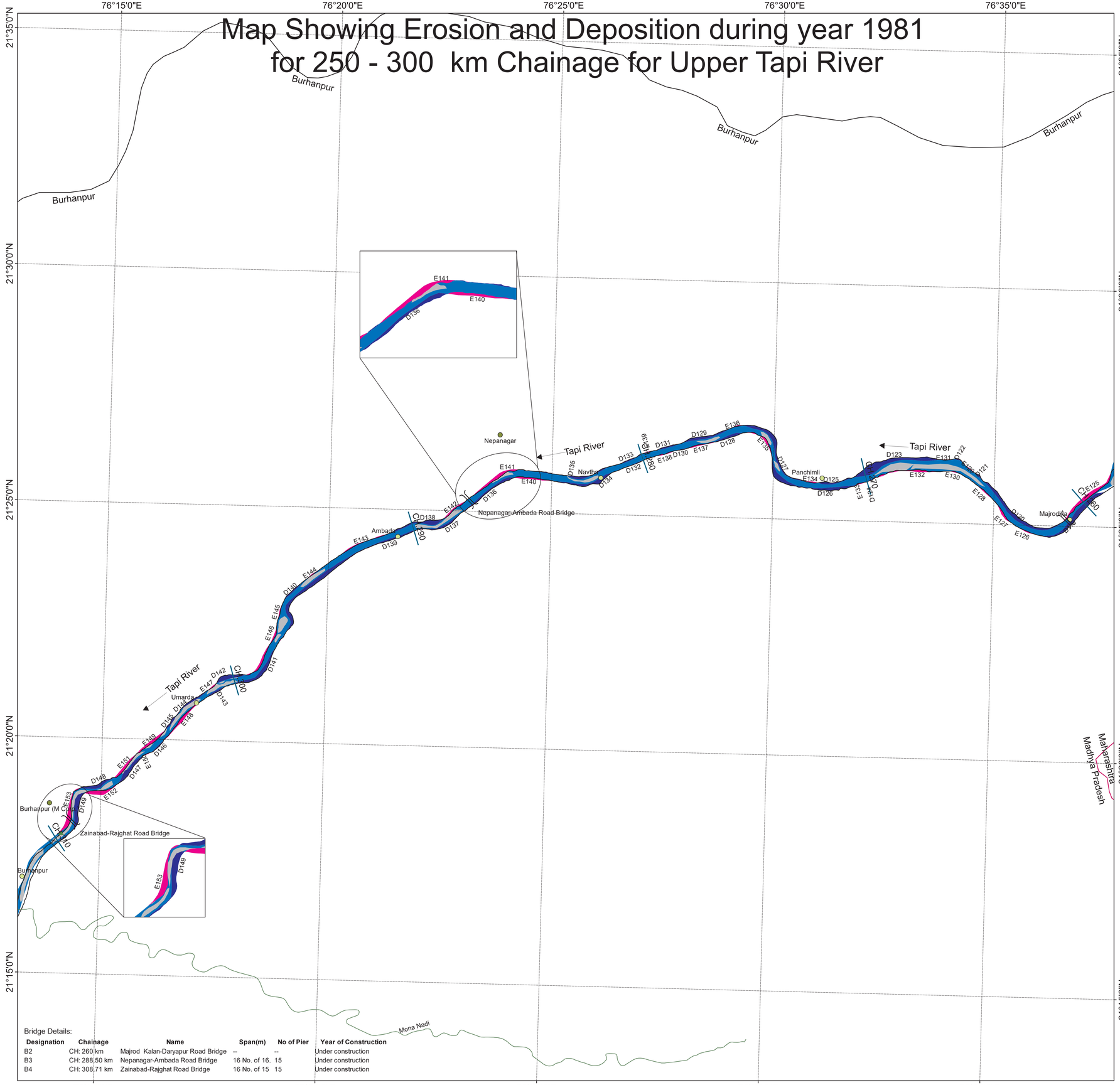
Prepared by

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Surat - 395007, Gujarat

Morpho/11/5/2017

Map Showing Erosion and Deposition during year 1981 for 250 - 300 km Chainage for Upper Tapi River

Appendix:A1(Ch.250 to300 km,Reach6)



Legend

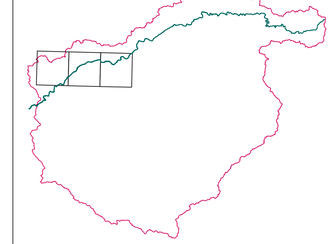
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

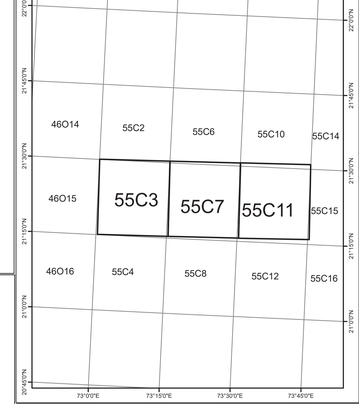
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction
B3	CH: 288.50 km	Nepanagar-Ambada Road Bridge	16 No. of 16.	15	Under construction
B4	CH: 308.71 km	Zainabad-Rajghat Road Bridge	16 No. of 15	15	Under construction

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E125	228844
E129	10573
E131	6185
E134	15694
E136	9686
E139	6340
E141	149124
E142	46874
E143	46703
E144	12707
E145	15683
E146	116015
E147	12235
E149	99089
E151	86885
E153	177363

RBL

Location	Area(sqm)
D120	352269
D121	14774
D122	12061
D123	520715
D125	65078
D127	280431
D129	128377
D131	33082
D133	28486
D135	98807
D138	166888
D140	38310
D142	129806
D144	60733
D145	35755
D148	119393

LBL

Location	Area(sqm)
E126	15031
E127	44829
E128	23329
E130	8944
E132	89003
E133	8718
E135	57491
E137	29617
E138	17148
E140	67379
E148	106451
E150	5824
E152	133912

LBL

Location	Area(sqm)
D119	365999
D124	6771
D126	324142
D128	75666
D130	8872
D132	18634
D134	166775
D136	142159
D137	73534
D139	579441
D141	206303
D143	39811
D146	21608
D147	156540
D149	234244

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
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Surat - 395007, Gujarat

Morpho/11/6/2017

Map Showing Erosion and Deposition during year 1981 for 300 - 350 km Chainage for Upper Tapi River

Appendix:A1(Ch.300 to350 km,Reach7)

Legend

- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Plate Reference

SOI Toposheet Reference

46O14 55C2 55C6
46O11 46O15 55C3 55C7
46O12 46O16 55C4 55C8
46P9 46P13 55D1 55D5

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E154	266837
E155	12759
E157	26770
E158	44612
E159	47540
E161	151717
E162	179047
E164	54965
E166	326194
E169	76200
E170	11655
E171	50311
E173	442944
E175	75549
E176	176890

LBL

Location	Area(sqm)
E156	55083
E160	52125
E163	7279
E165	372591
E167	167306
E168	101746
E172	24605
E174	331142
E177	28421

RBL

Location	Area(sqm)
D151	47139
D152	244248
D154	33089
D156	172396
D158	5473
D159	34228
D160	306744
D162	377546
D165	106237
D166	215783
D168	28012
D171	69443
D172	8464

LBL

Location	Area(sqm)
D150	360454
D153	131210
D155	275763
D157	720391
D161	639009
D163	21094
D164	557897
D167	341911
D169	87045
D170	179595
D173	14915
D174	8516

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B5	CH: 317.21 km	Hatnur-Bhatkheda Road Bridge	12 No. of 17.50 m	11	1985
B6	CH: 338 km	Pimprinandu,Maharastra	--	4	2001

Prepared for

Central Water Commission
New Delhi

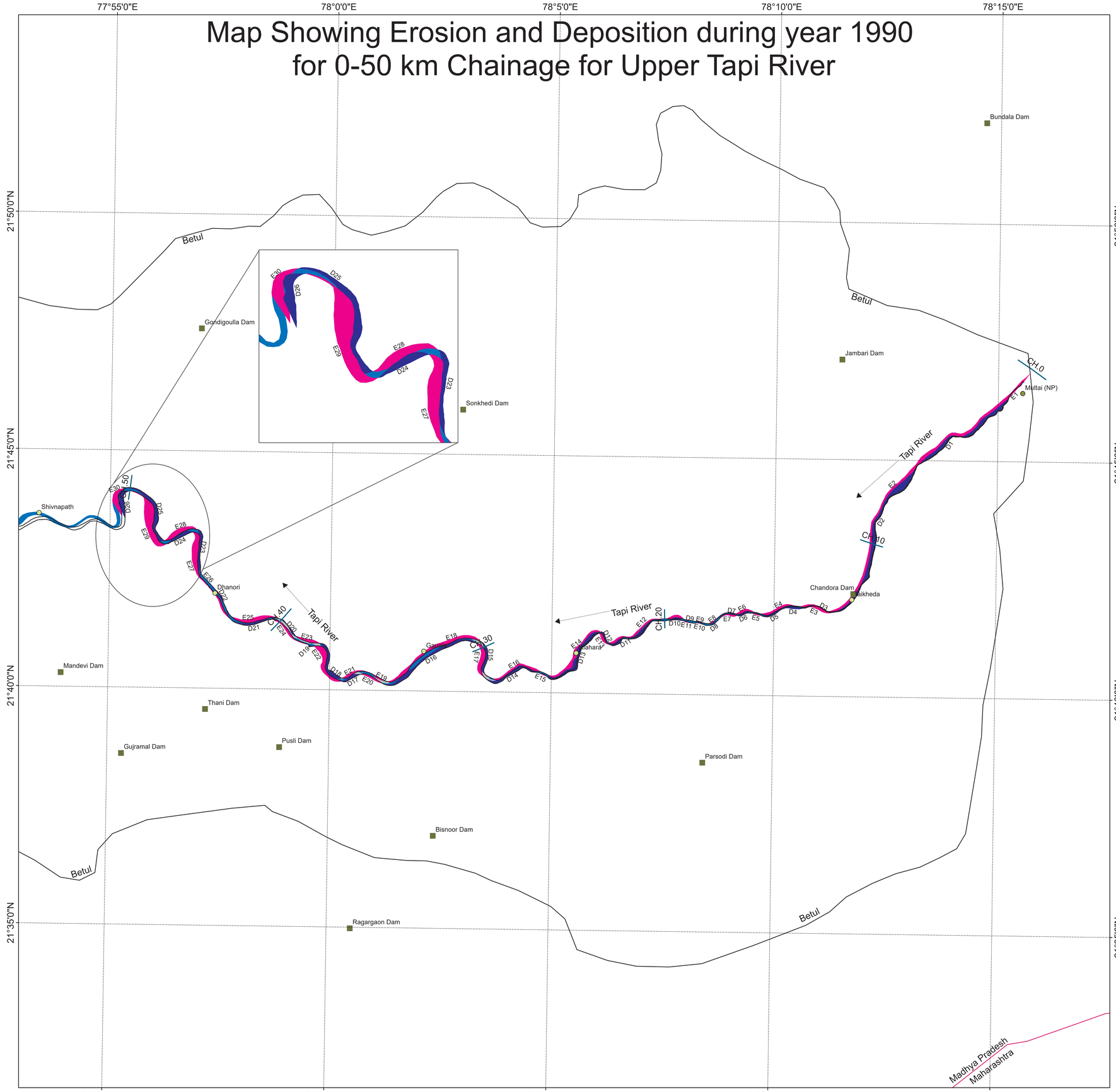
Prepared by

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Surat - 395007, Gujarat

Morpho/11/7/2017

Map Showing Erosion and Deposition during year 1990 for 0-50 km Chainage for Upper Tapi River

Appendix: A2(Ch. 0 to 50 km, Reach 1)



Legend

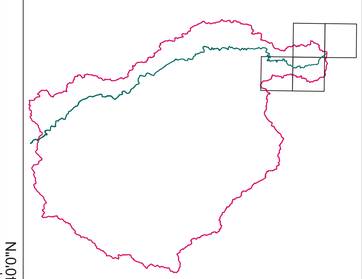
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

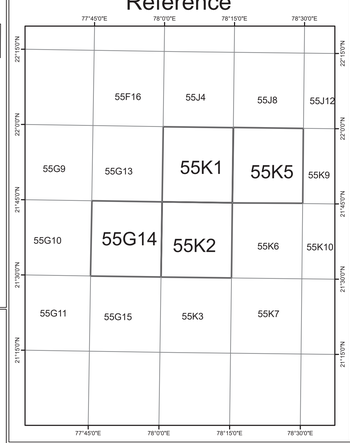
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E2	2176094
E4	142336
E6	56553
E8	19345
E9	5677
E12	276065
E14	476406
E16	178174
E18	409166
E19	20635
E21	62510
E23	74203
E25	188704
E26	5950
E28	186474
E30	198976

RBL

Location	Area(sqm)
D3	15708
D7	13628
D9	5763
D12	39276
D15	141376
D18	244623
D20	31575
D22	45114
D23	227061
D25	445768

LBL

Location	Area(sqm)
E1	18808
E3	66806
E5	14265
E7	36320
E10	6519
E11	8014
E13	46803
E15	8595
E17	195831
E20	54990
E22	284053
E24	92819
E27	432819
E29	559847

LBL

Location	Area(sqm)
D1	496012
D2	830152
D4	42880
D5	51433
D6	31142
D8	12018
D10	37284
D11	166390
D13	354654
D14	193078
D16	369405
D17	62940
D19	9468
D21	94117
D24	119089
D26	175079

Prepared for

Central Water Commission
New Delhi

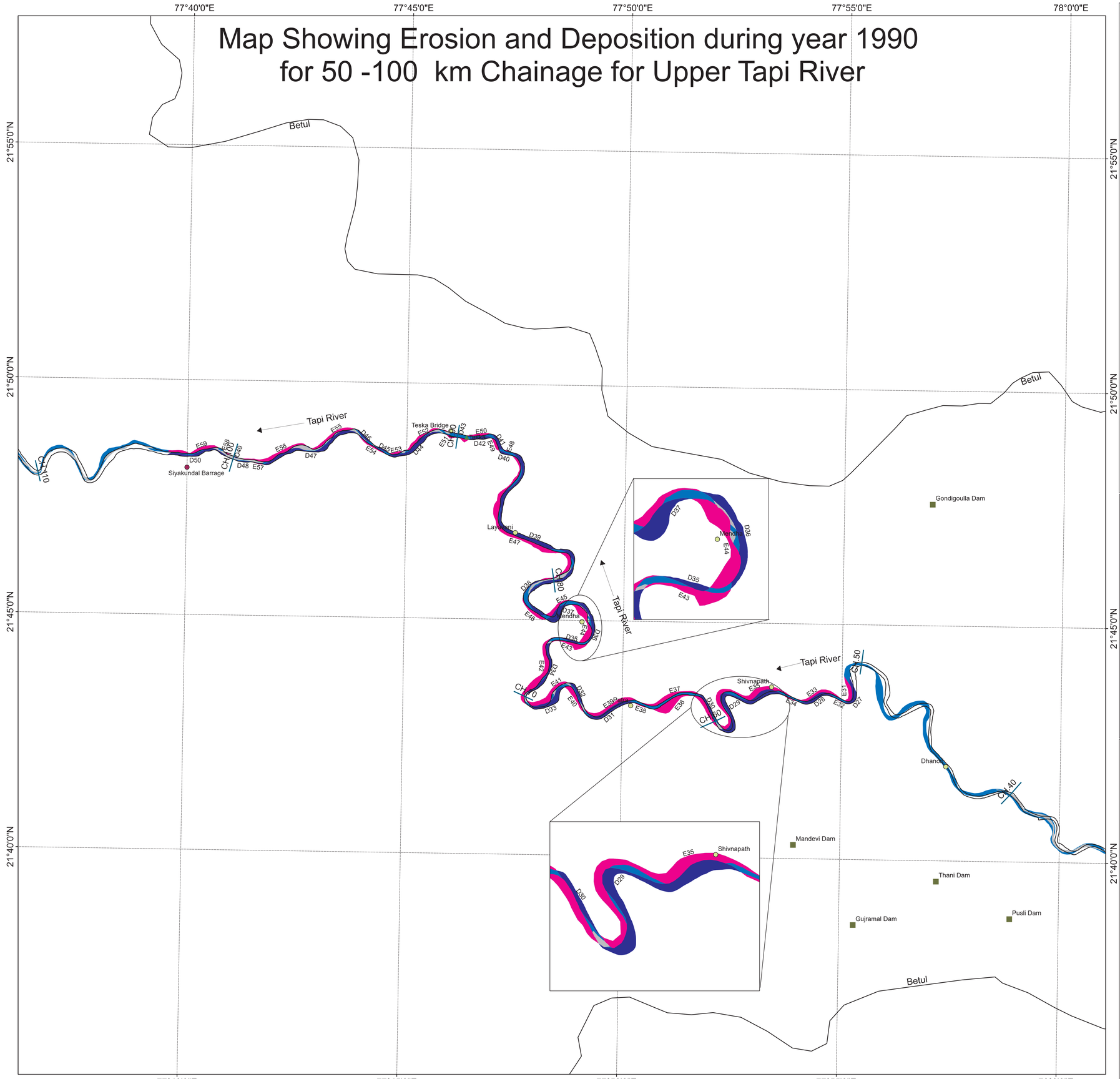
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Morpho/11/8/2017

Map Showing Erosion and Deposition during year 1990 for 50 -100 km Chainage for Upper Tapi River

Appendix:A2(Ch.50 to100 km,Reach 2)



Legend

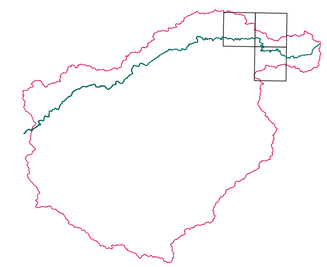
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

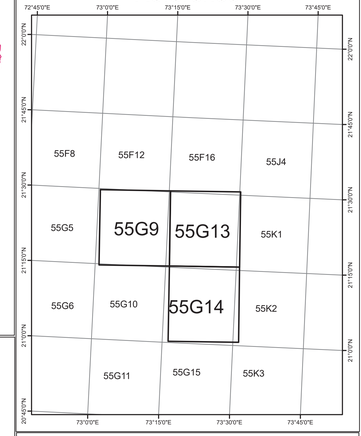
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E31	147231
E33	197906
E35	725458
E37	204710
E39	288778
E41	313825
E43	144249
E45	136089
E48	6877
E50	55740
E52	133576
E53	33437
E55	167473
E56	224102
E58	7958
E59	174147

RBL

Location	Area(sqm)
D30	99423
D32	88469
D34	262751
D36	225055
D39	1048504
D41	77523
D43	12578
D45	24186
D46	43779
D49	8694

LBL

Location	Area(sqm)
E32	6773
E34	17196
E36	487851
E38	15078
E40	139331
E42	455124
E44	319087
E46	105363
E47	831989
E49	47976
E51	54486
E54	56853
E57	9618

LBL

Location	Area(sqm)
D27	141911
D28	159087
D29	595163
D31	236455
D33	254035
D35	48227
D37	212960
D38	32419
D40	27111
D42	62999
D44	253610
D47	391822
D48	17786
D50	175452

Prepared for

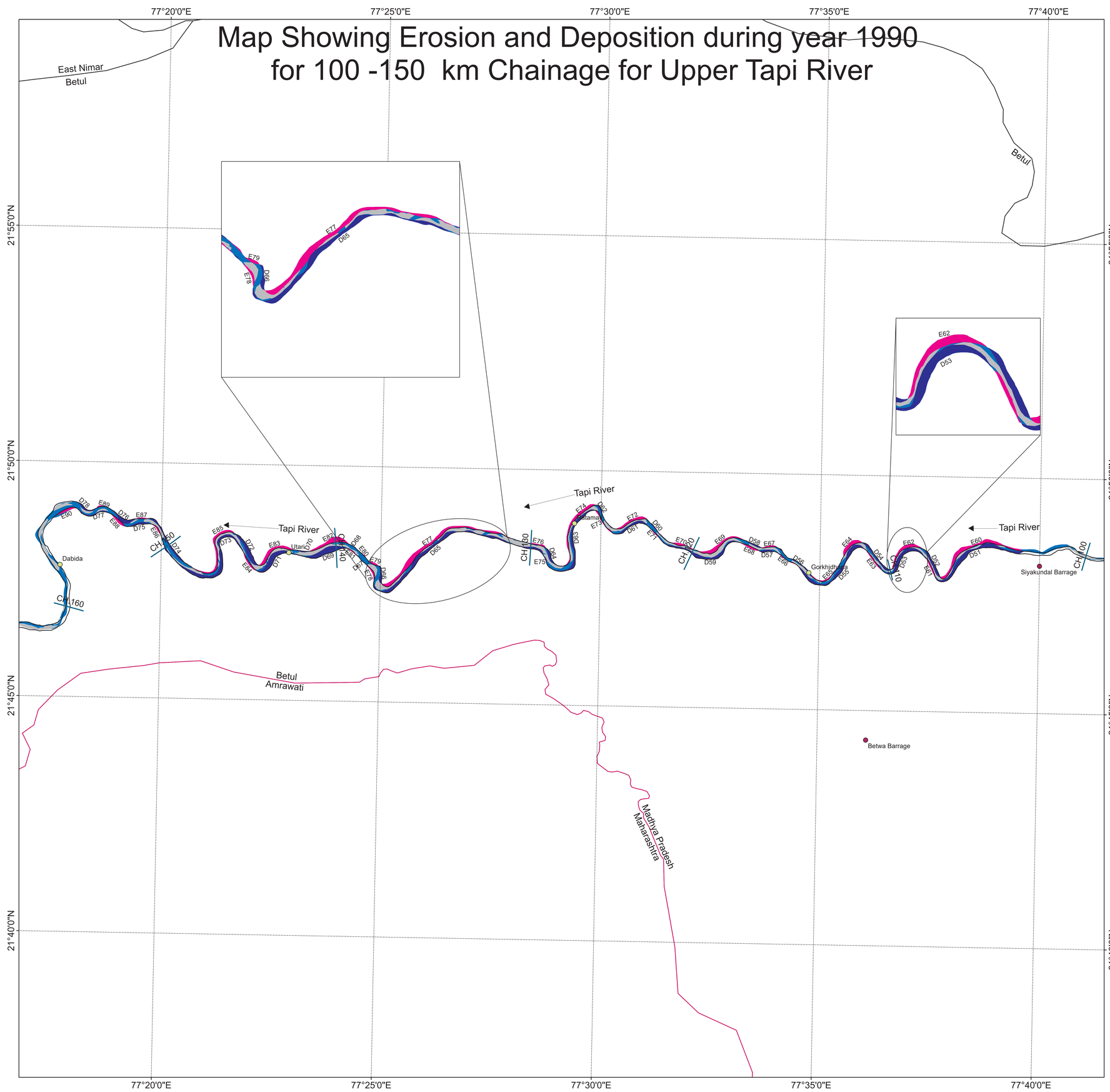
Central Water Commission
New Delhi

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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/9/2017

