

ECOLOGICAL HEALTH ASSESSMENT OF THE GANGA RIVER BASED ON RIVER ECOSYSTEM HEALTH ASSESSMENT CRITERIA





DRAFT FOR REVIEW

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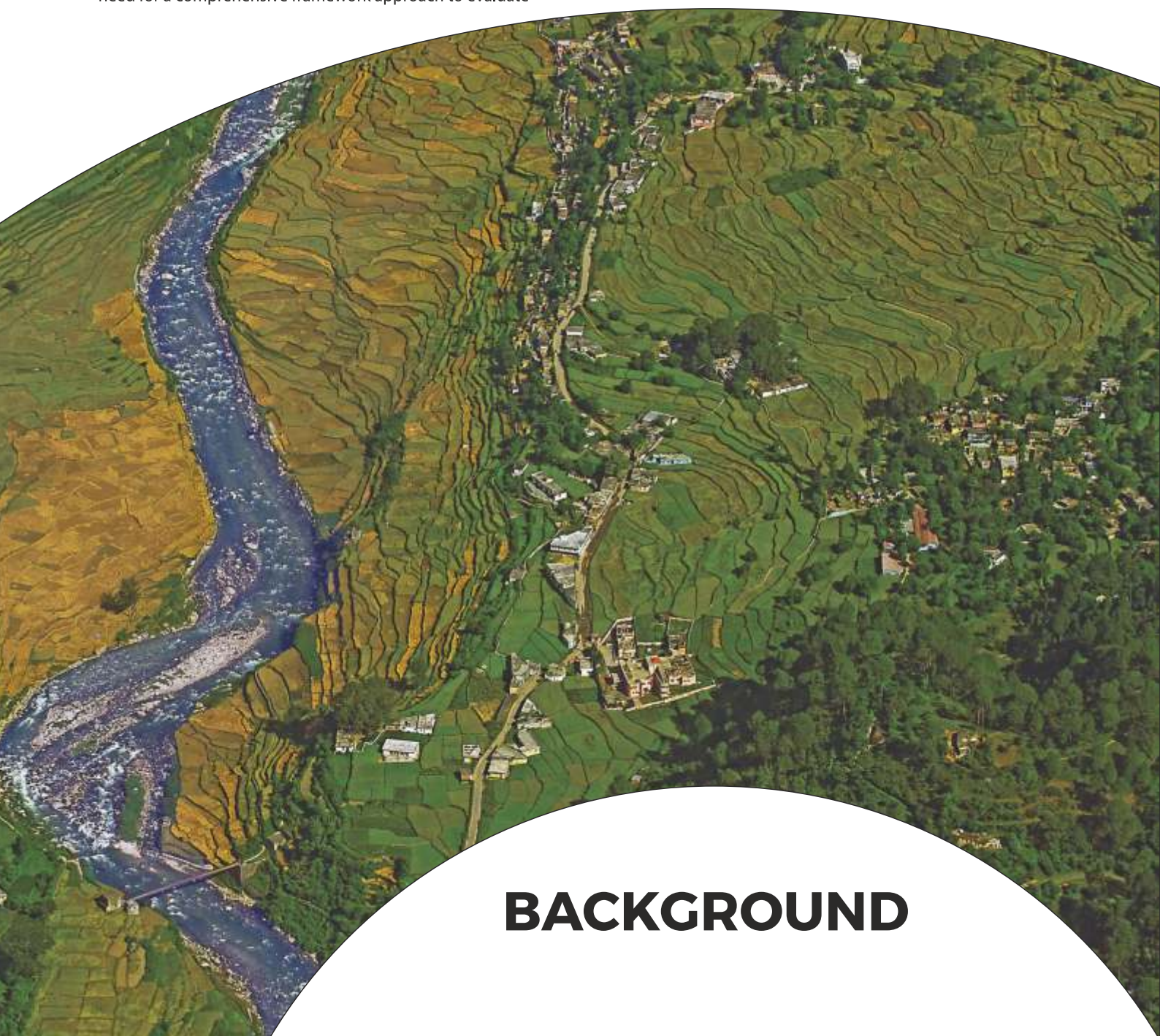
The Ganga River is characterized by a highly variable flow regime throughout its length and large tidal volumes in its lower stretch beyond the Farakka barrage. This, coupled with diverse geomorphological features and climatic variations has resulted in a continuous gradient of habitats, which supports a diverse assemblage of flora and fauna. Several conservation significant species such as the Gangetic river dolphin, gharial, otters, turtles and several aquatic and terrestrial birds are found along the river. However, the aquatic diversity of the Ganga River and their habitats are in peril due to a multitude of factors arising primarily from unsustainable resource use practices. Morphological alterations through dams and barrages, unsustainable water extraction, wastewater inflow, discharge of persistent pollutants and xenobiotic compounds, and change in floodplain and riverbed land use has altered the hydrologic regime of the river and has compromised the ecological health of the whole river ecosystem. Taking into consideration the ecological as well economic significance of the Ganga, assessment of the overall state of its health is critical. In effect, river health assessments are now globally recognized crucial for coordinated management of land and water resources, especially in large river basins (Whittington et al. 2001, Davies et al. 2010). However, river health (Rapport 1995, Chipeniuk 1996) has always been associated with misinterpretations by the wider public, resonating only vitality and vigor, and failing to interpret significant ecological