Map Showing Erosion and Deposition during year 1990 for 100 -150 km Chainage for Upper Tapi River



Appendix:A2(Ch.100 to150 km,Reach3)

Legend

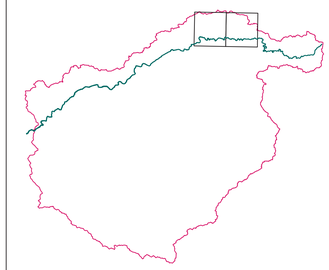
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

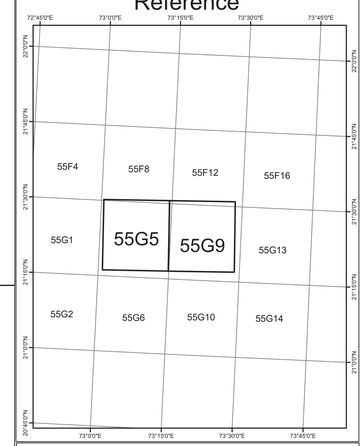
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E60	357879
E62	133077
E64	116127
E65	46802
E67	26878
E69	162615
E70	46305
E72	100545
E74	198418
E76	30202
E77	561615
E79	22888
E80	8694
E82	190238
E83	159028
E85	191982
E87	15989
E89	15718

RBL

Location	Area(sqm)
D52	99675
D54	94117
D56	35396
D58	27889
D60	11919
D62	29029
D64	56751
D66	49113
D68	5744
D70	16654
D72	179280
D74	125863
D76	106420
D78	45923

LBL

Location	Area(sqm)
E61	37384
E63	41079
E66	18944
E68	43302
E71	13006
E73	37358
E75	5307
E78	32096
E81	13788
E84	43165
E86	23553
E88	48663
E90	54769

LBL

Location	Area(sqm)
D51	414613
D53	207875
D55	302555
D57	36983
D59	230897
D61	96999
D63	244555
D65	601532
D67	6032
D69	253365
D71	237245
D73	404538
D75	52894
D77	47574

Prepared for

Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/10/2017

Map Showing Erosion and Deposition during year 1990 for 150 -200 km Chainage for Upper Tapi River

Appendix:A2(Ch.150 to 200 km,Reach4)

Legend

- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

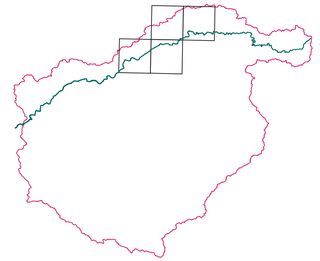
Scale

Kilometers

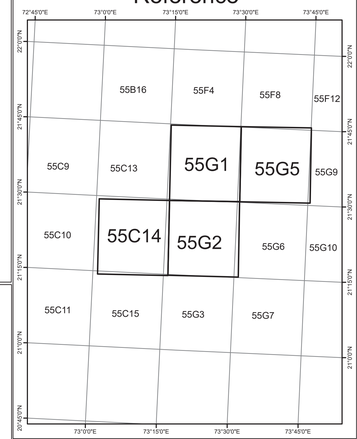
0 5 10

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E92	20674
E93	54329
E94	34905
E96	123231
E97	7633
E98	4904
E99	15398
E100	278258
E102	552856
E103	36199
E104	380798
E106	534821
E108	1876191
E109	40576
E110	10830
E111	275974

RBL

Location	Area(sqm)
D79	26205
D85	34781
D87	6073
D88	5542
D90	9265
D93	49042
D95	15737

LBL

Location	Area(sqm)
E91	29361
E95	12194
E101	10048
E105	72134
E107	46429

LBL

Location	Area(sqm)
D80	30485
D81	26208
D82	322200
D83	331451
D84	19314
D86	1006189
D89	6497
D91	15163
D92	506247
D94	1650783
D96	455604

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New Delhi

Prepared by

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Surat - 395007, Gujarat

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Map Showing Erosion and Deposition during year 1990 for 200 - 250 km Chainage for Upper Tapi River

Appendix:A2(Ch.200 to 250 km,Reach5)

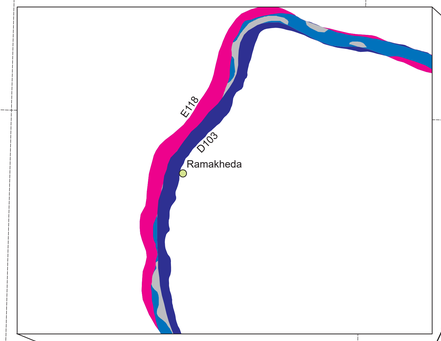
76°35'0"E 76°40'0"E 76°45'0"E 76°50'0"E 76°55'0"E

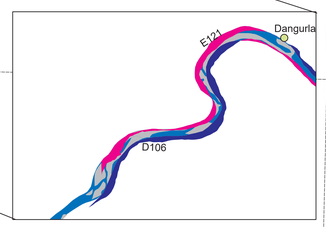
21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N

East Nimar
Betul
Burhanpur
Amrawati
Tapi River
Madhya Pradesh
Maharashtra
Ramakheda
Dangurla
Chetar
Majrod
Majrod Kalan-Daryapur Road Bridge
Khandwa-Dedtalai Rd
Sipna N
Mandwa Dam
Jutpani Dam
Khari Dam
Sadrabadi Dam
Gaolandoh Dam

CH: 200
CH: 220
CH: 240
CH: 260

E118 E119 E120 E121 E112 E113 E114 E115 E116 E117
D103 D104 D105 D106 D97 D98 D99 D100 D101 D102





Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B1	CH: 235 km	Khandwa-Dedtalai Rd	7 No. of 41.50 m and 2 No. of 17.25 m	8	1992
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction

Legend

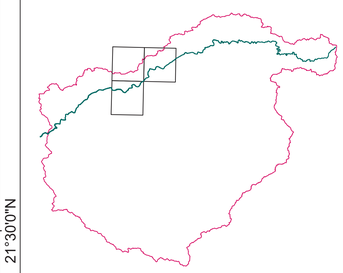
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

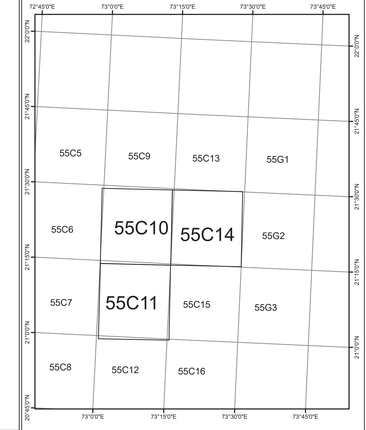
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E112	917899
E114	55740
E115	412281
E117	30161
E118	1285108
E119	1564002
E121	963654

RBL

Location	Area(sqm)
D98	10435
D99	109298
D102	9324
D105	166693

LBL

Location	Area(sqm)
E113	110617
E116	65578
E120	167672

LBL

Location	Area(sqm)
D97	792538
D100	42650
D101	476341
D103	2284275
D104	659438
D106	1145451

Prepared for

Central Water Commission
New Delhi

Prepared by

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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/12/2017

Map Showing Erosion and Deposition during year 1990 for 250 - 300 km Chainage for Upper Tapi River

Appendix:A2(Ch.250 to 300 km,Reach6)

76°15'0"E 76°20'0"E 76°25'0"E 76°30'0"E 76°35'0"E

21°35'0"N 21°30'0"N 21°25'0"N 21°20'0"N 21°15'0"N

Burhanpur

Navlia E127 D115

Nepanagar

Tapi River

E127 D115 CH: 260

E126 D114 E125 D113 CH: 270

Panchimli E124 D112 D111 D110 D109 E123 D108

Majrod E122 D107 CH: 260

Nepanagar-Ambada Road Bridge

Ambada E128 D116 CH: 250

Tapi River

D117 CH: 280

Umarda E129 D118

Umarda C7

Maharashtra
Madhya Pradesh

Burhanpur (M Corp.)

Zainabad-Rajghat Road Bridge

CH: 310

Burhanpur

Mona Nadi

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction
B3	CH: 288.50 km	Nepanagar-Ambada Road Bridge	16 No. of 16.47 m	15	Under construction
B4	CH: 308.71 km	Zainabad-Rajghat Road Bridge	16 No. of 15 m	15	Under construction

Legend

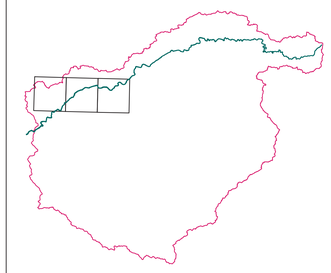
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

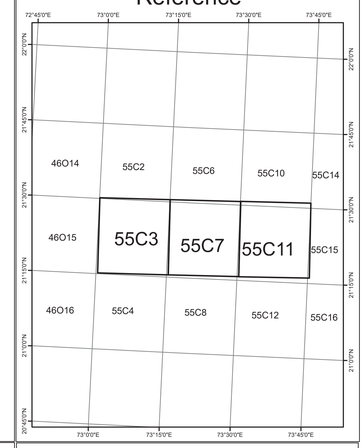
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	Area(sqm)
E122	711686
E124	482522
E125	46964
E127	608828
E128	1530507
E129	806881

RBL Location	Area(sqm)
D108	211600
D109	10745
D110	42804
D114	90232
D117	20961

LBL Location	Area(sqm)
E123	185778
E126	89122

LBL Location	Area(sqm)
D107	677197
D111	73464
D112	65201
D113	427328
D115	1547771
D116	125111
D118	1916802

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Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/13/2017

Map Showing Erosion and Deposition during year 1990 for 300 - 350 km Chainage for Upper Tapi River

Appendix:A2(Ch.300 to350 km,Reach7)

75°55'0"E 76°0'0"E 76°5'0"E 76°10'0"E 76°15'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

West Nimar Jalgaon

Madhya Pradesh Maharashtra

Burhanpur Jalgaon

Umarti

Burhanpur (M Corp.)

Zainabad-Rajghat Road Bridge

CH: 313.10

E139

Burhanpur

Tapi River

Mona Nadi

D120

Hatnur-Bhatkheda Road Bridge

E131

CH: 317.21

Ajnand

D121

D122

E132

Tapi River

D123

E133

CH: 338.00

E134

Tarkole

D124

E135

E137

D125

Pimprinandu,Maharastra

E136

CH: 340.00

E138

D127

D126

D128

Nalgaon

Burhanpur Jalgaon

Morzira Dam

E140

Tapi River

E141

CH: 350.00

D129

E142

Changdev

E143

D130

E144

Upper Tapi Hatnur Dam

Hatnur

Purna Nadi

Madhya Pradesh Maharashtra

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B5	CH: 317.21 km	Hatnur-Bhatkheda Road Bridge	12 No. of 17.50 m	11	1985
B6	CH: 338 km	Pimprinandu,Maharastra	--	4	2001

Legend

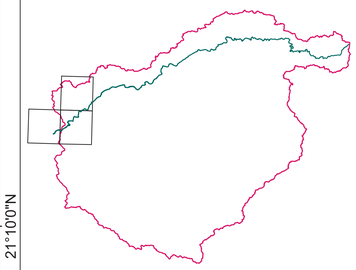
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

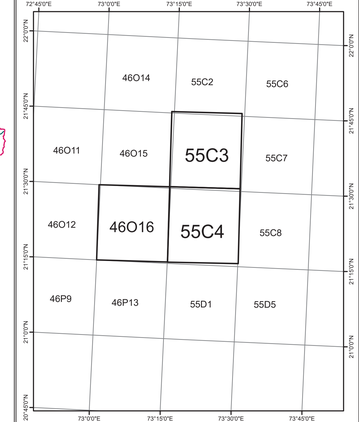
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E130	599072
E131	599257
E132	789820
E133	102705
E135	1652844
E141	4653618

RBL

Location	Area(sqm)
D119	33680
D120	9918
D121	22996
D123	43305
D126	180760

LBL

Location	Area(sqm)
E134	184540
E136	12435
E137	18672
E138	51063
E139	141277
E140	387472
E142	42399
E143	7552
E144	1216557

LBL

Location	Area(sqm)
D122	2526699
D124	835221
D125	245529
D127	7513
D128	40114
D129	687321
D130	28287

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Prepared by

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Morpho/11/14/2017

Map Showing Erosion and Deposition during year 2000 for 0-50 km Chainage for Upper Tapi River

Appendix: A3(Ch.0 to 50 km,Reach1)

N

Legend

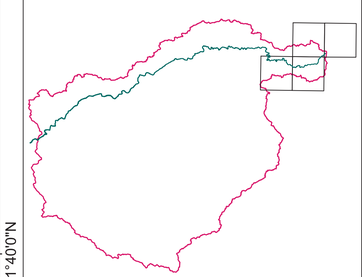
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

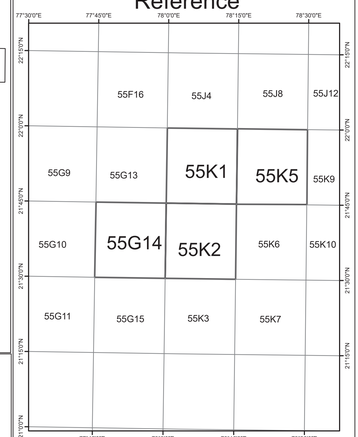
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E1	1528094
E2	149164
E4	36600
E6	7272
E7	20191
E8	235551
E10	388448
E11	150825
E13	466150
E15	111768
E17	78823
E19	346454
E21	27586
E23	118496

LBL

Location	Area(sqm)
E3	8176
E5	6311
E9	36693
E12	176902
E14	36339
E16	179649
E18	15627
E20	24442
E22	264899
E24	456890

RBL

Location	Area(sqm)
D6	7943
D8	37399
D11	9173
D12	147753
D15	187719
D17	6598
D19	10555
D21	281034
D23	389605
D24	61935

LBL

Location	Area(sqm)
D1	368103
D2	973005
D3	173822
D4	34141
D5	45373
D7	256859
D9	372584
D10	209552
D13	454988
D14	73055
D16	52933
D18	269408
D20	22821
D22	111202
D25	178269

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Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/15/2017

Map Showing Erosion and Deposition during year 2000 for 50 -100 km Chainage for Upper Tapi River

77°40'0"E 77°45'0"E 77°50'0"E 77°55'0"E 78°0'0"E

21°55'0"N 21°50'0"N 21°45'0"N 21°40'0"N

Betul

Tapi River

Siyakundal Barrage

Teska Bridge

Teska

Layadoni

Mendha

Shivnapath

Gondigoulla Dam

Mandevi Dam

Thani Dam

Gujramal Dam

Pusli Dam

Dhandra

CH 10 CH 20 CH 30 CH 40 CH 50 CH 60 CH 70 CH 80 CH 90 CH 100

Appendix: A3(Ch.50 to100 km,Reach2)

N

Legend

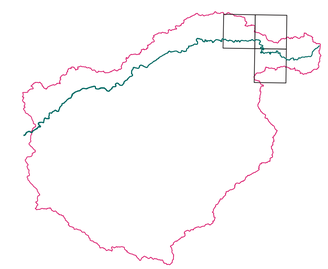
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

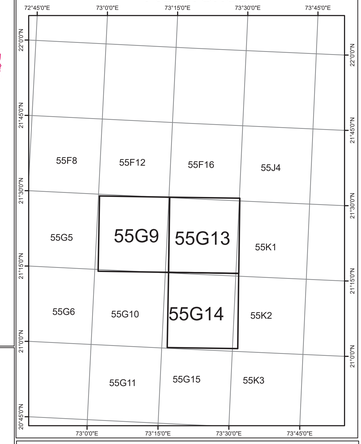
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E25	292902
E27	905290
E29	685550
E33	335381
E35	58926
E37	9565
E38	170735
E39	8545
E41	16312
E43	28309
E45	446778
E48	244638
E49	260881
E50	205528

RBL

Location	Area(sqm)
D27	13753
D30	125602
D34	61639
D36	165569
D37	165253
D38	13719
D40	51945
D41	316340
D42	647821
D44	23616
D47	28367
D49	6208

LBL

Location	Area(sqm)
E26	49117
E28	169724
E30	160051
E31	27169
E32	87501
E34	423433
E36	290528
E40	393209
E42	622459
E44	30453
E46	8683
E47	7605

LBL

Location	Area(sqm)
D26	138243
D28	137590
D29	471104
D31	39494
D32	11304
D33	189744
D35	199042
D39	233598
D43	24864
D45	108515
D46	273470
D48	418827
D50	151956

Prepared for

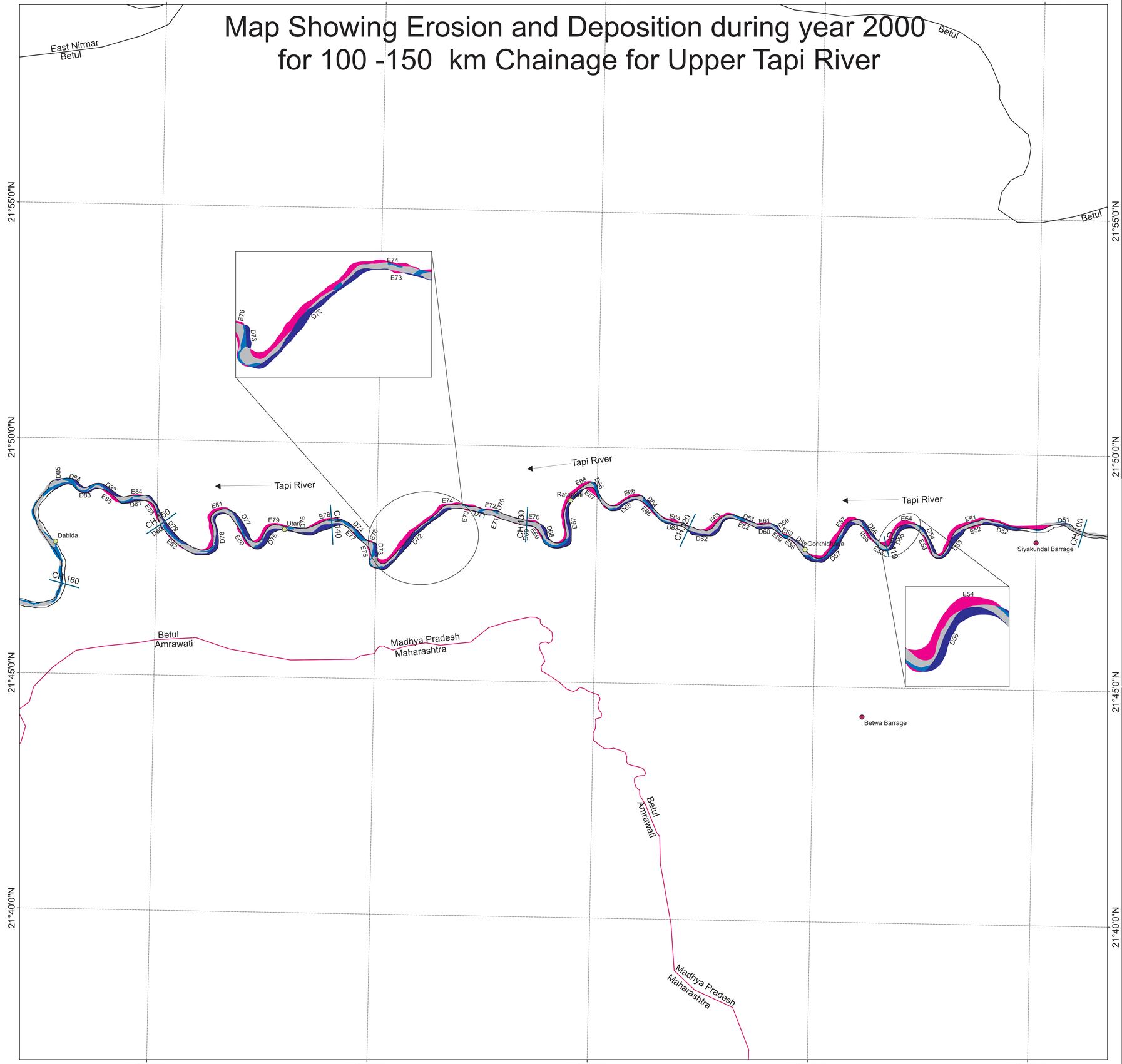
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Morpho/11/16/2017

Map Showing Erosion and Deposition during year 2000 for 100 -150 km Chainage for Upper Tapi River



Appendix:A3(Ch.100 to150 km,Reach3)

Legend

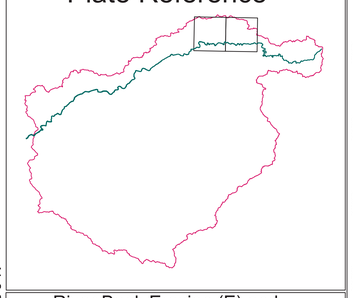
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

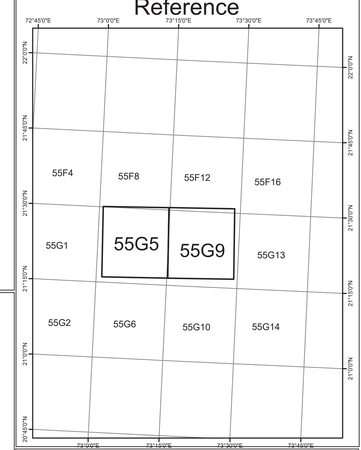
0 5 10 Kilometers

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Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL		RBL	
Location	**Area(sqm)**	**Location**	**Area(sqm)**
E51	506744	D51	16121
E54	232001	D54	93654
E57	319144	D56	86583
E59	9649	D58	42391
E61	29267	D59	18980
E63	133035	D61	23174
E64	47451	D64	45270
E66	93214	D66	14904
E68	306985	D68	67385
E70	29289	D70	5599
E72	17450	D73	58358
E74	527099	D74	42244
E76	10549	D75	15003
E78	92053	D77	167644
E79	149736	D79	175593
E81	248056	D82	78575
E84	21306	D84	53366
		D85	12754

LBL	
Location	**Area(sqm)**
E52	31786
E53	59203
E55	6719
E56	48497
E58	9466
E60	9678
E62	15874
E65	35372
E67	86890
E69	24000
E71	6791
E73	10623
E75	30359
E77	15312
E80	57438
E82	26847
E83	67682
E85	72874

LBL	
Location	**Area(sqm)**
D52	119284
D53	209285
D55	179359
D57	304629
D60	56609
D62	175518
D63	32799
D65	80761
D67	315745
D69	15913
D71	22449
D72	422209
D76	432446
D78	221587
D80	5496
D81	45873
D83	74492

Prepared for

Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/17/2017

Map Showing Erosion and Deposition during year 2000 for 150 -200 km Chainage for Upper Tapi River

Appendix:A3(Ch.150 to200 km,Reach4)

N

Legend

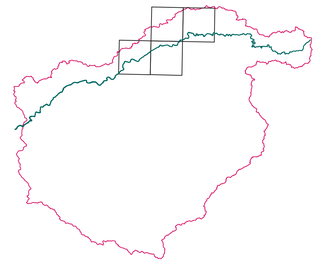
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

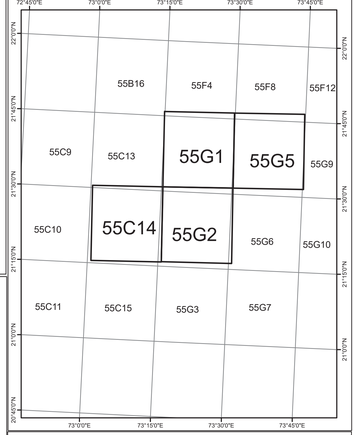
0 5 10 Kilometers

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Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E86	330815
E87	5594
E88	7849
E89	245641
E92	591955
E93	16226
E95	330657
E97	8417
E98	354146
E100	1756176
E101	393005

RBL

Location	Area(sqm)
D87	18360
D88	8043
D91	36001
D95	7451
D96	24910
D99	25078
D100	10284
D102	34140
D105	12236

LBL

Location	Area(sqm)
E90	5160
E91	34280
E94	22618
E96	33044
E99	38153

LBL

Location	Area(sqm)
D86	415918
D89	305232
D90	5514
D92	152187
D93	277755
D94	51183
D97	231707
D98	5373
D101	279450
D103	1608862
D104	369283

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Morpho/11/18/2017

Map Showing Erosion and Deposition during year 2000 for 200 - 250 km Chainage for Upper Tapi River

Appendix:A3(Ch.200 to250 km,Reach5)

76°35'0"E 76°40'0"E 76°45'0"E 76°50'0"E 76°55'0"E

21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N

East Nimar
Burhanpur
East Nimar
Burhanpur
East Nimar
Betul
Madhya Pradesh
Maharashtra
Tapi River
Nagotar
Ramakheda
CH: 230
Dharni
Sipna N
Mandwa Dam
Jutpani Dam
Khari Dam
Gaolandoh Dam
Sadrabadi Dam
Tapi River
Bhakri Bhorakund
Dedtalai
Khandwa-Dedtalai Rd
Daiyat
Dangurla
Tapi River
Majrod
CH: 260
Majrod Kalan-Daryapur Road Bridge
Madhya Pradesh
Maharashtra
Burhanpur
Amrawati

E102 E104 E103 E105 E106 E107 E108 E109 E110 E111 E112 E113 E114 E115
D106 D107 D108 D109 D110 D111 D112 D113 D114 D115 D116 D117 D118

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B1	CH: 235 km	Khandwa-Dedtalai Rd	7 No. of 41.50 m and 2 No. of 17.25 m	8	1992
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction

Legend

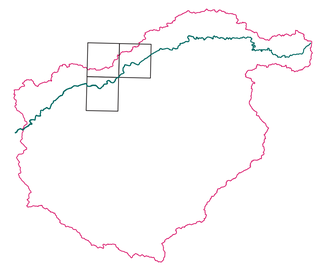
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

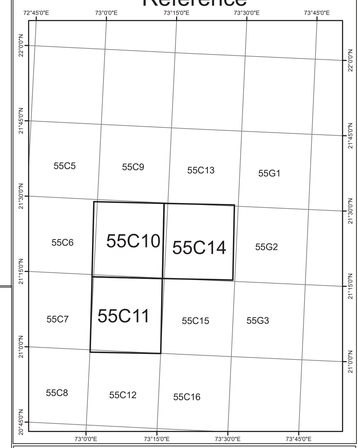
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E102	735656
E104	10441
E107	47039
E108	406818
E109	50394
E110	1754433
E111	74851
E112	479634
E114	283737
E115	487373

RBL

Location	Area(sqm)
D108	44039
D110	6138
D112	9751
D115	108141
D116	26936

LBL

Location	Area(sqm)
E103	24888
E105	7342
E106	7220
E113	79896

LBL

Location	Area(sqm)
D106	260668
D107	430072
D109	5938
D111	88620
D113	2513455
D114	578195
D117	6421
D118	1031010

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Morpho/11/19/2017

Map Showing Erosion and Deposition during year 2000 for 250 - 300 km Chainage for Upper Tapi River

Appendix:A3(Ch.250 to300 km,Reach6)

76°15'0"E 76°20'0"E 76°25'0"E 76°30'0"E 76°35'0"E

21°35'0"N 21°30'0"N 21°25'0"N 21°20'0"N 21°15'0"N

Burhanpur

Tapi River

Nepanagar

Nepanagar-Ambada Road Bridge

Ambada

Majrod

Zainabad-Rajghat Road Bridge

Burhanpur (M Corp.)

Panchimli

Mona Nadi

Maharashtra

Madhya Pradesh

CH: 260.00

CH: 288.50

CH: 308.71

Legend

- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

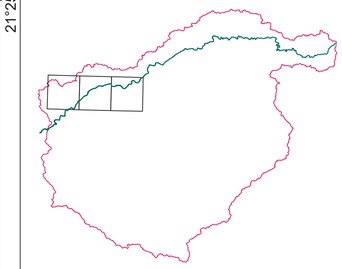
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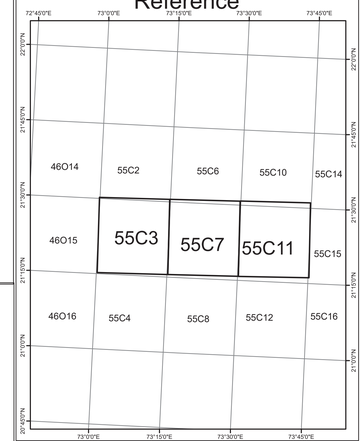
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction
B3	CH: 288.50 km	Nepanagar-Ambada Road Bridge	16 No. of 16.47 m	15	Under construction
B4	CH: 308.71 km	Zainabad-Rajghat Road Bridge	16 No. of 15 m	15	Under construction

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E116	520458
E118	9909
E119	7976
E120	77461
E122	449016
E123	29521
E125	31783
E126	14293
E127	9570
E128	185187
E129	416448
E131	434562
E133	121676
E134	77680
E135	16045
E136	340364
E138	231153

RBL

Location	Area(sqm)
D120	134959
D121	11495
D122	6872
D127	108919
D128	20025
D129	8189
D131	8321
D132	21014
D135	46966

LBL

Location	Area(sqm)
E117	106748
E121	8308
E124	121007
E130	17726
E132	198427
E137	32699

LBL

Location	Area(sqm)
D119	586853
D123	73579
D124	14631
D125	18097
D126	474372
D130	1209787
D133	84850
D134	1210943
D136	339702

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New Delhi

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Surat - 395007, Gujarat

Morpho/11/20/2017

Map Showing Erosion and Deposition during year 2000 for 300 - 350 km Chainage for Upper Tapi River

Appendix:A3(Ch.300 to350 km,Reach7)

Legend

- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 1:50,000 10 Kilometers

Madhya Pradesh
Maharashtra
West Nimar
Jalgaon
Burhanpur
Jalgaon
Madhya Pradesh
Maharashtra
Tapi River
Tapi River
Tapi River
Burhanpur
Jalgaon
Madhya Pradesh
Maharashtra
Purna Nadi
Mona Nadi
Umarda
Burhanpur (M Corp.)
Zainabad-Rajghat Road Bridge
Burhanpur
Hatnur-Bhatkheda Road Bridge
Ajnand
Chandgev
Pimprinandu,Maharastra
Naigaon
Morzira Dam
Upper Tapi Hatnur Dam
Hatnur
E160
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D276

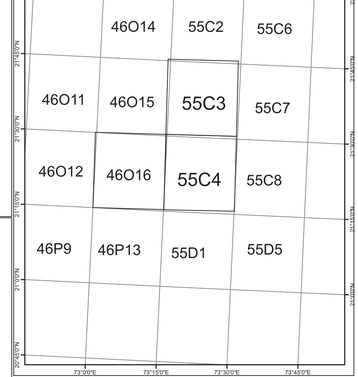
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B5	CH: 317.21 km	Hatnur-Bhatkheda Road Bridge	12 No. of 17.50 m	11	1985
B6	CH: 338 km	Pimprinandu,Maharastra	--	4	2001

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E139	366969
E140	390143
E141	629630
E142	36602
E144	578653
E146	11561
E147	72831
E149	60822
E151	7157
E153	17400
E154	9073
E156	2101690

RBL

Location	Area(sqm)
D137	155090
D139	35637
D140	150768
D142	47542
D145	13984
D147	78326
D148	15490
D149	11723

LBL

Location	Area(sqm)
E143	89683
E145	54955
E148	18004
E150	34996
E152	44908
E155	521357
E157	372944
E158	56082
E159	292318
E160	5280

LBL

Location	Area(sqm)
D138	2014687
D141	715406
D143	88574
D144	16599
D146	31199
D150	325141
D151	17158
D152	54079

Prepared for

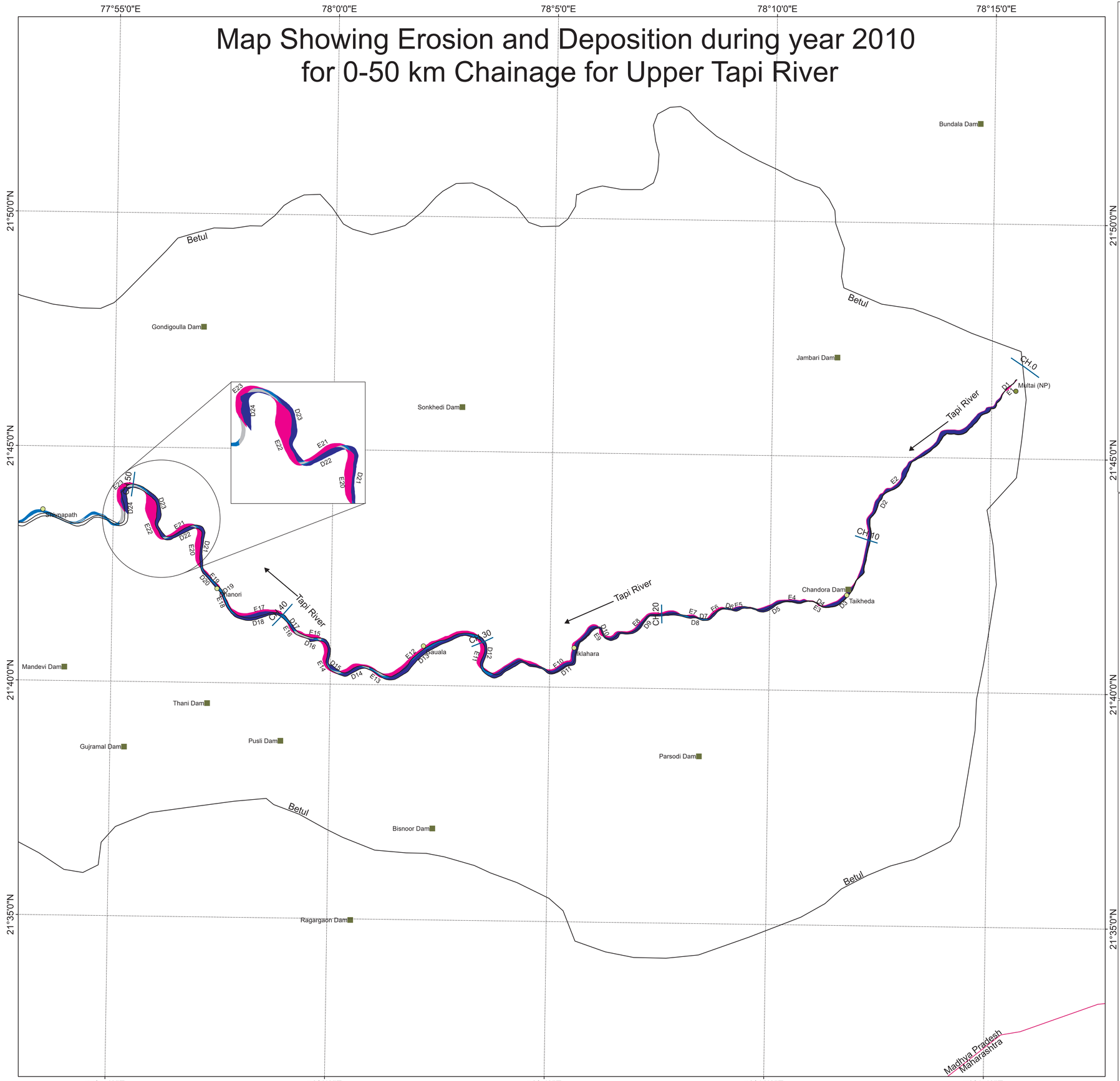
Central Water Commission
New Delhi

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Surat - 395007, Gujarat

Morpho/11/21/2017

Map Showing Erosion and Deposition during year 2010 for 0-50 km Chainage for Upper Tapi River



Appendix: A4 (Ch. 0 to 50 km,Reach1)

N

Legend

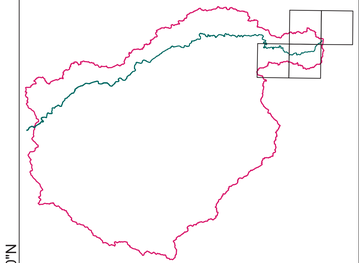
- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bank line of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

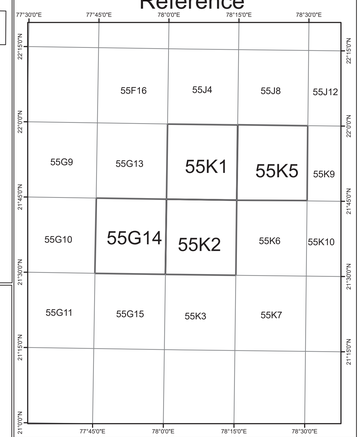
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E2	1385850
E4	188501
E5	29116
E6	51993
E7	24963
E8	297514
E10	701757
E12	579818
E15	84704
E17	325506
E19	32790
E21	134998
E23	227925

RBL

Location	Area(sqm)
D1	15987
D4	5069
D6	6122
D7	6330
D10	28731
D12	170089
D15	166377
D17	24027
D19	7280
D21	276445
D23	386814

LBL

Location	Area(sqm)
E1	18064
E3	5457
E9	25824
E11	170160
E13	19054
E14	170078
E16	35399
E18	21150
E20	266986
E22	498724

LBL

Location	Area(sqm)
D2	1155605
D3	175962
D5	287089
D8	89152
D9	326324
D11	743439
D13	488547
D14	117560
D16	24780
D18	299629
D20	48604
D22	144181
D24	224360

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New Delhi

Prepared by

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Morpho/11/22/2017

Map Showing Erosion and Deposition during year 2010 for 50 -100 km Chainage for Upper Tapi River

Appendix:A4(Ch.50 to100 km,Reach2)

N

Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

0 5 10 Kilometers

1:50,000

77°40'0"E 77°45'0"E 77°50'0"E 77°55'0"E 78°0'0"E

21°55'0"N 21°50'0"N 21°45'0"N 21°40'0"N

Betul

Tapi River

Siyakundal Barrage

Teska Bridge

Layakhani

Betwa Barrage

Mendha

Jamdha

Shivnapath

Pathrot

Dhanora

Gondigoulla Dam

Mandevi Dam

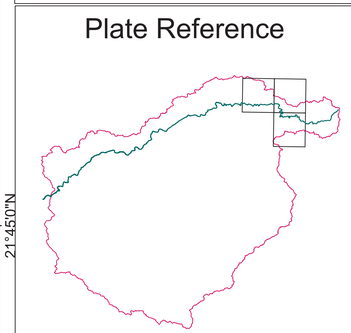
Thani Dam

Gujramal Dam

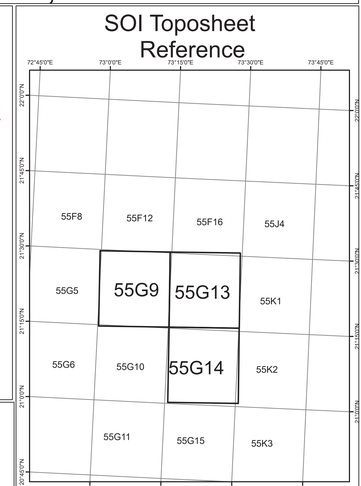
Pusli Dam

CH 10 CH 20 CH 30 CH 40 CH 50 CH 60 CH 70 CH 80 CH 90 CH 100

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E24	84044
E27	392291
E28	248826
E30	613129
E32	340302
E34	24858
E36	10877
E37	231457
E39	84396
E41	8206
E43	99486
E44	196576
E45	42117
E47	226788
E48	214155
E49	12294
E50	219660

LBL

Location	Area(sqm)
E25	25234
E26	8962
E29	151297
E31	65848
E33	427308
E35	263083
E38	10701
E40	973521
E42	19737
E46	41444

RBL

Location	Area(sqm)
D26	16115
D29	16320
D30	129355
D32	65301
D34	83842
D35	83787
D36	138478
D37	6979
D39	22056
D41	363242
D42	457968
D44	42547
D47	7422
D48	29661
D51	8880

LBL

Location	Area(sqm)
D25	88203
D27	142719
D28	435295
D31	541285
D33	265518
D38	301538
D40	17124
D43	25341
D45	103345
D46	228903
D49	463147
D50	31374
D52	196287

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Morpho/11/23/2017

Map Showing Erosion and Deposition during year 2010 for 100 -150 km Chainage for Upper Tapi River

Appendix:A4(Ch.100 to150 km,Reach3)

N

77°20'0"E 77°25'0"E 77°30'0"E 77°35'0"E 77°40'0"E

21°55'0"N 21°50'0"N 21°45'0"N 21°40'0"N

East Nirmar
Betul

Betul

Tapi River

Tapi River

Tapi River

Dabida

Utari

Gorkhidabra

Siyakundal Barrage

Betwa Barrage

CH 160

CH 150

CH 140

CH 130

CH 120

CH 110

CH 100

Madhya Pradesh
Maharashtra

Betul
Amrawati

Madhya Pradesh
Maharashtra

Betul
Amrawati

Legend

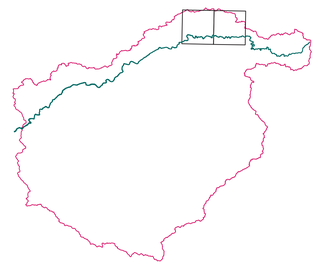
- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

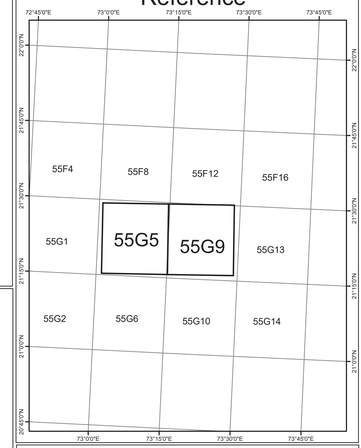
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E51	513883
E53	219524
E55	329350
E56	22867
E58	150961
E60	22398
E62	109092
E64	257075
E66	17880
E67	56035
E68	528280
E70	22037
E71	357021
E73	262230
E77	7393

RBL

Location	Area(sqm)
D54	60679
D56	81999
D58	18271
D60	24792
D62	34545
D64	12839
D66	29071
D68	18551
D70	62695
D71	5234
D74	51116
D76	7677
D78	162514
D80	6263
D81	77735
D84	81602
D85	67053

LBL

Location	Area(sqm)
E52	36188
E54	69514
E57	11457
E59	6452
E61	27147
E63	66656
E65	26817
E69	15612
E72	76638
E74	5764
E75	39261
E76	56063

LBL

Location	Area(sqm)
D53	456931
D55	166122
D57	357433
D59	8844
D61	56574
D63	227501
D65	31452
D67	105084
D69	335929
D72	568855
D73	8532
D75	13252
D77	554282
D79	284626
D82	37964
D83	64700
D86	134149

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New Delhi

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Surat - 395007, Gujarat

Morpho/11/24/2017

Map Showing Erosion and Deposition during year 2010 for 150 -200 km Chainage for Upper Tapi River