functions essential to societal well-being. Health assessments should thus consider riverine processes crucial to its overall health and its biodiversity, and determine what range of conditions matters to society (Fairweather 1999). However, most approaches in the past assessed river health only on the basis of physico-chemical water quality and/or a biological indicator (Barbour et al. 1999, Boulton 1999). This is also true for the Ganga River, wherein numerous studies have been conducted to assess its 'health'. However, these studies were not holistic and although they addressed the cause and impact of river habitat degradation, they could not fulfill the necessary inclusiveness of methods and lacked the integrated approach to comprehend the ecological health of the Ganga riversystem. This lack of coherence in the design and implementation of river health assessments emphasizes the need for a comprehensive framework approach to evaluate

the overall ecological health of the Ganga river system with considerations of environmental complexities and external dynamics. Such an approach should aid in strategizing site-specific interventions for maintaining ecological resilience in healthy stretches and improving and restoration of degraded ones.

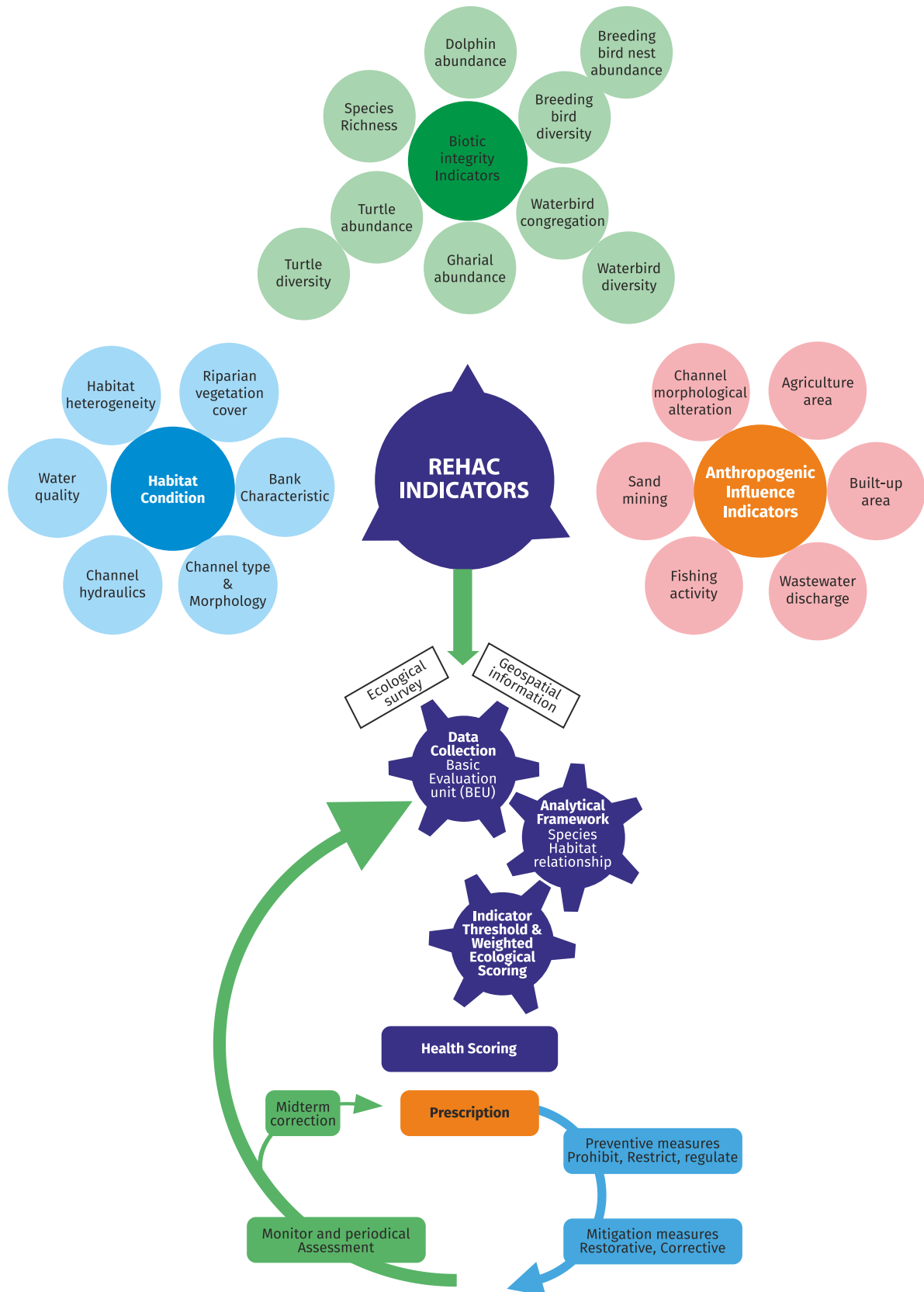
Thus, this ecological health card for the Middle and Lower Ganga River aims to provide information on the status of habitat, biotic integrity and anthropogenic influence in a simple communicable format with the vision of inclusive and adaptive management application.