Appendix:A4(Ch.150 to200 km,Reach4)

N

Legend

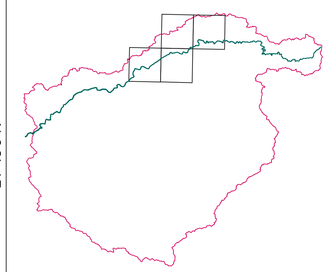
- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation

Scale

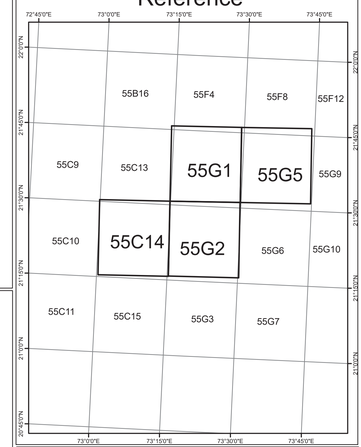
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E78	93232
E79	142898
E80	433303
E82	803684
E83	349787
E85	39939
E86	494448
E88	1921171
E89	15077
E90	47959
E91	50872
E92	186312
E93	7704

RBL

Location	Area(sqm)
D88	26580
D90	21532
D92	7092
D94	10158
D96	15947
D98	5649

LBL

Location	Area(sqm)
E81	5088
E84	8146
E87	23146

LBL

Location	Area(sqm)
D87	124750
D89	983696
D91	1163935
D93	21340
D95	564465
D97	2403210

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New Delhi

Prepared by

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Morpho/11/25/2017

Map Showing Erosion and Deposition during year 2010 for 200 - 250 km Chainage for Upper Tapi River

Appendix:A4(Ch.200 to250 km,Reach5)

N

76°35'0"E 76°40'0"E 76°45'0"E 76°50'0"E 76°55'0"E

21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N

East Nimar

Ramakheda

E100 D102

Tapi River

E97 E96 D99 E95 E94

Amrawati

Madhya Pradesh

Maharashtra

Betul

East Nimar

Chetar

CH: 210

Burhanpur

Dharni

Sipna N

Mandwa Dam

Jutpani Dam

Khari Dam

Gaolandoh Dam

Sadrabadi Dam

CH: 230

E100 D102 E99 D101 D100 E98

Tapi River

E101

Dedtalai Bhorabhi

Khandwa-Dedtalai Rd

CH: 215

D104 E102

Dangurla

E105

CH: 250

E106 D107 D108 D106 D105 E103

Tapi River

E107 D109 D110 D111

CH: 260

Majrodkla

Majrod Kalan-Daryapur Road Bridge

Madhya Pradesh

Maharashtra

Burhanpur

Amrawati

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B1	CH: 235 km	Khandwa-Dedtalai Rd	7 No. of 41.50 m and 2 No. of 17.25 m	8	1992
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction

Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Plate Reference

SOI Toposheet Reference

55C5 55C9 55C13 55G1

55C6 55C10 55C14 55G2

55C7 55C11 55C15 55G3

55C8 55C12 55C16

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E94	524513
E95	14477
E96	6528
E97	335562
E98	24371
E99	14292
E100	949858
E101	563724
E102	463402
E103	20548
E105	9408
E106	268858
E107	342459

RBL

Location	Area(sqm)
D99	40212
D100	5492
D101	18929
D103	15769
D104	12781
D105	57189
D107	25658
D109	7224
D111	39183

LBL

Location	Area(sqm)
E104	14181

LBL

Location	Area(sqm)
D102	4924092
D106	9381
D108	9472
D110	1338509

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Morpho/11/26/2017

Map Showing Erosion and Deposition during year 2010 for 250 - 300 km Chainage for Upper Tapi River

Appendix:A4(Ch.250 to300 km,Reach6)

Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Burhanpur
Nepanagar
Navlia
Panchimli
Majrod
Ambada
Umarda
Burhanpur (M Corp.)
Tapi River
Nepanagar-Ambada Road Bridge
Majrod Kalan-Daryapur Road Bridge
Zainabad-Rajghat Road Bridge
Mona Nadi
Maharashtra
Madhya Pradesh

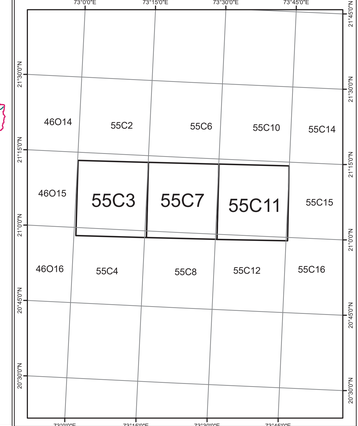
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B2	CH: 260 km	Majrod Kalan-Daryapur Road Bridge	--	--	Under construction
B3	CH: 288.50 km	Nepanagar-Ambada Road Bridge	16 No. of 16.47 m	15	Under construction
B4	CH: 308.71 km	Zainabad-Rajghat Road Bridge	16 No. of 15 m	15	Under construction

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E108	575067
E110	594641
E111	24094
E113	90683
E114	6413
E115	188491
E116	471104
E117	45914
E118	266521
E119	116721
E120	132501
E121	244036
E122	121224

RBL

Location	Area(sqm)
D113	121341
D115	5396
D116	75354
D117	15957
D118	29227
D120	15637
D121	86786
D122	176729

LBL

Location	Area(sqm)
E109	27335
E112	37777

LBL

Location	Area(sqm)
D112	745715
D114	866237
D119	3919583

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Morpho/11/27/2017

Map Showing Erosion and Deposition during year 2010 for 300 - 350 km Chainage for Upper Tapi River

Appendix:A4(Ch.300 to350 km,Reach7)

75°55'0"E 76°0'0"E 76°5'0"E 76°10'0"E 76°15'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

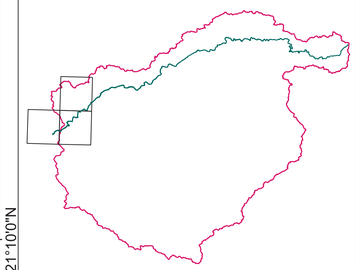
Madhya Pradesh
Maharashtra
West Nimar
Jalgaon
Burhanpur
Jalgaon
Madhya Pradesh
Maharashtra
Tapi River
Ajnand
Burhanpur
Jalgaon
Tapi River
Pimprinandu,Maharastra
Burhanpur
Jalgaon
Madhya Pradesh
Maharashtra
Tapi River
Changdev
Hatnur
Upper Tapi Hatnur Dam
Purna Nadi
Morzira Dam
Mona Nadi
Umarde
Burhanpur (M Corp.)
Burhanpur
Burhanpur
Hatnur-Bhatkheda Road Bridge
Naigaon
Changdev

Legend

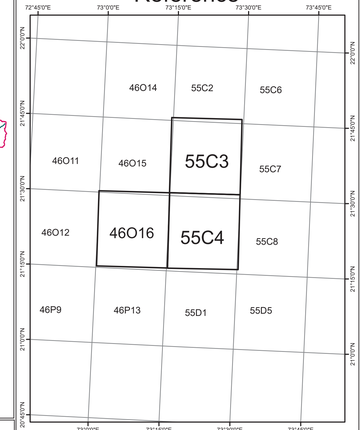
- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale
0 5 10 Kilometers
1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E123	347362
E124	5209
E125	10305
E126	368993
E127	523362
E128	37442
E130	442665
E132	17980
E133	92005
E134	57444
E136	22256
E138	107436
E139	1879114

RBL

Location	Area(sqm)
D123	115516
D125	35668
D127	154501
D129	49369
D132	213843
D133	22063
D135	11005

LBL

Location	Area(sqm)
E129	65084
E131	16895
E135	83815
E137	137691
E140	39313

LBL

Location	Area(sqm)
D124	2638722
D126	6691
D128	659370
D130	149103
D131	251525
D134	8818
D136	765100
D137	36791
D138	6622
D139	336731

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B5	CH: 317.21 km	Hatnur-Bhatkheda Road Bridge	12 No. of 17.50 m	11	1985
B6	CH: 338 km	Pimprinandu,Maharastra	--	4	2001

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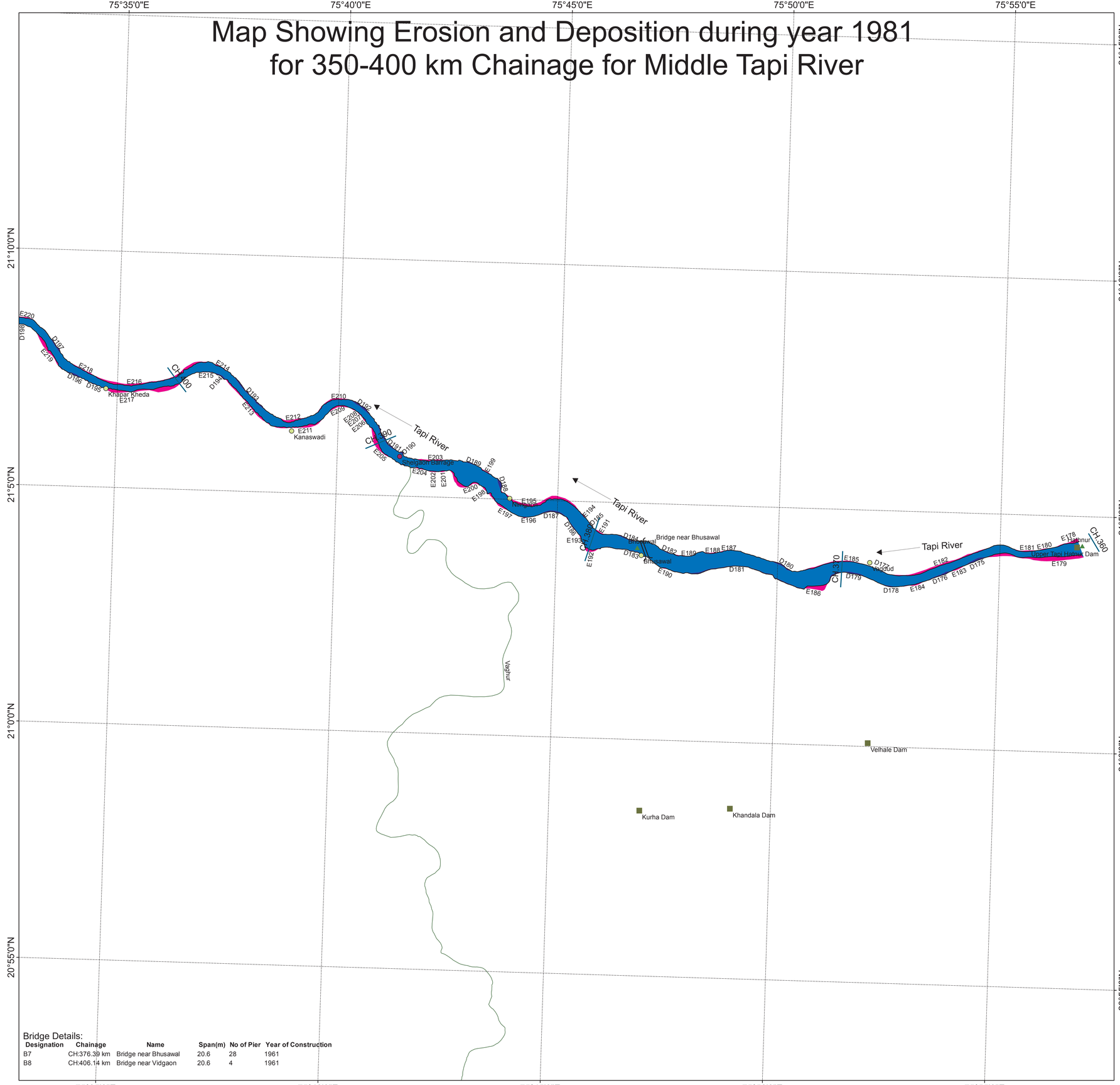
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Morpho/11/28/2017

Map Showing Erosion and Deposition during year 1981 for 350-400 km Chainage for Middle Tapi River

Appendix:B1(Ch.350 to400 km,Reach8)



Legend

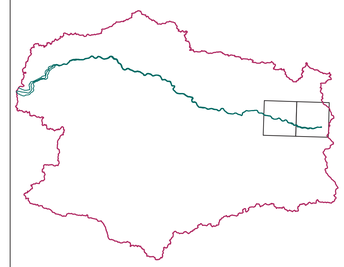
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

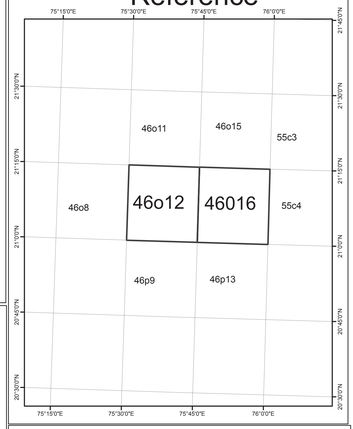
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL		LBL		RBL	
Location	**Area (sqm)**	**Location**	**Area(sqm)**	**Location**	**Area (sqm)**
E178	53901	E179	384474	D177	11591
E180	9345	E183	19253	D180	33181
E181	24683	E184	24449	D182	11903
E182	183908	E186	110542	D184	24463
E185	66173	E190	6559	D185	5526
E187	9558	E192	36476	D188	37125
E188	12110	E193	5229	D189	12668
E189	14996	E196	5399	D190	9936
E191	14362	E197	47751	D191	53511
E194	5712	E198	10159	D192	49193
E195	228867	E200	103691	D193	64680
E199	10003	E201	7817	D197	26387
E203	36368	E202	8851		
E210	45946	E204	10765		
E212	52228	E205	126479	LBL	
E214	12077	E206	8228	**Location**	**Area (sqm)**
E216	237474	E207	5850	D175	44994
E218	25361	E208	5519	D176	36683
E220	165419	E209	36693	D178	13483
		E211	89932	D179	62551
		E213	96542	D181	128646
		E215	8823	D183	40399
		E217	262854	D186	13051
		E219	114271	D187	45484
				D194	18457
				D195	7801
				D196	26516
				D198	32515

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B7	CH:376.39 km	Bridge near Bhusawal	20.6	28	1961
B8	CH:406.14 km	Bridge near Vidgaon	20.6	4	1961

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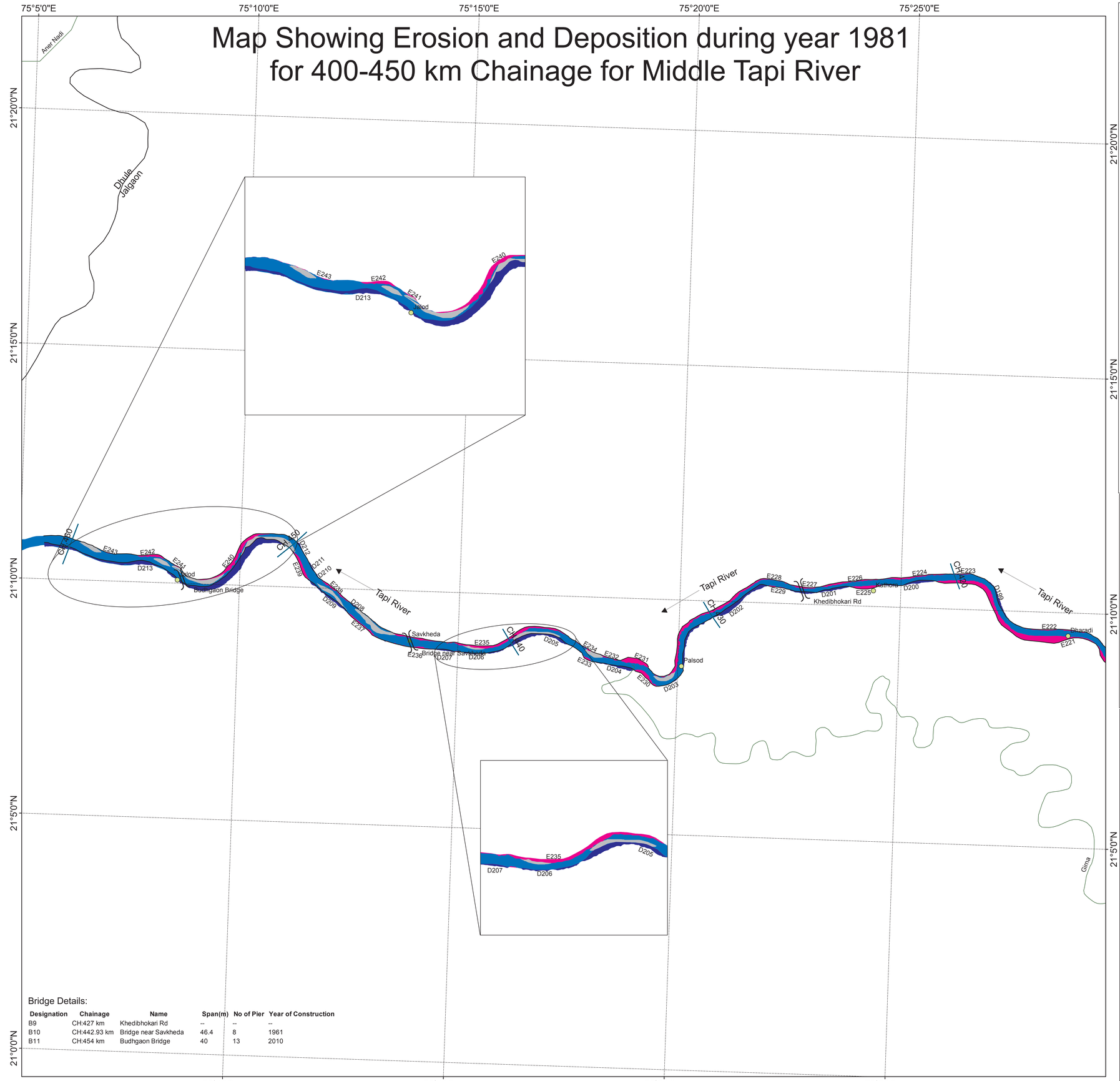
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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/29/2017

Map Showing Erosion and Deposition during year 1981 for 400-450 km Chainage for Middle Tapi River

Appendix:B1(Ch.400 to450 km,Reach9)



Legend

- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

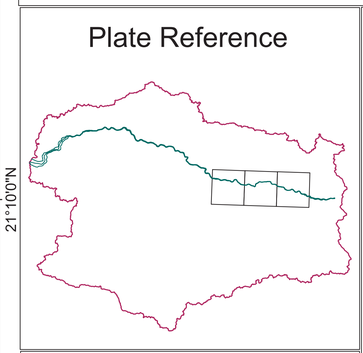
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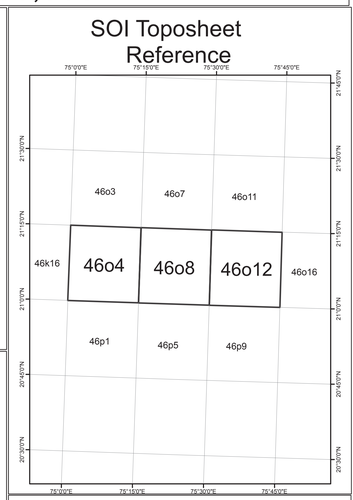
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B9	CH:427 km	Khedibhokari Rd	--	--	--
B10	CH:442.93 km	Bridge near Savkheda	46.4	8	1961
B11	CH:454 km	Budhgaon Bridge	40	13	2010

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E222	62813
E223	18790
E224	108749
E226	102891
E227	44478
E228	467810
E231	171236
E232	20499
E234	11395
E235	443620
E238	57509
E240	304880
E241	9640
E242	71618
E243	5184

RBL

Location	Area (sqm)
D199	80168
D208	10473
D210	6545
D211	14575
D212	17424

LBL

Location	Area (sqm)
E221	1166565
E225	98552
E229	18231
E230	98225
E233	19897
E236	28543
E237	64944
E239	107383

LBL

Location	Area (sqm)
D200	107986
D201	132890
D202	410609
D203	10266
D204	89358
D205	293261
D206	23821
D207	32164
D209	109662
D213	1302968

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/30/2017

Map Showing Erosion and Deposition during year 1981 for 450-500 km Chainage for Middle Tapi River

Appendix:B1(Ch.450to500 km,Reach10)

74°45'0"E 74°50'0"E 74°55'0"E 75°0'0"E 75°5'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N

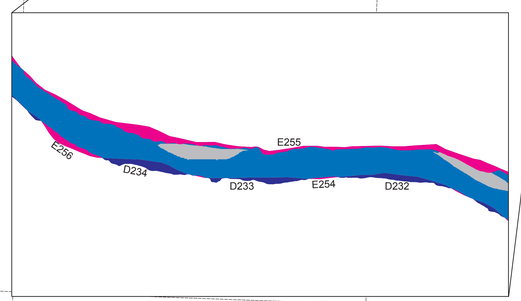
Jalod Dam

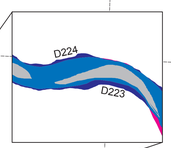
M.P
Maharshtra

Hispur
Nevada
Sulwade Barrage
Sulwade Barrage,Uparpind
Gidhade
Bura
Tapi Bridge near Sukwad
Dhule
Mumbai-Agra National Highway
Vikvel
Nish
Lower Tapi Dam
Kolath

Tapi River
Amer Nadi
Arunavati Nadi
Panjhara
Bori
Dhule
Jalgaon

CH 450
CH 460
CH 470
CH 480
CH 490





Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B12	CH:492 km	Mumbai-Agra National Highway	--	--	--
B13	CH:496 km	Tapi Bridge near Sukwad	12	27	1933
B14	CH:498 km	Sulwade Barrage,Uparpind	--	--	--

Legend

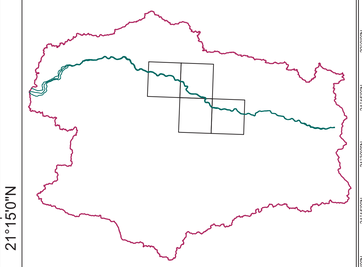
- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

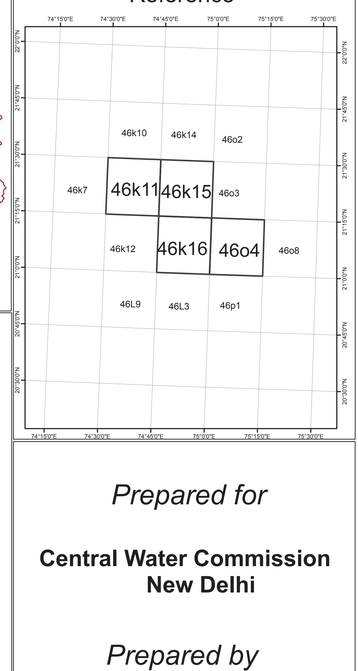
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E244	20043
E245	6594
E247	116400
E249	28973
E252	40307
E255	624231
E258	6444
E260	156862
E263	91142

RBL

Location	Area (sqm)
D215	26853
D219	26468
D222	246881
D224	60540
D225	449336
D227	13372
D229	34235
D237	127934
D238	42409
D240	88542

LBL

Location	Area (sqm)
E246	135817
E248	12996
E250	286901
E251	320491
E253	68627
E254	5186
E256	59119
E257	34782
E259	231958
E261	94519
E262	7359
E264	7773

LBL

Location	Area (sqm)
D214	71026
D216	33847
D217	10200
D218	32299
D220	17381
D221	5179
D223	150854
D226	70206
D228	52344
D230	23844
D231	16729
D232	79535
D233	65486
D234	99549
D235	14772
D236	64573
D239	95798
D241	6539
D242	98599

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/31/2017

Map Showing Erosion and Deposition during year 1981 for 500-550 km Chainage for Middle Tapi River

Appendix:B1(Ch.500to550km,Reach11)

Legend

- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydraulic Observation
- Bridge

Scale

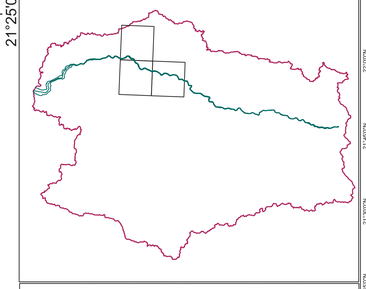
0 5 10 Kilometers

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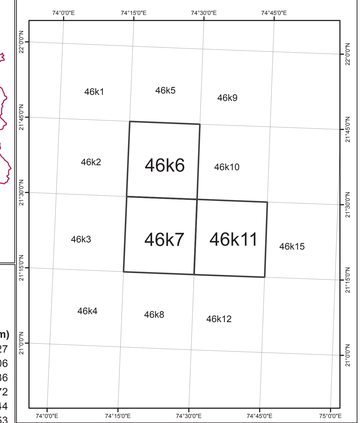
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B15	CH:537.9 km	Bridge near Sarangkheda	46.64	10	1957

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area(sqm)	LBL Location	LBL Area (sqm)	RBL Location	RBL Area (sqm)
E266	60571	E265	19184	D244	18927
E267	10838	E268	7068	D247	19706
E269	63568	E271	137827	D249	10136
E270	28282	E272	6869	D255	10472
E274	636066	E273	44747	D256	14744
E279	18622	E275	42373	D258	11853
E280	104968	E276	20546	D259	18388
E282	8392	E277	28208	D261	5527
E286	7602	E278	26999	D262	21600
E287	22534	E281	212608	D272	26553
E288	131926	E283	14542	D273	6440
E290	200477	E284	46638	D275	10300
E291	438567	E285	13819	D276	54099
E293	5147	E289	17125	D277	26413
E297	11415	E292	10378	LBL	
E299	81603	E294	9998	Location	Area (sqm)
E303	14951	E295	26931	D243	12923
		E296	16761	D245	14547
		E298	35872	D246	85874
		E300	26926	D248	7391
		E301	6629	D250	57866
		E302	34536	D251	9131
				D252	27938
				D253	21482
				D254	12087
				D257	419624
				D260	17224
				D263	59473
				D264	26734
				D265	107708
				D266	35157
				D267	5292
				D268	201643
				D269	28704
				D270	9437
				D271	5265
				D274	70884
				D278	13170

Prepared for

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New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/32/2017

Map Showing Erosion and Deposition during year 1981 for 550-581 km Chainage for Middle Tapi River

Appendix:B1(Ch.550to581km,Reach12)

Legend

- Active river channel during 1981 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale 1:50,000

0 5 10 Kilometers

Nandurbar
Maharashtra
Gujarat
Nandurbar Tapi
Talode (M Cl)
Tapi River
CH:600
CH:550
CH:500
CH:450
CH:400
CH:350
CH:300
CH:250
CH:200
CH:150
CH:100
CH:50
GJ SH198,Kavithe
Vaki Nadi
Prakasha Barrage
Bridge near Prakasha
Gomai River
Prakasha Nandark
Nijhar
Tapi Nandurbar
Gujarat Maharashtra
Maharashtra Gujarat

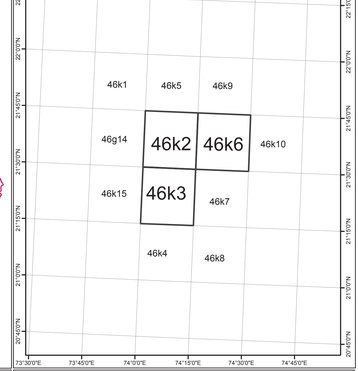
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B16	CH:561 km	Bridge near Prakasha	15.25	38	--
B17	CH:589 km	GJ SH198,Kavithe	--	--	1961

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E304	195190
E306	36172
E308	631213
E309	303636
E310	835824
E311	7701

LBL

Location	Area (sqm)
E305	15568
E307	11045

RBL

Location	Area (sqm)
D283	6596
D288	17182
D298	10483
D300	21894

LBL

Location	Area (sqm)
D279	100278
D280	6511
D281	10014
D282	7858
D284	223131
D285	100442
D286	8039
D287	27803
D289	31880
D290	55557
D291	7847
D292	12861
D293	10626
D294	8273
D295	353924
D296	130054
D297	12185
D299	39383
D301	17504

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/33/2017

Map Showing Erosion and Deposition during year 1990 for 350-400 km Chainage for Middle Tapi River

Appendix:B2(Ch.350 to 400 km,Reach8)

75°35'0"E 75°40'0"E 75°45'0"E 75°50'0"E 75°55'0"E

21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N

E175 Bridge near Vidgaon D157 D158 E174 E173 Tapi River E172 Khapar Kheda D155 CH:390 E171 E170 D154 E169 E168 Kumbhaswadi D153 E167 D152 E166 CH:360 E165 D151 D150 E164 Shelgaon Barrage D149 E163 D147 D146 E162 E160 D144 Nimgaon E159 E158 E157 E155 D143 E156 D142 E154 D141 D153 CH:338 D139 Bhusawal D138 Bridge near Bhusawal E150 E149 D136 D140 D152 E151 D137 D134 E147 CH:310 Vagdud D133 E146 D131 E145 D132 E148 D135 Tapi River

Bhusawal (M Cl)

Vaghur

Velhale Dam

Kurha Dam

Khandala Dam

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B7	CH:376.39 km	Bridge near Bhusawal	20.6	28	1961
B8	CH:406.14 km	Bridge near Vidgaon	20.6	4	1961

Legend

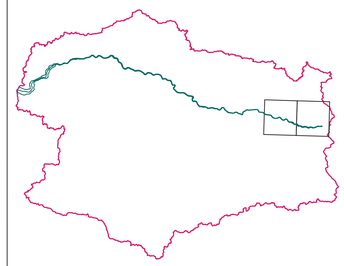
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

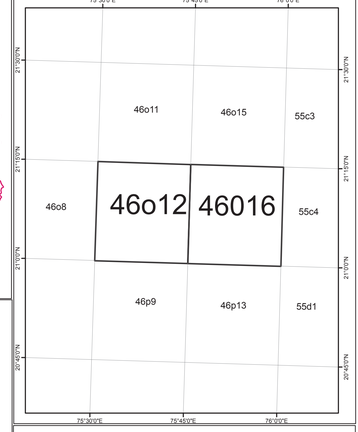
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Topsheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E145	220696
E146	382455
E147	199031
E149	49033
E150	39889
E153	23301
E155	453236
E160	27243
E163	60544
E167	68297
E168	117748
E171	18936
E172	472981
E175	417065

LBL

Location	Area (sqm)
E148	96472
E151	13945
E152	6616
E154	9135
E156	5519
E157	6956
E158	13908
E159	12741
E161	9289
E162	46181
E164	10822
E165	80489
E166	16900
E169	9200
E170	21791
E173	5606
E174	13393

RBL

Location	Area (sqm)
D131	15446
D133	26214
D134	64364
D136	8708
D138	22899
D139	180224
D141	13218
D144	43891
D146	29712
D147	5209
D149	20233
D152	227509
D154	135019
D156	87205

LBL

Location	Area (sqm)
D132	735788
D135	47260
D137	358805
D140	67019
D142	30106
D143	94171
D145	65766
D148	44787
D150	44097
D151	7609
D153	386608
D155	730148
D157	682874

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/34/2017

Map Showing Erosion and Deposition during year 1990 for 400-450 km Chainage for Middle Tapi River

Appendix:B2(Ch.400 to450 km,Reach9)

Legend

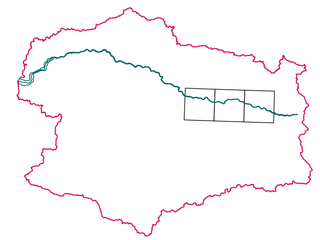
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

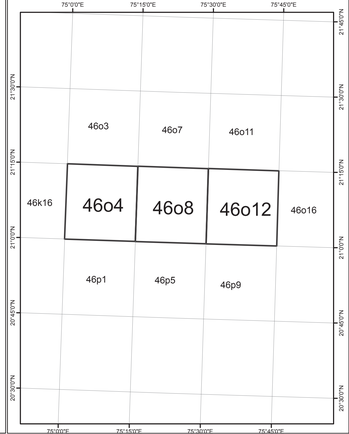
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E176	13110
E177	14353
E179	138388
E181	1373571
E183	28265
E184	51155
E185	27234
E186	710537
E187	9367
E189	22373
E191	579328
E194	74309
E195	8503

LBL

Location	Area (sqm)
E178	42683
E180	192597
E182	13735
E188	5525
E190	177444
E192	5411
E193	14884

RBL

Location	Area (sqm)
D159	6147
D161	162531
D162	9030
D172	27385
D174	8156
D175	214239
D177	46733
D180	21254

LBL

Location	Area (sqm)
D158	154487
D160	90799
D163	304728
D164	65602
D165	709019
D166	38227
D167	34095
D168	13778
D169	546622
D170	90955
D171	12893
D173	5797
D176	559753
D178	15002
D179	82009

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B9	CH:427 km	Khedibhokari Rd	--	--	--
B10	CH:442.93 km	Bridge near Savkheda	46.4	8	1961
B11	CH:454 km	Budhgaon Bridge	40	13	2010

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/35/2017

Map Showing Erosion and Deposition during year 1990 for 450-500 km Chainage for Middle Tapi River

Appendix:B2(Ch.450to500km,Reach10)

Legend

- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Plate Reference

SOI Toposheet Reference

46k10 46k14 46o2
46k7 46k11 46k15 46o3
46k12 46k16 46o4 46o8
46L9 46L3 46p1

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E196	51556
E197	12231
E200	40228
E201	140477
E202	50546
E207	10041
E208	5327
E209	61895
E210	7233
E214	413125
E216	27632
E217	13857
E218	44399
E220	49361
E222	140911
E225	17011
E226	125257

LBL

Location	Area (sqm)
E198	14922
E199	5848
E203	402321
E204	40309
E205	416176
E206	39848
E211	29437
E212	35949
E213	28643
E215	12074
E219	9634
E221	226156
E223	12243
E224	11587

RBL

Location	Area (sqm)
D183	68068
D187	7080
D188	473963
D190	925945
D193	6490
D194	42576
D195	15470
D196	156042
D201	288104
D205	221258

LBL

Location	Area (sqm)
D181	164576
D182	16149
D184	64032
D185	68963
D186	83858
D189	130770
D191	5739
D192	182311
D197	383227
D198	6358
D199	60177
D200	13958
D202	198164
D203	8196
D204	44418
D206	123316

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B12	CH:492 km	Mumbai-Agra National Highway	--	--	--
B13	CH:496 km	Tapi Bridge near Sukwad	12	27	1933
B14	CH:498 km	Sulwade Barrage,Uparpind	--	--	--

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/36/2017

Map Showing Erosion and Deposition during year 1990 for 500-550 km Chainage for Middle Tapi Basin

Appendix:B2(Ch.500to550km,Reach11)

Legend

- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B15	CH:537.9 km	Bridge near Sarangkheda	46.64	10	1957

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	Area (sqm)
E227	54491
E229	136711
E233	39024
E235	126979
E237	7784
E239	29443
E240	143565
E242	5499
E244	15601
E245	13578
E247	167391
E248	213877
E249	449843
E254	21860
E256	79805
E259	34946

LBL Location	Area (sqm)
E228	6909
E230	42509
E231	63562
E232	20955
E234	16632
E236	14490
E238	48337
E241	357647
E243	12157
E246	32348
E250	13041
E251	10136
E252	18568
E253	40214
E255	10012
E257	10972
E258	8651

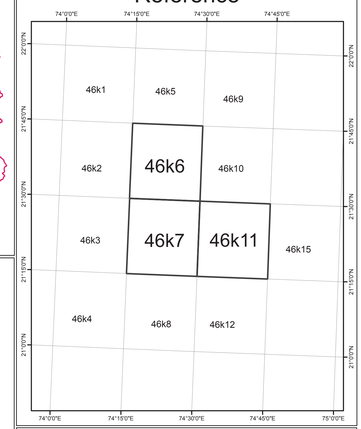
RBL Location	Area (sqm)
D208	49347
D210	95434
D212	9215
D213	56869
D215	11643
D218	18433
D220	8629
D221	23815
D222	29372
D223	23996
D224	52027
D225	9324
D226	12256
D227	45789
D231	63041
D232	9730
D235	137576

LBL Location	Area (sqm)
D207	56397
D209	145960
D211	81527
D214	9218
D216	126687
D217	7000
D219	280310
D228	200570
D229	821227
D230	35188
D233	17696
D234	112273
D237	31107

Plate Reference



SOI Toposheet Reference



Prepared for

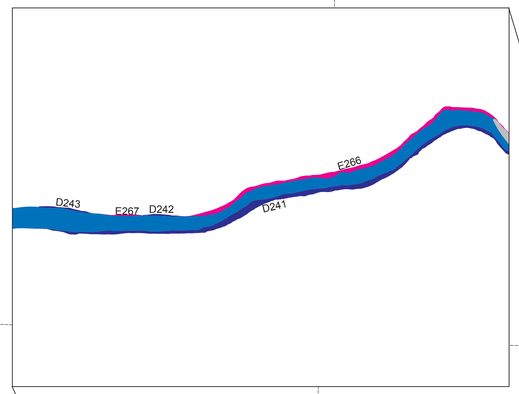
Central Water Commission
New Delhi

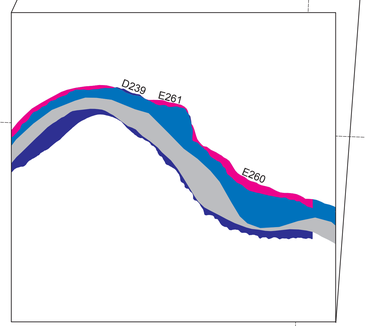
Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/37/2017

Map Showing Erosion and Deposition during year 1990 for 550-581 km Chainage for Middle Tapi River





Nandurbar
Talode (M Cl)
Maharashtra
Gujarat
Nandurbar
Tapi
Tapi River
Vaki Nadi
Gomai River
Prakasha Barrage
Bridge near Prakasha
Prakasha Nandark
GJ SH198,Kavithe
GH 600
CH 580
CH 570
CH 560
D243
E267
D242
D241
E266
E265
D240
E264
E263
D238
E262
D239
E261
E260
Tapi
Nandurbar
Gujarat
Maharashtra
Tapi
Nandurbar
Gujarat
Maharashtra

74°0'0"E
74°5'0"E
74°10'0"E
74°15'0"E
74°20'0"E
21°40'0"N
21°35'0"N
21°30'0"N
21°25'0"N
21°20'0"N

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B16	CH:561 km	Bridge near Prakasha	15.25	38	--
B17	CH:589 km	GJ SH198,Kavithe	--	--	1961

Appendix:B2(Ch.550to581km,Reach12)

Legend

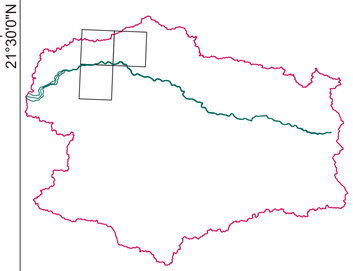
- Active river channel during 1990 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

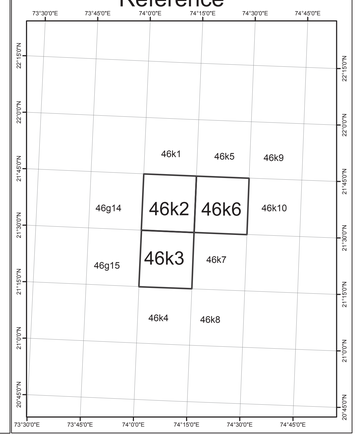
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E260	308096
E261	44645
E262	239902
E263	54029
E264	33563
E265	350675
E266	763233
E267	23266

RBL

Location	Area (sqm)
D239	15506
D240	47245
D242	35374
D243	51399

LBL

Location	Area (sqm)
D238	1611401
D241	1300168

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New Delhi

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Surat - 395007, Gujarat

Morpho/11/38/2017

Map Showing Erosion and Deposition during year 2000 for 350-400 km Chainage for Middle Tapi River

Appendix:B3(Ch.350 to 400km,Reach8)

75°35'0"E 75°40'0"E 75°45'0"E 75°50'0"E 75°55'0"E

21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N 20°55'0"N

Bridge near Vidgaon
Tapi River
Shelgaon Barrage
Nimgaon
Bridge near Bhusawal
Bhusawal
Vagdud
Bhusawal (M Cl)
Vaghur
Velhale Dam
Kurha Dam
Khandala Dam

Bridge Details:

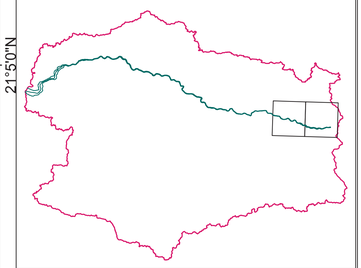
Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B7	CH:376.39 km	Bridge near Bhusawal	20.6	28	1961
B8	CH:406.14 km	Bridge near Vidgaon	20.6	4	1961

Legend

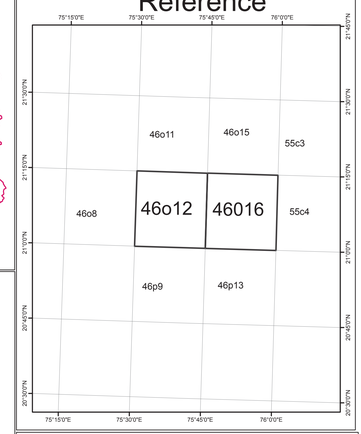
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale
0 5 10 Kilometers
1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)	Location	Area(sqm)
E162	905869	D156	77199
E164	55944	D157	18712
E165	69588	D159	5195
E166	141333	D160	37792
E169	107743	D162	10996
E171	18846	D165	40182
E172	5921	D166	48268
E176	28264	D168	31050
E180	49079	D171	274203
E181	43857	D173	8123
E183	7524	D174	179559
E184	122809	D176	8176
E185	89636	D177	9222
E187	7905	D180	132886
E190	106970		
E191	152062		

LBL

Location	Area (sqm)	Location	Area (sqm)
E161	5274	D153	45040
E163	49299	D154	688986
E167	13449	D155	51990
E168	71897	D158	421450
E170	85206	D161	8462
E173	14446	D163	5649
E174	7917	D164	36249
E175	66084	D167	47595
E177	5034	D169	30515
E178	89199	D170	13084
E179	5421	D172	288857
E182	18626	D175	263753
E186	23626	D178	26815
E188	17061	D179	47817
E189	6561	D181	477494

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Surat - 395007, Gujarat

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Map Showing Erosion and Deposition during year 2000 for 400-450 km Chainage for Middle Tapi River

Appendix:B3(Ch.400 to 450km,Reach9)

75°10'0"E 75°15'0"E 75°20'0"E 75°25'0"E 75°30'0"E

21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N

Dhule
Jalgaon
Tapi River
Jalod
Budhgaon Bridge
Bridge near Savkheda
Savkheda
Girna
Palsod
Khedibhokari Rd
Kathora
Dharadi
CH:400
CH:410
CH:420
CH:430
CH:440
CH:450

Legend

- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

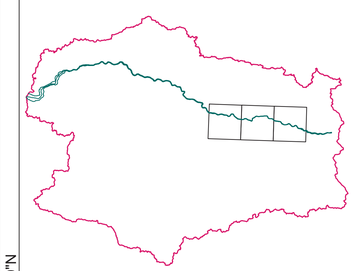
0 5 10 Kilometers

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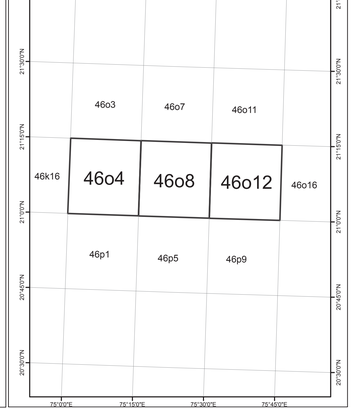
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B9	CH:427 km	Khedibhokari Rd	--	--	--
B10	CH:442.93 km	Bridge near Savkheda	46.4	8	1961
B11	CH:454 km	Budhgaon Bridge	40	13	2010