BACKGROUND



REHAC FRAMEWORK



A framework was created to assess the ecological status or health of the Ganga River on the basis of extensive surveys. The framework consists of 6 segments: (1) Establishment of River Ecosystem Health Assessment Criteria (REHAC) and Indicators, (2) Data collection framework, (3) Analytical framework, (4) Indicator threshold and weighted ecological scoring, (5) Health Scoring and development of Health Card, and (6) Prescription.

REHAC and Indicators

A multi-perspective approach was adopted to define the REHAC with ecologically relevant indicators. Twenty eight indicators were identified and categorized under three intertwined criteria such as Habitat, Biotic integrity and Anthropogenic influences.

Data collection framework

Primary information for the indicators was collected through a multi-phased approach, combining field data, geo-spatial information and literature. Ecological survey strategies such as continuous boat and foot transects along the banks were adopted for data collection.

Basic evaluation unit (BEU)

A 5 Km segment along the length of the river and 1 Km buffer from the maximum flood-line of both the banks of the river was considered as the BEU. Thus the area of each BEU was 10 km², while its length was 5 km.

Analytical framework

Critical and statistically significant indicators were identified and evaluated to determine their threshold and 'weight' based on their ecological importance.

Flow preference of river dolphins

Channel depth and flow utilization by river dolphins were compared with depth and flow availability to assess flow preference. Chi-square goodness-of-fit test (Neu et al., 1974; Hussain, 2009) was performed with the bathymetric information and dolphin abundance. Statistically significant data were further tested with Bonferroni-Z analysis (Byers et al., 1984) to determine preferred and avoided depth and flow regimes.

Habitat-species interactions

A step-wise GLM was performed to assess the significance of each habitat indicator. The group of indicators, thus selected, had lowest Akaike's information criterion (AIC) value and significant at 95% confidence level. Each of these indicators and combinations of them were further used to model Species richness, Dolphin abundance, Waterbird abundance, Waterbird diversity, Breeding bird diversity, Breeding bird nest abundance, Turtle abundance and Turtle diversity.

Bipartite ecological interaction network

To cross-validate habitat use and overlap among different species and habitat types, a bipartite analysis was carried out through R (Version 3.5.2 (2018-12-20)) and bipartite package (bipartite 2.11).

Indicator threshold and weighted ecological scoring

A multimetric methodology was adopted to determine thresholds for each indicator and weighted scoring was done by following the objective approach



(Blyth, 1972). The Habitat indicators were weighed according to the interactions with key aquatic fauna. Thresholds for flow was determined according to the flow preference of Gangetic river dolphins. The threshold for DO and pH were based on the USEPA Aquatic Life Criteria (www.epa.gov/wqc) and DBU criteria (CPCB, 2011). These indicators were assigned weightage on a scale of 2-5, in ascending order of positive influence on species assemblage. No thresholds were assigned for 'Bank characteristics' and 'Channel type & morphology' as value for these were determined on their presence-absence, their role in assuring species assemblage. Habitat condition score was calculated using the following equation (equation 1):

Habitat Condition Score

$$= \sum \left(\sum_{i=1}^n \text{RipCov} + \sum_{i=1}^n \text{HabHet} + \sum_{i=1}^n \text{Flow} + \sum_{i=1}^n \text{DO} + \sum_{i=1}^n \text{pH} \right)$$

Biotic integrity indicators were weighed according to their ecological role. The threshold were determined through quartile analysis, and were modified for Dolphin and Turtle abundance to an ecologically meaningful threshold. Biotic integrity score was calculated using the following equation (equation 2):