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E193	95163
E195	622042
E196	706986
E198	36156
E199	43019
E201	20097
E203	436039
E204	86763
E207	58238
E209	644959
E210	153745
E211	11059
E212	124504

LBL

Location	Area (sqm)
E192	64471
E194	248497
E197	37229
E200	12018
E202	18017
E205	8135
E206	16400
E208	37710

RBL

Location	Area (sqm)
D183	35443
D185	170163
D188	17504
D191	10688
D194	39219
D195	13431
D198	43565
D202	10536
D203	8236

LBL

Location	Area (sqm)
D182	95847
D184	45131
D186	405183
D187	743623
D189	24596
D190	9932
D192	478826
D193	6931
D196	40599
D197	9976
D199	553760
D200	35931
D201	119944
D204	124579

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New Delhi

Prepared by

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Surat - 395007, Gujarat

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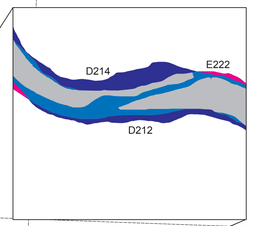
Map Showing Erosion and Deposition during year 2000 for 450-500 km Chainage for Middle Tapi River

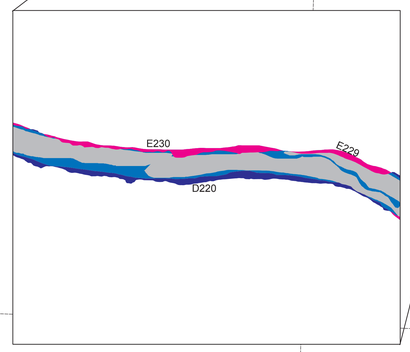
Appendix:B3(Ch.450to500km,Reach10)

74°45'0"E 74°50'0"E 74°55'0"E 75°0'0"E 75°5'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

Tapi River
Krunavati Nadi
Anar Nadi
Bura
Panjhara
Bori
Dhule
Jalgaon
Nevada
Sulwade Barrage
Sulwade Barrage,Uparpind
Gidhade
Tapi Bridge near Sukwad
Sindkheda
Mumbai-Agra National Highway
Nima
Lower Tapi Dam
Kalali
Ivkvel
CH 450
CH 460
CH 470
CH 480
CH 490
CH 500





Legend

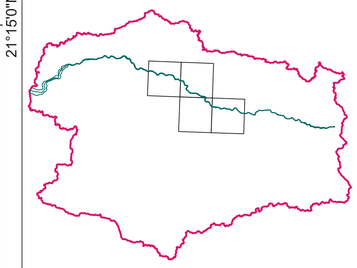
- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

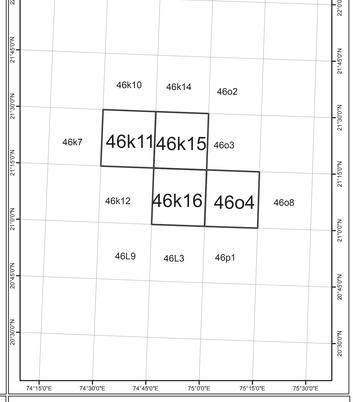
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B12	CH:492 km	Mumbai-Agra National Highway	--	--	--
B13	CH:496 km	Tapi Bridge near Sukwad	12	27	1933
B14	CH:498 km	Sulwade Barrage,Uparpind	--	--	--

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area (sqm)	LBL Location	LBL Area (sqm)	RBL Location	RBL Area (sqm)
E213	80884	E216	7452	D206	5055
E214	45568	E219	6041	D211	172439
E215	181581	E220	135426	D214	669417
E217	92988	E223	11762	D215	36762
E218	64018	E224	274456	D217	10981
E221	7574	E225	23944	D219	66724
E222	18405	E228	24501	D223	335490
E226	43318	E231	7797	D227	245684
E227	48737	E234	13041	LBL	
E229	93598	E235	255312	Location	Area (sqm)
E230	217123	E237	5527	D205	200185
E232	74348	E238	16151	D207	13383
E233	70833			D208	253242
E236	140437			D209	14210
E239	107747			D210	13512
				D212	143645
				D213	7772
				D216	190788
				D218	19428
				D220	366062
				D221	9140
				D222	31885
				D224	225246
				D225	5115
				D226	25603
				D228	288508

Prepared for

Central Water Commission
New Delhi

Prepared by

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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/41/2017

Map Showing Erosion and Deposition during year 2000 for 500-550 km Chainage for Middle Tapi River

Appendix:B3(Ch.500to550km,Reach11)

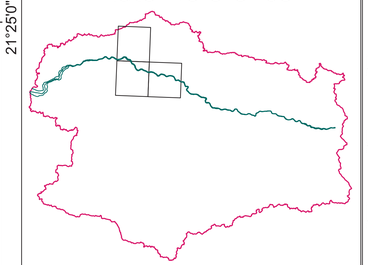
Legend

- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 1:50,000 10 Kilometers

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E240	52889
E241	108164
E244	15002
E245	6992
E246	61783
E247	128933
E249	8102
E250	136757
E252	20094
E254	169962
E255	530089
E259	40314
E261	32030

RBL

Location	Area (sqm)
D231	32734
D233	189388
D235	7923
D240	74425
D242	10210
D243	48051
D244	75920
D247	70697
D249	11080
D253	174454
D255	255927

LBL

Location	Area(sqm)
E242	38060
E243	5709
E248	5981
E251	139335
E253	13143
E256	7273
E257	116394
E258	21921
E260	61372

LBL

Location	Area(sqm)
D229	7636
D230	25716
D232	168103
D234	56672
D236	70061
D237	15186
D238	182025
D239	16387
D241	352699
D245	56103
D246	6166
D248	38933
D250	252354
D251	704329
D252	58036
D254	127443
D256	35289

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B15	CH:537.9 km	Bridge near Sarangkheda	46.64	10	1957

Prepared for

Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/42/2017

Map Showing Erosion and Deposition during year 2000 for 550-581 km Chainage for Middle Tapi Basin

Appendix:B3(Ch.550to581km,Reach12)

Legend

- Active river channel during 2000 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

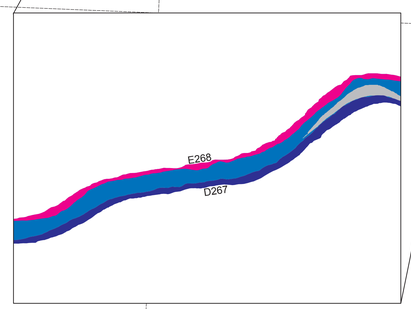
0 5 10 Kilometers

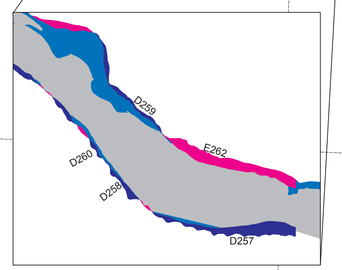
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74°0'0"E 74°5'0"E 74°10'0"E 74°15'0"E 74°20'0"E

21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N 21°20'0"N

Maharashtra
Gujarat
Nandurbar
Tapi
Talode (M Cl)
Vaki Nadi
Tapi River
GH.600
CH.550
CH.560
CH.570
CH.580
CH.589
D269 E269 D268 E270 D267 E268 D265 E267 D266 D265 E266 D263 D264 D262 E265 E264 D259 D260 D261 D258 E262 D257
GJ SH198,Kavithe
Prakasha Barrage
Bridge near Prakasha
Gomai River
Prakasha Nandark
Gujarat
Maharashtra
Tapi
Nandurbar
Gujarat
Maharashtra





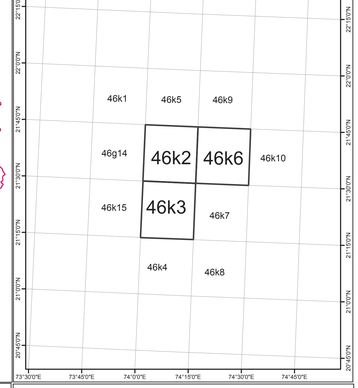
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B16	CH:561 km	Bridge near Prakasha	15.25	38	--
B17	CH:589 km	GJ SH198,Kavithe	--	--	1961

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E262	171888
E264	39038
E265	491288
E266	334246
E268	887767
E269	61592

RBL

Location	Area (sqm)
D259	51447
D263	141708
D266	116230
D268	9151
D269	43653

LBL

Location	Area (sqm)
E263	5437
E267	7085
E270	13043

LBL

Location	Area (sqm)
D257	148664
D258	25612
D260	8292
D261	16386
D262	1030050
D264	26272
D265	801941
D267	1415331

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/43/2017

Map Showing Erosion and Deposition during year 2010 for 350-400 km Chainage for Middle Tapi Basin

Appendix:B4(Ch.350 to400 km,Reach8)

75°30'0"E 75°35'0"E 75°40'0"E 75°45'0"E 75°50'0"E

21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N 20°55'0"N

Tapi River
Bridge near Vidgaon
Bridge near Khedi
Bridge near Bhusawal
Bhusawal
Nimgaon
Vagdud
Kondaswadi
Dhanora Barrage
Vaghur
Grima
Bhusawal (M Cl)
Velhale Dam
Kurha Dam
Khandala Dam

CH:350 CH:390 CH:400 CH:330

Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

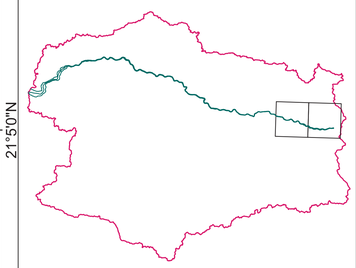
0 5 10 Kilometers

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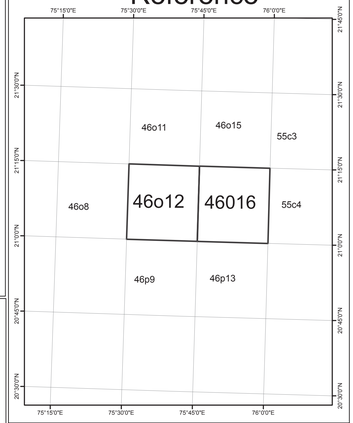
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B7	CH:376.39 km	Bridge near Bhusawal	20.6	28	1961
B8	CH:406.14 km	Bridge near Vidgaon	20.6	4	1961

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area (sqm)	RBL Location	RBL Area (sqm)
E141	1005331	D141	34362
E143	7653	D142	22539
E144	112885	D144	59795
E145	142416	D146	13768
E147	161152	D149	8622
E151	11103	D150	120308
E156	22794	D152	53895
E157	37122	D153	24950
E159	127032	D155	34621
E160	106798	D156	11764
E161	21582	D157	262607
E164	300200	D159	21380
		D160	270700
		D164	139391

LBL Location	LBL Area (sqm)	LBL Location	LBL Area (sqm)
E142	13595	D140	767904
E146	12474	D143	631029
E148	123058	D145	48529
E149	28031	D147	21557
E150	89486	D148	59939
E152	24132	D151	35100
E153	80244	D154	20799
E154	85717	D158	308286
E155	22975	D161	343724
E158	10457	D162	207213
E162	8144	D163	6669
E163	13391	D165	7568
		D166	607531

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New Delhi

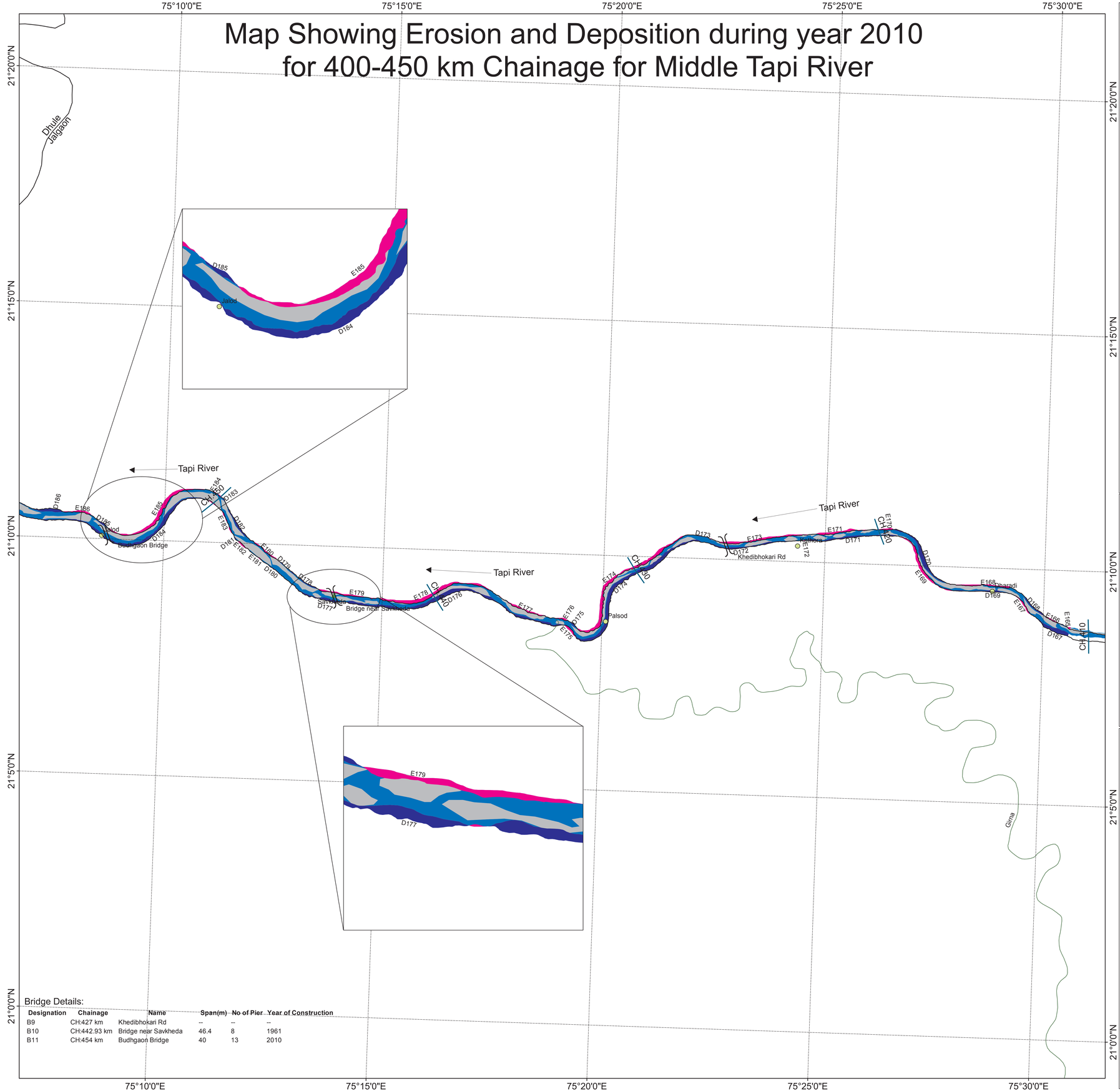
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Morpho/11/44/2017

Map Showing Erosion and Deposition during year 2010 for 400-450 km Chainage for Middle Tapi River

Appendix:B4(Ch.400 to450 km,Reach9)



Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

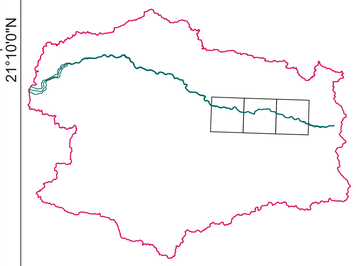
0 5 10 Kilometers

1:50,000

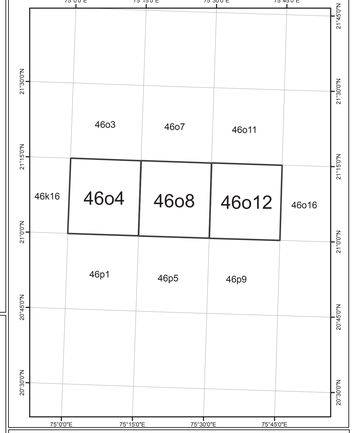
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B9	CH:427 km	Khedibhokari Rd	--	--	--
B10	CH:442.93 km	Bridge near Savkheda	46.4	8	1961
B11	CH:454 km	Budhgaon Bridge	40	13	2010

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area(sqm)	RBL Location	RBL Area(sqm)
E165	7121	D168	47494
E166	16425	D170	231484
E168	85939	D173	9230
E170	27502	D175	14278
E171	116095	D178	38210
E173	194142	D179	7373
E174	537213	D182	73251
E176	21064	D183	5352
E177	71283	D185	21099
E178	399838	D186	105949
E179	89527		
E180	38266		
E184	11853		
E185	366646		
E186	55627		

LBL Location	LBL Area(sqm)	LBL Location	LBL Area(sqm)
E167	36736	D167	156607
E169	190877	D169	70174
E172	6624	D171	145347
E175	36964	D172	121873
E181	5212	D174	723758
E182	18617	D176	717850
E183	37639	D177	95193
		D180	15742
		D181	5284
		D184	500014

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New Delhi

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Map Showing Erosion and Deposition during year 2010 for 450-500 km Chainage for Middle Tapi River

Appendix:B4(Ch.450to500km,Reach10)

Legend

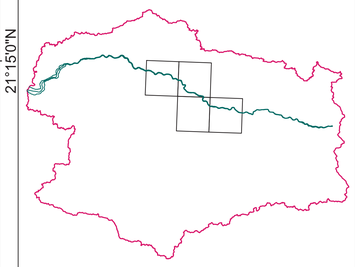
- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

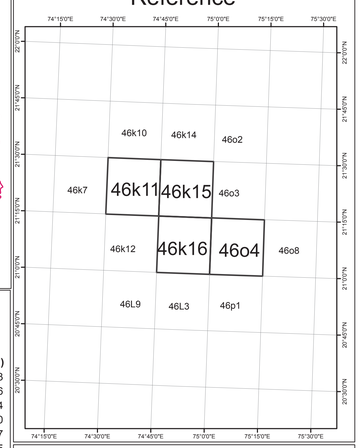
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL		LBL		RBL	
Location	Area(sqm)	Location	Area(sqm)	Location	Area(sqm)
E189	27516	E187	85382	D187	71783
E193	24805	E188	34776	D188	50596
E197	38818	E190	38354	D190	37144
E202	6695	E191	48982	D192	51970
E203	34100	E192	36948	D195	169607
E205	116366	E194	9392	D197	176705
E208	61286	E195	6918	D200	340502
E210	6458	E196	25328	D203	24146
E212	39937	E198	186438	D204	6591
E214	12813	E199	6015	D207	56358
E215	241677	E200	16018	D210	290856
E218	24178	E201	85245	D213	6158
E223	71579	E204	6593	D215	208207
		E206	6326	D217	10785
		E207	25175		
		E209	18967	LBL	
		E211	27818	Location	Area(sqm)
		E213	36835	D189	5885
		E216	11880	D191	10150
		E217	19917	D193	21758
		E219	135284	D194	9611
		E220	7196	D196	81308
		E221	21048	D198	5859
		E222	126391	D199	27693
				D201	35192
				D202	7398
				D205	19095
				D206	74080
				D208	94206
				D209	14970
				D211	102237
				D212	40400
				D214	20411
				D216	5969

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B12	CH:492 km	Mumbai-Agra National Highway	--	--	--
B13	CH:496 km	Tapi Bridge near Sukwad	12	27	1933
B14	CH:498 km	Sulwade Barrage,Uparpind	--	--	--

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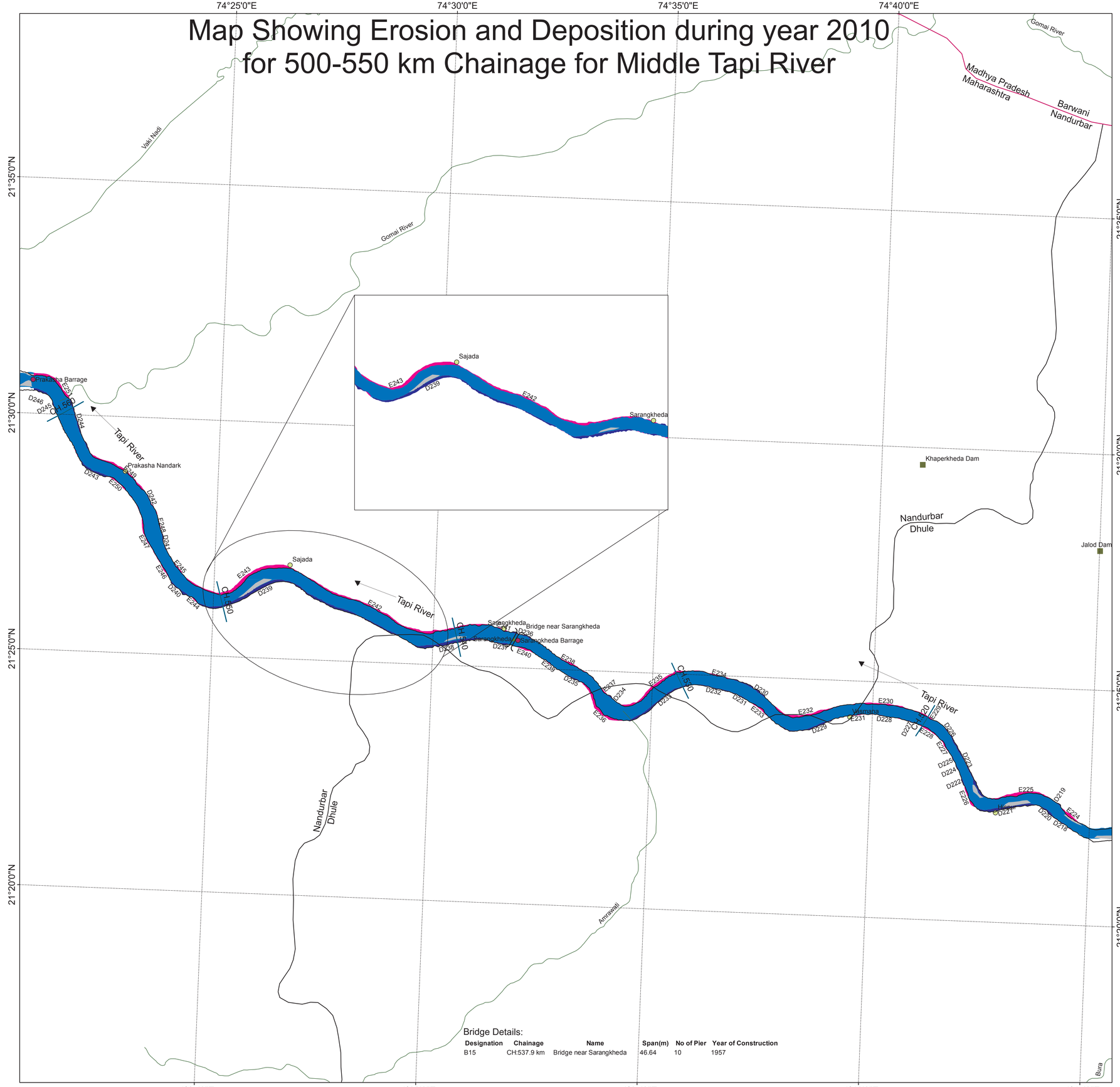
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Map Showing Erosion and Deposition during year 2010 for 500-550 km Chainage for Middle Tapi River