Biotic Integrity Score

$$= \sum \left(\sum_{i=1}^n \text{DoIAb} + \sum_{i=1}^n \text{BBDiv} + \sum_{i=1}^n \text{BBNAb} + \sum_{i=1}^n \text{WBAb} + \sum_{i=1}^n \text{WBDiv} + \sum_{i=1}^n \text{GhAb} + \sum_{i=1}^n \text{TurAb} + \sum_{i=1}^n \text{TurDiv} + \sum_{i=1}^n \text{SpRich} \right)$$

Thresholds for anthropogenic influence indicators were determined based on the environmental risk they pose and their effect on biodiversity and river ecosystem. Anthropogenic influence score was calculated using the following equation (equation 3):

Anthropogenic Influence Score

Where, i = Number of BEUs

$$= \sum \left(\sum_{i=1}^n \text{CMA} + \sum_{i=1}^n \text{Agri} + \sum_{i=1}^n \text{Built} + \sum_{i=1}^n \text{WWD} + \sum_{i=1}^n \text{BOD} + \sum_{i=1}^n \text{Nit} + \sum_{i=1}^n \text{TC} + \sum_{i=1}^n \text{Fish} + \sum_{i=1}^n \text{SaMin} \right)$$

Ecological Health Scoring

The scores were calculated by adding individual indicator weighted scores. It was presumed that the higher the habitat (C1) and biotic integrity scores (C2), the better is the ecological health. On the other hand, the anthropogenic influences (C3) beyond carrying capacity of the system often disturb ecosystem dynamics. Thus, C3 would have a negative influence. Following equation was formulated to assess the 'Health score' of each BEU.

Health score

$$= \frac{\sum \text{Habitat Condition Score} \times \sum \text{Biotic Integrity score}}{\sum \text{Anthropogenic Influence Score}}$$

Composite ecological health score was obtained by aggregation of individual BEUscores. These scores were classified into four Categories on the basis of the health score range.



THRESHOLD FOR INDICATORS

RIVER ECOSYSTEM HEALTH ASSESSMENT CRITERIA
AND THEIR JUSTIFICATION AS INDICATORS

Criteria	Justification (References)
HABITAT CONDITION	Riparian vegetation cover regulate energy and water fluxes, such as subsidization of stream food webs, rain interception, evapotranspiration, and infiltration. Forests filter pollutants before they reach waterbodies, and stabilize soil and stream banks to mitigate erosion (Bunn 1999, Furniss et al. 2010, Storer et al. 2011, Alemu et al. 2018).
	It is assumed that the more intact the catchment, the more it will give resilience to the headwater streams as well as the banks of the 3rd or 4th order rivers. Thus, riparian vegetation cover was taken as an indicator (Davies et al. 2010, Scherman et al. 2004).
	Habitat availability and diversity determine aquatic community structure. Habitat degradation adversely affects biological communities.
	Occurrence and diversity of the geomorphologic or habitat features of a river determine suitability of the river stretch to the species assemblage (Raven et al. 1998), thus it is crucial to determine both (diversity and occurrence) for informed management decisions (Raven et al. 1998).
	The criterion is an indicator of alteration in natural hydrology regime and describes the change in habitat and ecosystem connectivity, deleterious changes in water chemistry and determine distribution of species. More natural hydrology regime sustain the life history strategies of aquatic species (Tonkin et al. 2018, Richter et al. 2010).
	River channel depth (Gorman and Karr 1978), channel type, floodplain and channel features, floodplain substrate are some of the features that determine habitat suitability (Scherman et al. 2004, Sinha 2017).
	The criterion addresses the habitat connectivity and habitat availability concerns for riverine biota, especially umbrella species like river dolphin.



Criteria	Justification (References)
HABITAT CONDITION	It also addresses the physiochemical and microbial water quality aspects to determine the suitability of the chemical water environment and microbial human health implication. Dissolved Oxygen (DO), acid-base balance defined by pH are most widely used parameters for assessing water quality^{1,2} (Rawi et al. 2013).
	- The followings indicators were selected to assess habitat condition 1.1 Riparian vegetation cover (%) 1.2 Habitat type 1.2.1 Bank characteristics 1.2.2 Channel type & morphology 1.2.3 Channel hydraulics 1.3 Habitat heterogeneity 1.4. Water quality
BIOTIC INTEGRITY	The criteria is an indicator measure of biodiversity, biotic assemblage, their sensitivity to habitat alteration and ecosystem resilience.
	The correlation between species diversity and ecosystem stability as well as productivity is substantiated by several studies (Odum 1953, Gardner & Ashby 1970, May 1973). In effect, ecosystem health depends on the ability of communities to contain species, or functional groups, that are capable of differential response, and the greater the species diversity in an ecosystem the lesser is the risk of ecological collapse (Palmer et al. 2010, Mellin et al. 2014).
	Along with the diversity, the occurrence of nesting indicate undisturbed habitat condition (Partridge 1978). Thus, breeding bird nest abundance was taken as a criteria.
	Waterbirds are ideal bio-indicators and useful models for studying a variety of environmental problems (Newton 1995) as respond to environmental changes over many spatial scales (Temple and Wiens 1989). They are also well suited for long term monitoring (Carignan 2002).
	Their occurrence (Villard et al. 1995), abundance (Robbins et al. 1989, Mazerolle and Villard 1999) and reproductive success (Villard et al. 1993, Robinson et al. 1995) have been shown to be influenced by the nature and configuration of surrounding habitats. Ramsar criteria for evaluation of wetland condition are based on waterbird assemblage (Ramsar 1971).
	The diversity and occurrence of conservation significant species of higher vertebrate fauna including umbrella species are considered as indicators of biotic integrity (Launer & Murphy 1994).
	- Thus, the following indicators were selected to assess biotic integrity, 2.1 River dolphin abundance 2.2 Breeding bird diversity 2.3 Breeding bird nest abundance 2.4 Waterbird congregation 2.5 Waterbird diversity 2.6 Gharial abundance 2.7 Turtle abundance 2.8 Turtle diversity 2.9 Species richness

Criteria	Justification (References)
ANTHROPOGENIC INFLUENCE	Human impacts are one of the major drivers of ecosystem function degradation and decline, and therefore, should be considered a major factor attributing to the health of the ecosystem. In human dominated landscapes, unsustainable use and extraction of river's resources leads to loss of river function and therefore, health (Palmer et al. 2010, Jackson 2009).
	Nutrient enrichment through wastewater inflow (Sewage, industrial effluent), loss of riparian vegetation cover by agricultural clear felling and developmental activities, fishing and sand mining are some of the anthropogenic drivers that negatively influence river's health, which is reflected in the water quality. Hence, Biochemical oxygen demand (BOD), presence of Total Coliform (TC) bacteria and nitrate levels were chosen as indicators of anthropogenic influence (Karr 1999).
	Processes such as resistance to surface runoff, bank strength, sediment storage, bed stability, nutrient capture and stream morphology are especially important in landscapes dominated by agricultural or urban land cover, where nutrient input from upland ecosystems is typically high. Changes in land use and land cover may sometimes be irreversible and specific sections of the river can be highly vulnerable. Hence, extent of agriculture area and built-up area were taken as indicators of anthropogenic influence.
	These indicators were assessed based on the extent of area in the Basic Evaluation Unit*, numbers and occurrence record along the Ganga river within the study area.
	- The following indicators were selected to assess anthropogenic influence 3.1 Channel morphological alteration 3.2 Agricultural area 3.3 Built-up area 3.4 Wastewater discharge 3.5 Fishing activity 3.6 Sand mining 3.7 Biological oxygen demand 3.8 Nitrate 3.9 Total Coliform bacteria

*Basic Evaluation Unit (BEU): a 5 Km stretch along the river with 1 km buffer from high-flood zone on both the banks, thus a BEU has an area of 10 Km²

¹USEPA Aquatic Life Criteria (<https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>)

²CPCB Water Quality Monitoring Criteria (cpcb.nic.in)