Appendix:B4(Ch.500to550km,Reach11)



Legend

- Active river channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Tapi&Tributary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

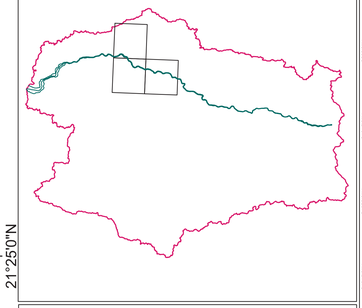
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1:50,000

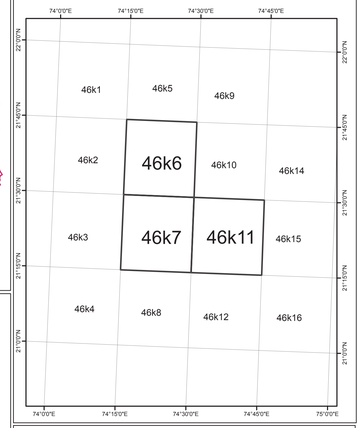
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B15	CH:537.9 km	Bridge near Sarangkheda	46.64	10	1957

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E224	56412
E225	146795
E229	29423
E230	77268
E232	151661
E234	20553
E235	225571
E237	10980
E238	36558
E241	17160
E242	405158
E243	422562
E245	14487
E248	6808
E249	130258
E251	136638

LBL

Location	Area(sqm)
E226	39665
E227	17504
E228	35399
E231	13916
E233	28933
E236	174800
E239	9238
E240	33347
E244	10718
E246	19444
E247	68055
E250	27828

RBL

Location	Area(sqm)
D219	10230
D223	134113
D226	6362
D230	56781
D234	14368
D236	28211
D241	19261
D242	7998
D244	75268

LBL

Location	Area(sqm)
D218	6588
D220	32035
D221	161657
D222	14223
D224	7666
D225	6078
D227	6258
D228	6461
D229	73617
D231	9714
D232	37380
D233	141891
D235	20122
D237	24114
D238	225109
D239	570240
D240	42240
D243	80900
D245	7609
D246	39933

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New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/47/2017

Map Showing Erosion and Deposition during year 2010 for 550-581 km Chainage for Middle Tapi River

Appendix:B4(Ch.550to581km,Reach12)

Legend

- Active channel during 2010 and water bodies
- Sand
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 1:50,000 10 Kilometers

74°0'0"E 74°5'0"E 74°10'0"E 74°15'0"E 74°20'0"E

21°40'0"N 21°35'0"N 21°30'0"N 21°25'0"N

Nandurbar

Maharashtra
Gujarat

Nandurbar
Tapi

Tapi River

Talode (M Cl)

E257 D253 E256 E255 E254 D250 D251 E254 D252 E253 D249 D248 D247 E252

GJ SH198,Kavithe

Prakasha Barrage
Bridge near,Prakasha

Gomai River

Vaki Nadi

Prakasha Nandarbar

Gujarat
Maharashtra

Tapi
Nandurbar

CH:561

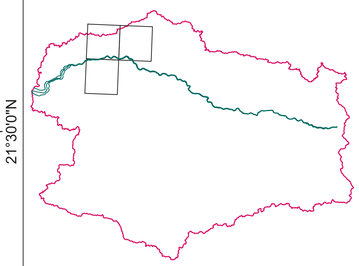
CH:589

GH:690

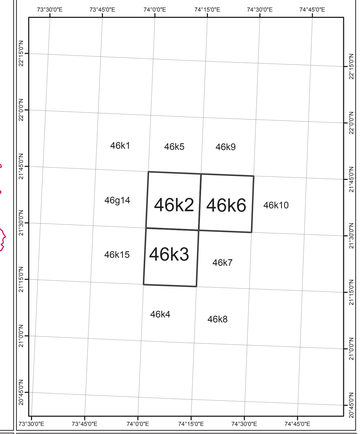
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B16	CH:561 km	Bridge near Prakasha	15.25	38	--
B17	CH:589 km	GJ SH198,Kavithe	--	--	1961

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E252	22109
E253	691419
E254	20075
E256	1995872

RBL

Location	Area(sqm)
D248	158690
D250	6956

LBL

Location	Area(sqm)
E255	7784
E257	14655

LBL

Location	Area(sqm)
D247	276761
D249	979733
D251	9740
D252	395294
D253	961631

Prepared for

Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/48/2017

Map Showing Erosion and Deposition during year 1981 for 647-697 km Chainage for Lower Tapi River

Appendix:C1(Ch.647to697km,Reach13)

73°15'0"E 73°20'0"E 73°25'0"E 73°30'0"E 73°35'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

Surat

Ver - I /Gordha Weir

Lakhigam Dam

Kevadi Dam

Surat Tapi

Tapi River

E316

Veratha Village

E315

Kakrapar Barrage

Kakrapar

D303

D302

CH: 690

CH:670

E314

Tapi River

E313

E312

Ukai

Ukai Dam

Ukai Dam

Mandvi

E318

Tapi River

Unn

CH: 700

Mandvi Bridge

E317

CH: 690

Surat

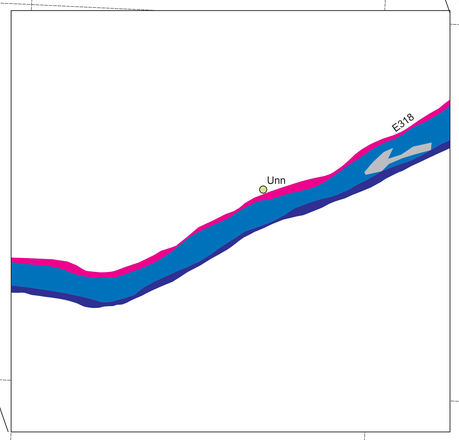
Surat Tapi

Tapi

Gujarat

Maharashtra

Tapi



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B18	CH: 695 km	Mandvi Bridge	12 No.of 48 m	13	--

Legend

- Active river channel during 1981 and water bodies
- Sand
- Island
- Rock
- River Bank Erosion
- River Bank Deposition
- River Bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

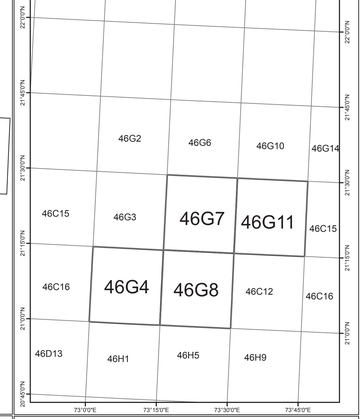
Scale

0 5 1:50,000 10 Kilometers

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E312	132578
E313	568401
E314	775153
E315	25411
E316	54461
E317	129629
E318	1581526

RBL

Location	Area (sqm)
D303	124120

LBL

Location	Area (sqm)
D302	4714901

Prepared for

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New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/49/2017

Map Showing Erosion and Deposition during year 1981 for 697-747 km Chainage for Lower Tapi River

Appendix:C1(Ch.697to747km,Reach14)

72°49'0"E 72°54'30"E 73°0'0"E 73°5'30"E 73°11'0"E

21°22'30"N 21°17'0"N 21°11'30"N 21°6'0"N

Bharuch
Surat
Motinaroli
Ghala
Bodhan
D305
E320
Gaipagla
D307
D308
D309
E321
E322
E323
D310
D311
Kholvad Bridge
E324
E326
E327
D312
E328
E329
E330
D314
Savjibhai Korat Bridge
Sachana
Railway Bridge No.452
Utran-Kapodra Bridge
Kapodara
D315
E331
Amroli Bridge
Dabholi Jahagirpura Bridge
Daboli
E333
Morarji Desai Setu (weir cum causeway)
E332
Surat (M Corp.)
Kgardan
Surat(Seasonal)
SMC Palroad
D316
E334
Tapi River
Bodhan Flyover
D304
E319
Kataroli
CH: 721
CH: 739
CH: 748
CH: 750
CH: 751
CH: 757
CH: 761
CH: 763

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B19	CH: 721 km	Bodhan Flyover	--	--	--
B20	CH: 739 km	Kholvad Bridge	38	10	--
B21	CH: 748 km	Savjibhai Korat Bridge	11 No. of 42 m,2 No. of 41.3 m	12	2001
B22	CH: 750 km	Utran-Kapodra Bridge	--	--	--
B23	CH: 751 km	Railway Bridge No.452	57	9	1915
B24	CH: 757 km	Amroli Bridge	50.61	11	1982
B25	CH: 761 km	Dabholi Jahagirpura Bridge	--	--	--
B26	CH: 763 km	Morarji Desai Setu (weir cum causeway)	6.2	15	1995

Legend

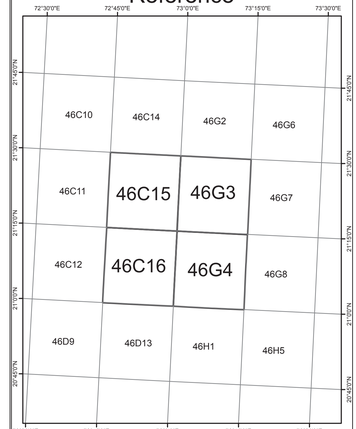
- Active river channel during 1981 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale
0 5 10 Kilometers
1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E319	40205
E320	1142017
E321	50663
E322	12874
E324	80485
E326	100901
E327	145786
E328	11174
E329	118181
E331	505241
E332	620915

RBL

Location	Area (sqm)
D304	6537
D306	9405
D307	13011
D308	6249
D309	69797
D313	11009
D314	24626
D316	5681

LBL

Location	Area (sqm)
E323	8813
E325	20150
E330	15811
E333	33955
E334	191072

LBL

Location	Area (sqm)
D305	2527128
D310	49652
D311	45542
D312	307927
D315	1264716

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/50/2017

Map Showing Erosion and Deposition during year 1981 for 747-792 km Chainage for Lower Tapi River

Appendix:C1(Ch.747to792km,Reach15)

72°35'0"E 72°40'0"E 72°45'0"E 72°50'0"E 72°55'0"E

21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N

Surat

Tapi River

Kapodara

Parthana

Kadodara

Kamrej

Chalthan

Zaboli

Ghala

Olpad

Sarthana

Kosamba

Mahuva

Bardoli

Vyara

Songadh

Nizar

Uchchhal

Dolvan

Valod

Vyara

Songadh

Nizar

Uchchhal

Dolvan

Valod

CH:747.0 CH:760 CH:770 CH:780 CH:790

E348 D331 D330 E346 D328 E341 E342 D327 D332 D333 E343 E344 E347 D329 E345 D317 D318 E336 E338 D322 D325 E339 D323 E340 D326 E337 D321 E335 D319 D320 E343

Surat (M Corp.)

Shri Chandra Sekhar Azad Bridge across river

Nehru Bridge

Swami Vivekanad Bridge

Sardar Patel Bridge

ONGC Bridge

SMC Boundary

Legend

- Active river channel during 1981 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

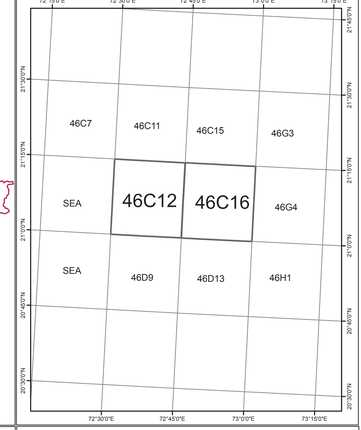
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B27	CH: 764 km	Shri Chandra Sekhar Azad Bridge across river	Max-50m, Min-25m	76	--
B28	CH: 765 km	Nehru Bridge	10 No.of 50.6 m,2 No.of 44.5 m,1 No.of 8.50 m	12	1966
B29	CH: 766 km	Swami Vivekanad Bridge	25	24	1996
B30	CH: 767 km	Sardar Patel Bridge	50	13	1991
B31	CH: 775 km	ONGC Bridge	50	17	1984

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E336	552021
E337	520687
E338	166074
E341	10385814
E343	2349377

RBL

Location	Area (sqm)
D317	69183
D318	160930
D322	11483
D326	89813

LBL

Location	Area (sqm)
E335	113296
E339	12393
E340	25662
E342	17236
E344	52985
E345	6970940
E346	24466
E347	3758809
E348	309443

LBL

Location	Area (sqm)
D319	20455
D320	8464
D321	623949
D323	117729
D324	14420
D325	105786
D327	416614
D328	11381
D329	89762
D330	175093
D331	118580
D332	6430
D333	6078

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Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/51/2017

Map Showing Erosion and Deposition during year 1990 for 647-697 km Chainage for Lower Tapi River

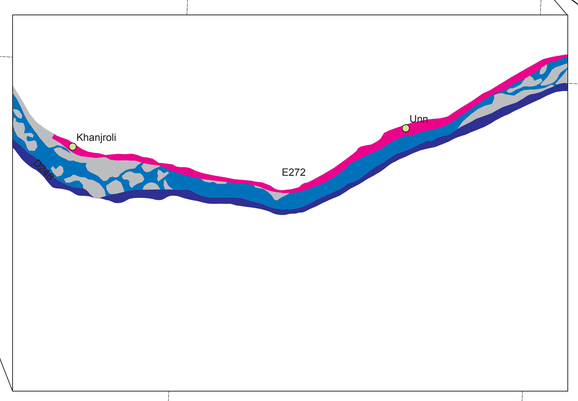
Appendix:C2(Ch.647to697km,Reach13)

73°10'0"E 73°15'0"E 73°20'0"E 73°25'0"E 73°30'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

Surat
Surat
Surat
Tapi
Surat
Tapi
Tapi

Ver - I /Gordha Weir
Lakhigam Dam
Kevadi Dam
Mandvi
Mandvi Bridge
Kakrapar Barrage
Kakrapar
Veratha Village
Khanjroli
Unn
Tapi River
Tapi River
Tapi River
Tapi River
E271
E272
E270
E268
E269
D247
D246
D245
D244
D248
CH:680
CH:670
CH:690
CH:690



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B18	CH: 695 km	Mandvi Bridge	12 No.of 48 m	13	--

Legend

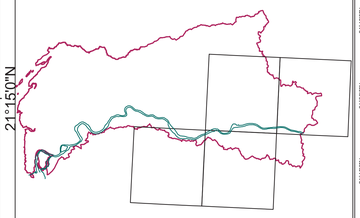
- Active river channel during 1990 and water bodies
- Sand
- Island
- Rock
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

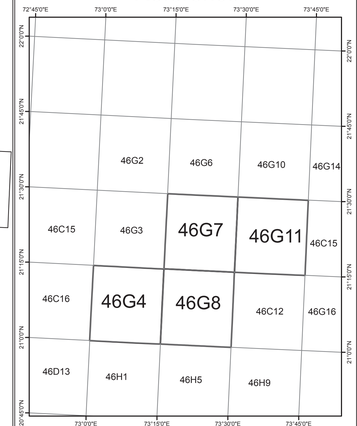
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area (sqm)
E268	1711859
E269	151091
E270	320743
E271	102290
E272	2086932

RBL Location	RBL Area (sqm)
D245	9158
D246	7396
D247	6430

LBL Location	LBL Area (sqm)
D244	5650892
D248	531780

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New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/52/2017

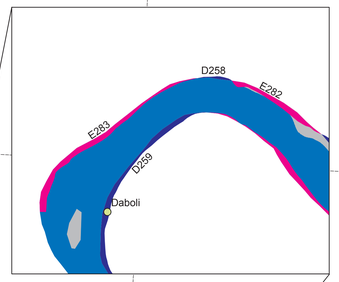
Map Showing Erosion and Deposition during year 1990 for 697-747 km Chainage for Lower Tapi River

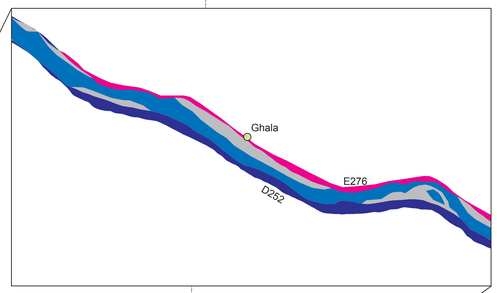
Appendix:C2(Ch.697to747km,Reach14)

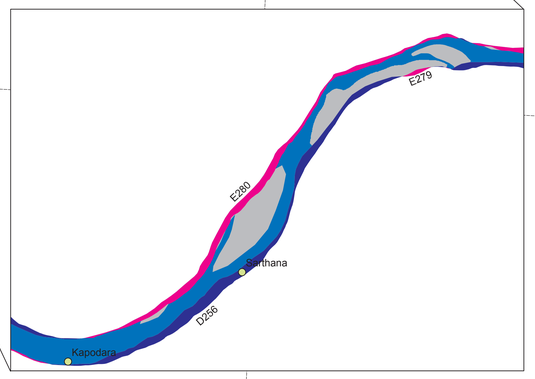
72°50'0"E 72°55'0"E 73°0'0"E 73°5'0"E 73°10'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

Bharuch
Surat
Motinaroli
Gaipagla
Ghala
Khalipoli
Tapi River
Kholvad Bridge
Dabholi Jahagirpura Bridge
Dabholi
Amroli Bridge
Railway Bridge No.452
Savjibhai Korat Bridge
Utran-Kapodra Bridge
Kapodara
Sarthana
Morarji Desai Setu (weir cum causeway)
Bodhan Flyover
Bodhan
Surat (M Corp.)
Kgardan
Surat(Seasonal)
SMC Palroad
CH: 720
CH: 740
CH: 750
CH: 760
CH: 780
CH: 790







Legend

- Active river channel during 1990 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

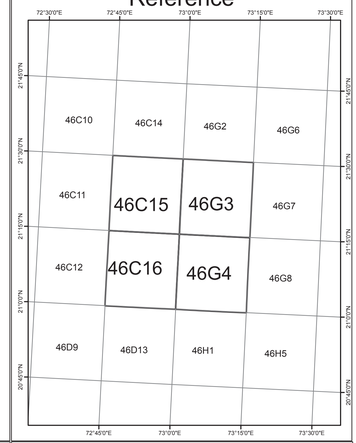
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E273	40406
E274	39293
E275	54120
E276	1061780
E277	96399
E278	254578
E280	933059
E282	125330
E283	259739

RBL

Location	Area (sqm)
D249	30895
D251	17933
D253	14493
D254	7488
D255	15055
D257	380218
D258	15390

LBL

Location	Area (sqm)
E279	31319
E281	246105

LBL

Location	Area (sqm)
D250	327331
D252	2872600
D256	1179450
D259	451011

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B19	CH: 721 km	Bodhan Flyover	--	--	--
B20	CH: 739 km	Kholvad Bridge	38	10	--
B21	CH: 748 km	Savjibhai Korat Bridge	11 No. of 42 m,2 No. of 41.3 m	12	2001
B22	CH: 750 km	Utran-Kapodra Bridge	--	--	--
B23	CH: 751 km	Railway Bridge No.452	57	9	1915
B24	CH: 757 km	Amroli Bridge	50.61	11	1982
B25	CH: 761 km	Dabholi Jahagirpura Bridge	--	--	--
B26	CH: 763 km	Morarji Desai Setu (weir cum causeway)	6.2	15	1995

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Central Water Commission
New Delhi