CRITERIA, INDICATORS, THRESHOLD AND SCORE FOR EACH INDICATORS

REHA Criteria	Indicators		Threshold Value		Score	Justification	Method
Habitat condition	Riparian vegetation cover	Cover percentage	< 15% 15-30% > 30%	Poor Fair Good	1 2 3	Indian Forest Policy (1998) suggests at least 30% intact forest cover in the plains. The riparian cover in the BEU along the Ganga River varied between 0 to 33.7%. Thus the highest achievable target threshold was taken at 30%.	Vegetation area extraction through NDVI from satellite imageries
	Bank characteristics	Sandy Clayey-loamy Meander Braid Channel island	- - - - -	- - - - -	4 2 2 2 2	Habitat types were determined during field survey along the Ganga river during 2017-18. The individual values of the parameters from field observations were weighted according to their importance for species diversity and assemblage.	Ecological survey
	Channel hydraulics	Shallow (< 2m) Medium pool (2-4 m) Deep pool (> 4 m)	- - -	- - -	3 3 5	For channel depth, highest threshold was taken at > 4 m depth to ensure suitable habitat along at least 60-80% of the river from Bijnor, Uttar Pradesh to Nurgpur in West Bengal, based on the depth preference of Endangered umbrella species, viz., gharial and river dolphin (Hussain et al. 2011).	Sonar or Doppler-based instruments to get bathymetric information from fixed and representative locations.
		Flow ($\text{m}^3 \text{s}^{-1}$)	< 80 80-160 > 160	Poor Fair Good	1 2 3	Highest threshold level of >150 m^3/s flow was considered based on optimal streamflow regime and flow preference of Gangetic river dolphin (Hussain et al. 2011). This will maximize habitat availability for such umbrella species along with other species and ensure suitable habitat for at least 60-80% along the river from Bijnor, Uttar Pradesh to Nurgpur in West Bengal.	Sonar or Doppler-based instruments to get bathymetric information from fixed and representative locations.
	Water quality	DO (mg/L)	<5 5-6 >6	Poor Fair Good	1 2 3	DO level below 2 mg/L leads to DO-stress and is lethal for most of	Physio-chemical water quality assessment

REHA Criteria	Indicators		Threshold Value		Score	Justification	Method
Habitat condition						the species (Allan & Maguire 1991). While, DO level of <5 is ideal for aquatic life (USEPA Aquatic Life Criteria). Thus a DO level of < 5 was taken as lowest and >6 was taken as highest threshold.	following standard testing method prescribed by APHA (American Public Health Association).
	pH		<6 & >9 8.5 - 9 >7 -8.5	Poor Fair Good	1 2 3	USEPA suggests chronic threshold at 6.5-9. While, CPCB suggest threshold at 6.5-8.5 for Bathing Class suitable for human usage as well as aquatic life. Any variation in pH beyond the suggested threshold brings in acid-base and ionic imbalance and restricts aquatic species diversity and assemblage. Thus, threshold of > 7-8.5 was considered as ideal.	Physio-chemical water quality assessment by following standard testing method prescribed by APHA (American Public Health Association).
	Habitat heterogeneity	Diversity Score	None		Actual value	Added values of bank characteristics, Channel type & morphology	Ecological survey
Biotic integrity	River dolphin abundance (nos.)	Frequency per Km 2-8 >8	< 2 2-8 >8	Poor Fair Good	1 2 3	Encounter rate of river dolphins in the Ganga river and its basin rivers varied from 0.04 individuals/km in Sindh to 1.62 individuals/km from Buxar to Maniharighat in the Ganga River (WII-GACMC, 2018). During field surveys in 2018, the encounter rate ranged from 0.2 to 8.4. Considering the habitat fragmentation by barrages, reduced flow condition and habitat heterogeneity, 2 individuals per km of the study stretch was taken as lower threshold in ideal conditions.	Ecological survey
	Breeding bird diversity	Diversity Value	<0.12 0.12 - 0.46 >0.46	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold value.	Ecological survey
	Breeding bird nest abundance (nos.)	Frequency per Km	< 8 8 - 40 >40	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold value.	Ecological survey



REHA Criteria	Indicators		Threshold Value		Score	Justification	Method
Biotic integrity	Waterbird congregation (nos.)	Frequency per km	< 13 13-137 >137	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold value	Ecological survey
	Waterbird diversity	Diversity Value	< 0.7 0.7- 1.4 >1.4	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold value.	Ecological survey
	Gharial abundance (nos.)	Frequency per km	0 0-2 >2	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold value.	Ecological survey
	Turtle abundance (nos.)	Frequency per km	< 9 9-33 >33	Poor Fair Good	1 2 3	Turtle abundance ranged from 1 to 778 individuals within the BEU, quartile analysis was undertaken to determine the threshold value.	Ecological survey
	Turtle diversity	Diversity Value	<0.05 0.05 - 0.15 >0.15	Poor Fair Good	1 2 3	Thirteen species of freshwater turtles are found in the Ganga River, however, co-existence of species varies greatly, which determines the diversity value. During field survey, the diversity value ranged from 0.02 to 0.3, with a mean value of 0.15. Quartile analysis was undertaken to determine the threshold values.	Ecological survey
	Species richness	Richness Value	<2.5 2.5 - 4.4 >4.4	Poor Fair Good	1 2 3	Quartile analysis was undertaken to determine the threshold values.	Ecological survey
Anthro-pogenic influence	Channel morphological alteration (Km)	Length of stretch altered	0 >0	Low pressure High pressure	0 5	It is assumed that the higher the morphological integrity, the higher is the ecological health, hence any length of the river that has undergone morphological alteration was considered to have high pressure.	Assessment of physical extent of dry and/or inundated river channel.
	Agricultural area (m ²)	Percent length of stretch with agriculture area	<5% 5-10% >10%	Low pressure Medium pressure High pressure	1 2 3	Changes in land use and land cover may sometimes be irreversible and hampers the ecological functions that occurs at the interface of terrestrial	Area extraction through NDVI from satellite imageries.

REHA Criteria	Indicators		Threshold Value		Score	Justification	Method
Anthro-pogenic influence						and aquatic systems within a riverine ecosystem. Thus BEU with < 5% area under agriculture was taken as lower threshold, while the BEU with > 10% agriculture upper threshold.	
	Built-up area (m ²)	Percent length of stretch with built-up area	<5% 5 -7% >7%	Low pressure Medium pressure High pressure	1 2 3	Changes in land use and land cover may sometimes be irreversible and hampers the ecological functions that occurs at the interface of terrestrial and aquatic systems within a riverine ecosystem. The Ganga river basin has a total built-up area of 4.28%, thus BEU with < 5% area under built-up area was taken as lower threshold, while the BEU with > 7% built-up area was taken as upper threshold.	Area extraction through NDVI from satellite imageries.
	Wastewater discharge (nos.)	Frequency per km	0 >0	Low pressure High pressure	0 5	Wastewater discharge is highly detrimental for the aquatic ecosystem, thus presence of wastewater discharge was scored as 5 and was taken as the threshold value.	Ecological survey
	Fishing activity	Frequency per km	0 0-2 > 2	No pressure Low pressure High pressure	0 2 3	Presence of fishing gear and fishing boat were taken as indicators of fishing activity. Absence of any fishing activity is the most desired state and was hence taken as no pressure, whereas presence of more than two fishing instances in a BEU was considered to be a high pressure and an unfavorable scenario.	Ecological survey
	Sand mining	Frequency per km	<0.2 0.2-0.3 >0.3	Low pressure Medium pressure High pressure	1	Sand mining frequency in the study area varied from 0.2 to 3.8, with an average of 0.3 per km. Hence, mining frequency of < 0.2 was taken as low pressure, whereas frequency	Ecological survey



REHA Criteria	Indicators		Threshold Value		Score	Justification	Method
Anthro-pogenic influence	Pollution	BOD (mg/L)	>3	High organic load	3	of >0.3 was taken as high pressure and an unfavorable scenario.	Physio-chemical water quality assessment by following standard testing method prescribed by APHA.
			>2-3	Moderate organic load	2	CPCB suggests BOD threshold of < 2 to < 3 (mg/L) for bathing class water suitable for human usage as well as aquatic life. Hence, < 2 was taken as the most desired state, while a BOD above 3 mg/L was considered undesirable.	
			<2	Low organic load	1		
		Nitrate (mg/L)	>10	High nutrient load	3	McCoy (1972) suggests desirable nitrate levels for warm water fishes to be 5 mg/L or below, while Camargo et al. (2005) suggested that 2mg/L of nitrate would be appropriate for the most sensitive freshwater species. Whereas nitrate level > 10 mg/L is known to adversely impact freshwater species (Camargo et al 2005).	
			>2-10	Moderate nutrient load	2		
			<2	Low nutrient load	1		
		TC (MPN/ 100ml)	> 5000	High microbial contamination	3	CPCB suggests TC threshold of < 500 upto 5000 (MPN/100 ml) for bathing class water suitable for human use as well as aquatic life. Hence, < 500 was taken as the most desired state.	
			>500 - 5000	Medium microbial contamination	2		
			≤ 500	Low microbial contamination	1		

¹USEPA Aquatic Life Criteria (<https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>)

²CPCB Water Quality Monitoring Criteria (cpcb.nic.in)