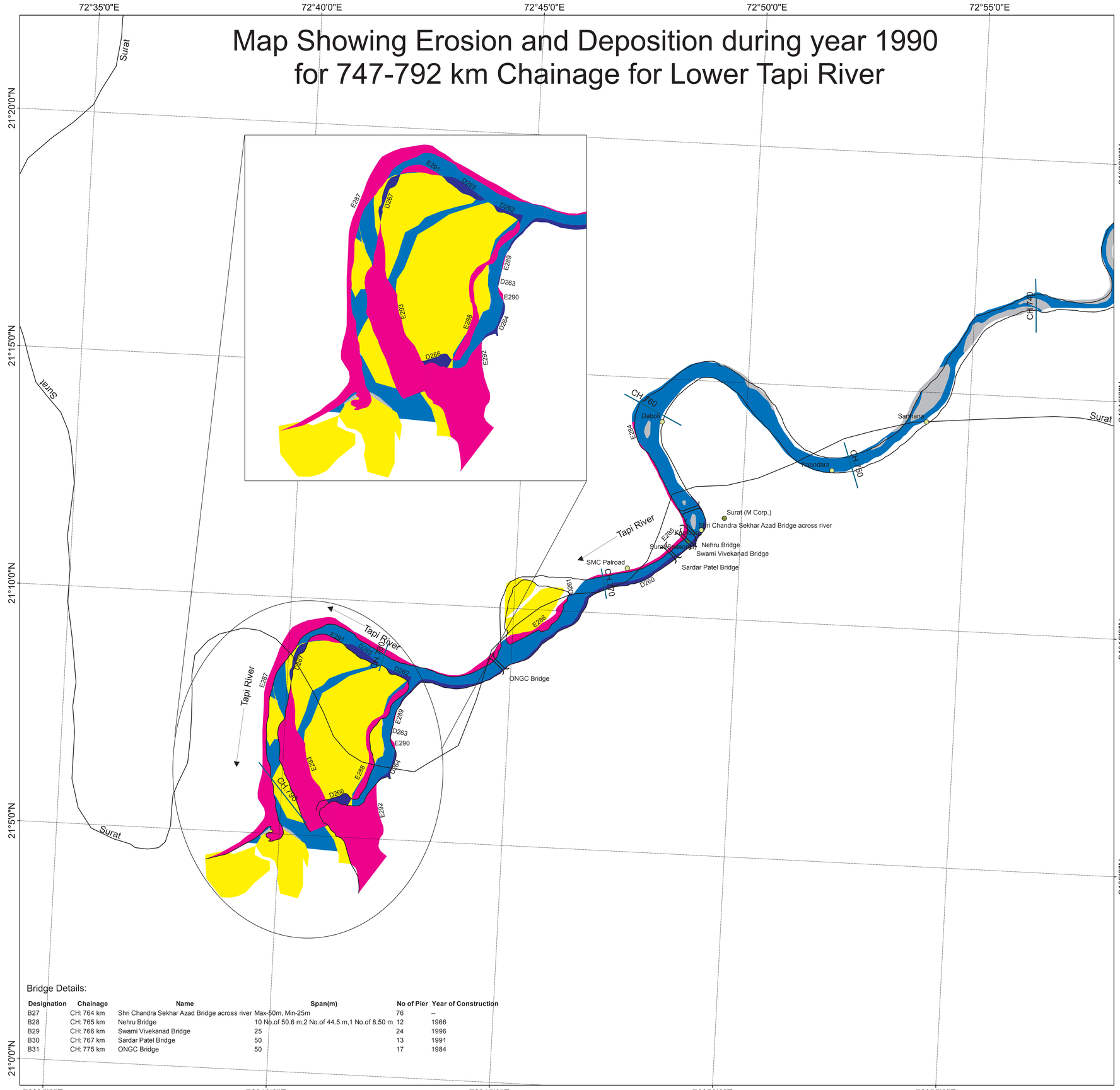
Prepared by

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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/53/2017

Map Showing Erosion and Deposition during year 1990 for 747-792 km Chainage for Lower Tapi River

Appendix:C2(Ch.747to792km,Reach15)



Legend

- Active river channel during 1990 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

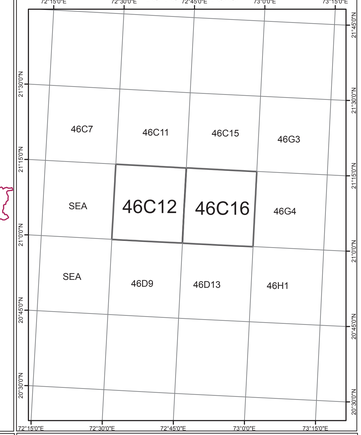
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B27	CH: 764 km	Shri Chandra Sekhar Azad Bridge across river	Max-50m, Min-25m	76	--
B28	CH: 765 km	Nehru Bridge	10 No.of 50.6 m,2 No.of 44.5 m,1 No.of 8.50 m	12	1966
B29	CH: 766 km	Swami Vivekanad Bridge	25	24	1996
B30	CH: 767 km	Sardar Patel Bridge	50	13	1991
B31	CH: 775 km	ONGC Bridge	50	17	1984

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area (sqm)
E284	47615
E285	647106
E286	597834
E287	4906855
E288	986029

RBL

Location	Area (sqm)
D261	13145
D266	1110866

LBL

Location	Area (sqm)
E289	12824
E290	28784
E291	220585
E292	4476573
E293	4460359

LBL

Location	Area (sqm)
D260	1509968
D262	128209
D263	13286
D264	125015
D265	312200
D267	240342

Prepared for

Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/54/2017

Map Showing Erosion and Deposition during year 2000 for 647-697 km Chainage for Lower Tapi River

Appendix:C3(Ch.647to697km,Reach13)

73°15'0"E 73°20'0"E 73°25'0"E 73°30'0"E 73°35'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N

Surat
Surat
Surat
Tapi
Tapi
Surat
Tapi
Tapi
Tapi
Tapi River
Tapi River
Tapi River
Tapi
Tapi
Nandurbar

Ver - I /Gordha Weir
Lakhigam Dam
Kevadi Dam
Mandvi
Mandvi Bridge
Kakrapar Barrage
Kakrapar
Veratha Village
Unn
Ukai
Ukai Dam
D270 Ukai Dam

CH:680
CH:690
CH:670

E271 D271 E272 D272 E273 D273 E274 D274 D275 D276 E275 D277

Legend

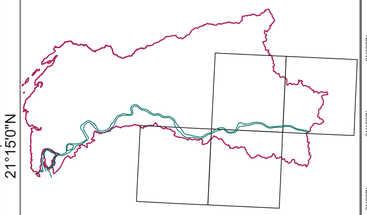
- Active river channel during 2000 and water bodies
- Sand
- Island
- Rock
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

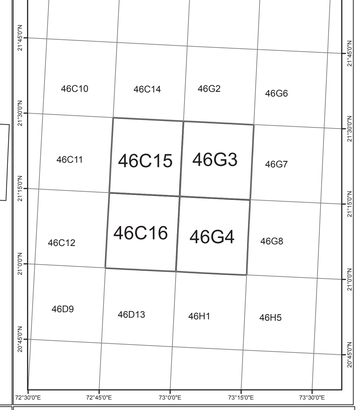
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B18	CH: 695 km	Mandvi Bridge	12 No.of 48 m	13	--

River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area(sqm)	RBL Location	RBL Area(sqm)
E271	1831086	D272	13351
E272	27012	D273	15232
E273	279527	D274	8043
E274	91738	D275	13712
E275	1375989	D276	16400

LBL Location	LBL Area(sqm)
D270	7810
D271	3939888
D277	2330572

Prepared for

Central Water Commission
New Delhi

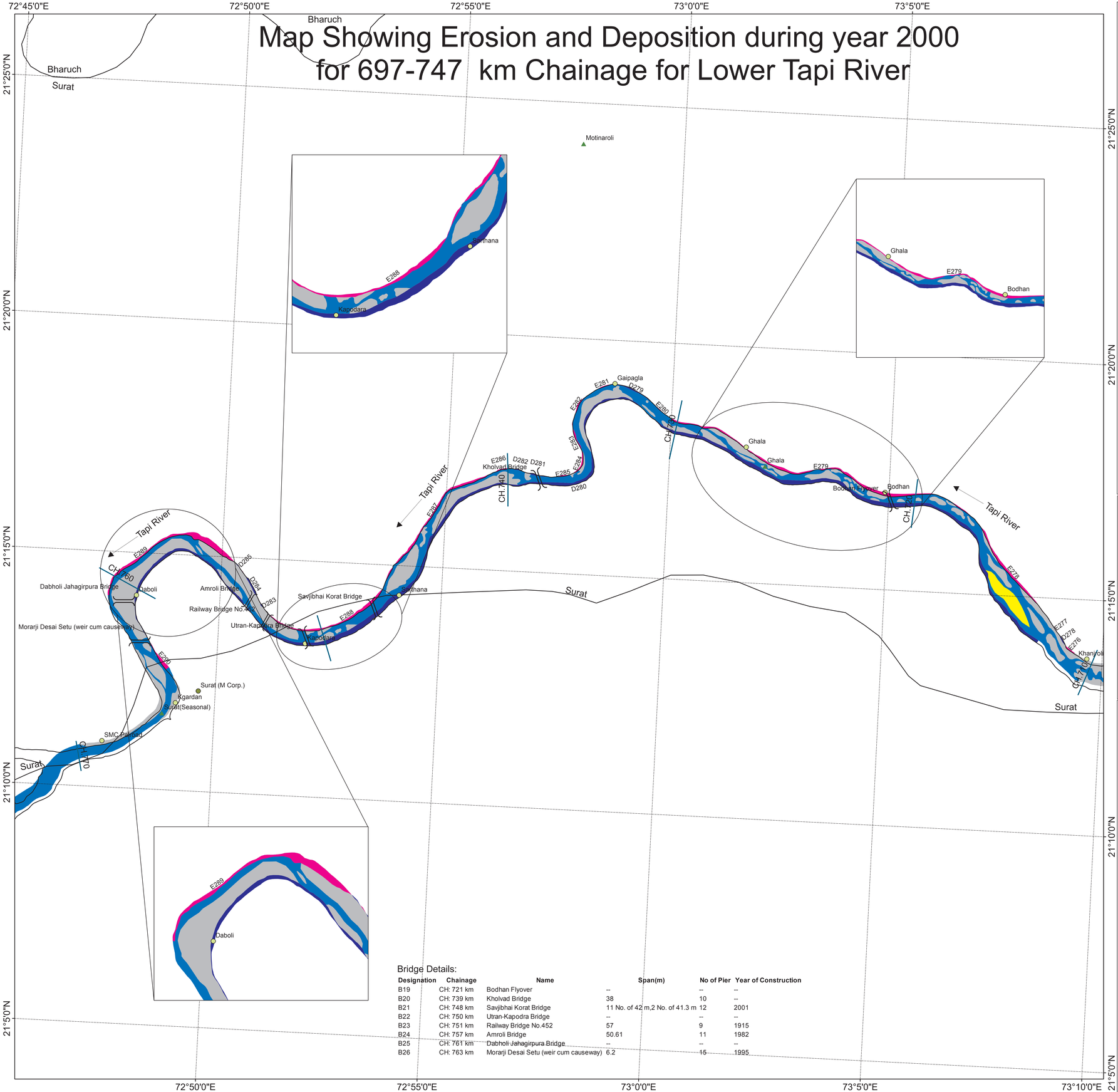
Prepared by

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S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/55/2017

Map Showing Erosion and Deposition during year 2000 for 697-747 km Chainage for Lower Tapi River

Appendix:C3(Ch.697to747km,Reach14)



Legend

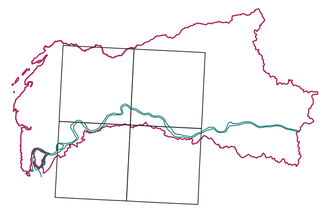
- Active river channel during 2000 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

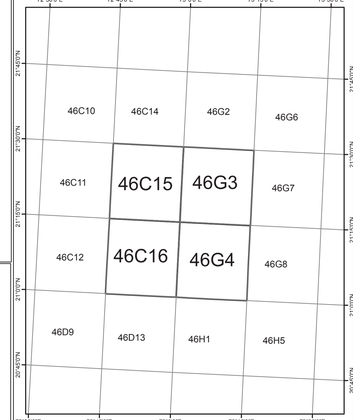
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E276	19155
E277	5144
E278	249777
E279	702751
E280	6096
E281	11909
E282	24613
E283	35145
E284	42151
E285	11417
E286	16980
E287	302495
E288	345856
E289	653625

RBL

Location	Area(sqm)
D278	15977
D279	49339
D281	25186
D282	9686
D283	5369
D284	45915
D285	5319

LBL

Location	Area(sqm)
E290	90938

LBL

Location	Area(sqm)
D280	4728375

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B19	CH: 721 km	Bodhan Flyover	--	--	--
B20	CH: 739 km	Kholvad Bridge	38	10	--
B21	CH: 748 km	Savjibhai Korat Bridge	11 No. of 42 m,2 No. of 41.3 m	12	2001
B22	CH: 750 km	Utran-Kapodra Bridge	--	--	--
B23	CH: 751 km	Railway Bridge No.452	57	9	1915
B24	CH: 757 km	Amroli Bridge	50.61	11	1982
B25	CH: 761 km	Dabholi Jahagirpura Bridge	--	--	--
B26	CH: 763 km	Morarji Desai Setu (weir cum causeway)	6.2	15	1995

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Central Water Commission
New Delhi

Prepared by

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Surat - 395007, Gujarat

Morpho/11/56/2017

Map Showing Erosion and Deposition during year 2000 for 747-792 km Chainage for Lower Tapi River

Appendix:C3(Ch.747to792km,Reach15)

72°35'0"E 72°40'0"E 72°45'0"E 72°50'0"E 72°55'0"E

21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N

Surat Tapi River Daboli Sarthana Kapodara Surat (M Corp.) Sardar Patel Bridge Swami Vivekanad Bridge Nehru Bridge Kgardan Sri Chandra Sekhar Azad Bridge across river SMC Railroad ONGC Bridge CH:760 CH:750 CH:740 CH:790

Legend

- Active river channel during 2000 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

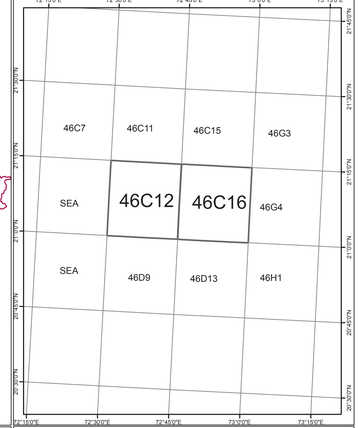
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B27	CH: 764 km	Shri Chandra Sekhar Azad Bridge across river	Max-50m, Min-25m	76	--
B28	CH: 765 km	Nehru Bridge	10 No.of 50.6 m,2 No.of 44.5 m,1 No.of 8.50 m	12	1966
B29	CH: 766 km	Swami Vivekanad Bridge	25	24	1996
B30	CH: 767 km	Sardar Patel Bridge	50	13	1991
B31	CH: 775 km	ONGC Bridge	50	17	1984

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E291	18182
E294	617128
E295	5506
E296	617575
E297	100792
E298	14063
E299	377911
E302	875614
E304	1861721
E306	2162554

RBL

Location	Area(sqm)
D286	35621
D287	11805
D288	5949
D289	11373
D291	88722
D293	1583173
D297	366597

LBL

Location	Area(sqm)
E292	90938
E293	61999
E300	10621
E301	32193
E303	6630316
E305	4515346

LBL

Location	Area(sqm)
D290	1653895
D292	56852
D294	121678
D295	200771
D296	861222

Prepared for

Central Water Commission
New Delhi

Prepared by

Civil Engineering Department,
S.V.National Institute of Technology,
Surat - 395007, Gujarat

Morpho/11/57/2017

Map Showing Erosion and Deposition during year 2010 for 647-697 km Chainage for Lower Tapi River

Appendix:C4(Ch.647to697km,Reach13)

73°10'0"E 73°15'0"E 73°20'0"E 73°25'0"E 73°30'0"E

21°25'0"N 21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N

Surat

Ver - I /Gordha Weir

Lakhigam Dam

Kevadi Dam

Surat Tapi

Tapi River

Mandvi

Mandvi Bridge

Verathe Village

Kakrapar

Kakrapar Barrage

Unn

Khanjroli

Surat Tapi

Tapi

CH:670

CH:680

CH:690

CH:700

E262 D258 E263 E264 D259 E261 D257 E260 D256 D255 E259 D254 E258

E262

E263

E264

Khanjroli

Unn

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B18	CH: 695 km	Mandvi Bridge	12 No.of 48 m	13	--

Legend

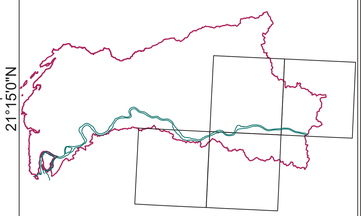
- Active river channel during 2010 and water bodies
- Sand
- Island
- Rock
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

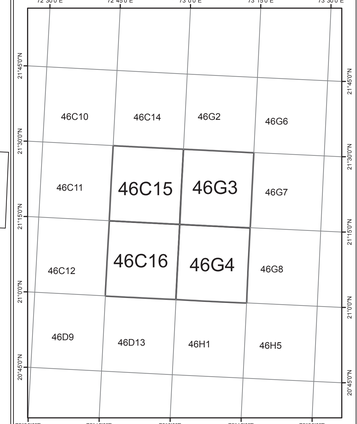
0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	Area(sqm)
E258	1587555
E259	38123
E260	33139
E261	145673
E262	79357
E263	1427835

RBL Location	Area(sqm)
D254	6873
D255	29832
D256	21232
D258	16402

LBL Location	Area(sqm)
E264	11609

LBL Location	Area(sqm)
D257	4662752
D259	362129

Prepared for

Central Water Commission
New Delhi

Prepared by

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S.V.National Institute of Technology,
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Map Showing Erosion and Deposition during year 2010 for 697-747 km Chainage for Lower Tapi River

Appendix:C4(Ch.697to747km,Reach14)

Legend

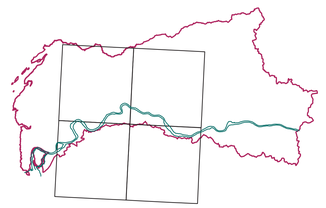
- Active river channel during 2010 and water bodies
- Sand
- Island
- River Basin Erosion
- River Basin Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Barrage
- Tapi_Dam
- Tapi_Hydrological Observation
- Bridge

Scale

0 5 10 Kilometers

1:50,000

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposotion (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL

Location	Area(sqm)
E265	15132
E266	688955
E267	7214
E268	55854
E269	37401
E270	47814
E271	136644
E272	272266
E273	355947
E274	11939
E275	628363

RBL

Location	Area(sqm)
D260	65142
D264	93339
D265	51124
D266	30772
D268	27756
D269	46561

LBL

Location	Area(sqm)
E276	54732

LBL

Location	Area(sqm)
D261	196819
D262	1507758
D263	5006
D267	1939898
D270	483826

Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B19	CH: 721 km	Bodhan Flyover	--	--	--
B20	CH: 739 km	Kholvad Bridge	38	10	--
B21	CH: 748 km	Savjibhai Korat Bridge	11 No. of 42 m,2 No. of 41.3 m	12	2001
B22	CH: 750 km	Utran-Kapodra Bridge	--	--	--
B23	CH: 751 km	Railway Bridge No.452	57	9	1915
B24	CH: 757 km	Amroli Bridge	50.61	11	1982
B25	CH: 761 km	Dabholi Jahagirpura Bridge	--	--	--
B26	CH: 763 km	Morarji Desai Setu (weir cum causeway)	6.2	15	1995

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New Delhi

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Map Showing Erosion and Deposition during year 2010 for 747-792 km Chainage for Lower Tapi River

Appendix:C4(Ch.747to792km,Reach15)

72°35'0"E 72°40'0"E 72°45'0"E 72°50'0"E 72°55'0"E

21°20'0"N 21°15'0"N 21°10'0"N 21°5'0"N 21°0'0"N

Bharuch

Surat

Daboli

Sarthana

Kapodara

CH:747.0

CH:752.0

CH:792.0

Surat (M Corp.)

Shri Chandra Sekhar Azad Bridge across river

Kgardan

Nehru Bridge

Swami Vivekanad Bridge

Sardar Patel Bridge

SMC Railroad

ONGC Bridge

Tapi River

E277 E278 E279 E280 E281 E282 E283 E284 E285 E286 E287 E288 E289 E290

D271 D272 D273 D274 D275 D276 D277 D278 D279 D280

Legend

- Active river channel during 2010 and water bodies
- Sand
- Island
- River Bank Erosion
- River Bank Deposition
- River bankline of Toposheet
- State boundary
- District boundary
- Village
- Tapi_Town
- Tapi_Dam
- Tapi_Barrage
- Tapi_Hydrological Observation
- Bridge

Scale

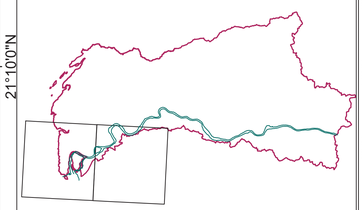
0 5 10 Kilometers

1:50,000

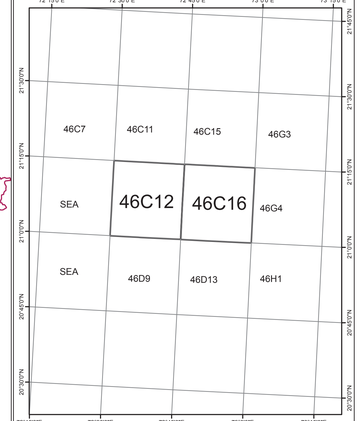
Bridge Details:

Designation	Chainage	Name	Span(m)	No of Pier	Year of Construction
B27	CH: 764 km	Shri Chandra Sekhar Azad Bridge across river	Max-50m, Min-25m	76	--
B28	CH: 765 km	Nehru Bridge	10 No.of 50.6 m,2 No.of 44.5 m,1 No.of 8.50 m	12	1966
B29	CH: 766 km	Swami Vivekanad Bridge	25	24	1996
B30	CH: 767 km	Sardar Patel Bridge	50	13	1991
B31	CH: 775 km	ONGC Bridge	50	17	1984

Plate Reference



SOI Toposheet Reference



River Bank Erosion (E) and Deposition (D) Statistics

(Area less than 5000 sqm not tabulated)

RBL Location	RBL Area(sqm)	RBL Location	RBL Area(sqm)
E277	8734	D272	72314
E279	441826	D274	301202
E280	671882	D277	716066
E282	884409	D279	86477
E285	580473	D280	1414817
E288	1588171		
E290	1748962		

LBL Location	LBL Area(sqm)	LBL Location	LBL Area(sqm)
E278	80641	D271	1590678
E281	33045	D273	4412936
E283	12794	D275	128429
E284	12912	D276	23170
E286	6497746	D278	156346
E287	52861		
E289	4412936		

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New Delhi

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Surat - 395007, Gujarat

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