ECOLOGICAL HEALTH CLASS, RANGE OF SCORE AND MANAGEMENT PRESCRIPTIONS

Ecological Health Class	Score range	Color code	Defining benchmarks	Management Prescriptions	
				Definite	Broad-spectrum
A (Very Good)	> 95		1. Less altered riparian . vegetation cover 2. Greater habitat heterogeneity. 3. Near natural channel morphology and hydraulics 4. Minimal altered flow regime and good water quality. 5. High species abundance and diversity. 6. Occurrence of breeding of species of conservation concern. 7. Act as source population for key aquatic species. 8. Minimum anthropogenic influence.	1. Prioritize for protection under the provisions of the Indian Wild Life (Protection) Act, 1972 and Environmental (Protection) Act, 1986. 2. Potential reintroduction site for conservation dependent species. 3. Prohibition of any new impoundments, or diversion or extraction of water. 4. Prohibition on conversion of riparian vegetation cover to other land uses. Afforestation measures to increase riparian vegetation cover. 5. Prohibition of wastewater inflow, sand mining, dredging, agriculture in river bank, river bed and floodplain, large-scale commercial and destructive fishing practices, poaching.	1. Science-based afforestation measures. 2. Promotion of sustainable way of agriculture (organic fertilizers, pesticides), sustainable cropping pattern, efficient water use, water conservation. 3. Community engagement in conservation and provision of alternate livelihood sources. 4. Prohibition of illegal poaching of aquatic fauna, especially conservation dependent species among local communities.
B (Good)	>37.6 - 95		1. Moderately altered riparian vegetation cover 2. Largely intact riverine habitat supporting species diversity and assemblage. 3. Occurrence of breeding of species of conservation concern. 4. Moderately altered flow regime and good water quality. 5. Moderate anthropogenic influences.	1. High biodiversity river stretches with upland riparian buffer may be declared as Eco-sensitive zones after feasibility assessment. 2. Afforestation measures, restriction on large-scale commercial fishing, mining and conversion of forested area to other land use in eco-sensitive zones. 3. Restriction of impoundments, or diversion or extraction of water. 4. Curtailment of anthropogenic activities that contribute to deterioration of habitat, water quality and biodiversity loss. 5. Reintroduction of conservation dependent species after addressing and mitigating anthropogenic influences.	5. Reduction in river resource dependency through technological and livelihood interventions.



Ecological Health Class	Score range	Color code	Defining benchmarks	Management Prescriptions	
				Definite	Broad-spectrum
C (Fair)	>17.6 - 37.6		1. Altered riparian vegetation cover. 2. Disturbed habitat, as well as breeding/ spawning grounds due to altered flow regime and water quality. 3. Reduced habitat heterogeneity and availability. 4. Lower than expected species diversity and richness. 5. Less occurrence of key aquatic species sensitive to environmental degradation. 6. Anthropogenic activities negatively influence the river ecosystem and biota.	1. Afforestation measures to increase riparian vegetation cover. 2. Regulation of impoundments, or diversion or extraction of water. 3. Restriction of anthropogenic activities that contribute to deterioration of habitat, water quality and biodiversity loss. 4. Habitat and species restoration measures may be adopted.	
D (Poor)	< 17.6		1. Highly altered riparian vegetation cover, dominance of agriculture and built up area in floodplain and catchment. 2. Altered channel morphology and hydraulics, loss of habitat. 3. Highly altered natural flow regime, barriers for upstream movement and migration. 4. Loss of biodiversity, reduced species richness, no instances of breeding of key aquatic species. 5. Poor water quality, potential for mass mortality of sensitive aquatic species. 6. Anthropogenic activities altered the river ecosystem and biota.	1. Extensive habitat restoration measures in terms of afforestation in floodplain and catchment, complete check in wastewater inflow from point and non-point sources, solid waste management measures, regulation of floodplain river bank and river bed agriculture, promotion of organic farming. 2. Restriction of impoundments, or diversion or extraction of water. 3. Regulation of anthropogenic activities that contribute to deterioration of hydro-geo-morphology of the river.	

ACHIEVABLE ECOLOGICAL HEALTH SCORE (AEHS)



■ Habitat 18
■ Biotic Integrity, 58
■ Anthropogenic Influence, 11

The achievable score takes into account the biotic integrity a habitat can support, under the current circumstances of infrastructure development. Thus AEHS is equivalent to the ecological health of least disturbed sites/BEUs, if best possible management practices are adopted. The lower limit of AEHS is set by the Critical Ecological Health Score (CEHS), which calls for immediate need for management intervention. Thus in BEUs with habitat score above achievable and biotic integrity score below critical level, species restoration measures should be adopted. While in BEUs with habitat score below achievable level, habitat improvement measures need to be adopted.

CRITICAL ECOLOGICAL HEALTH SCORE (CEHS)



■ Habitat 14
■ Biotic Integrity, 24
■ Anthropogenic Influence, 19

CONSERVATION PRIORITY ZONE ALONG WITH GANGA RIVER

Conservation priority zones	Location		Length (km)	Prescription
	From	To		
1	Abusaidpur, Bijnor, Uttar Pradesh (50 km from Haridwar)	Bangarpur, Amroha, Uttar Pradesh (155 km from Haridwar)	110	- This stretch is a part of the Hastinapur Wildlife Sanctuary. - It can be designated as a potential rehabilitation site for conservation dependent species such as gharial and turtles. - Agriculture along the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - This stretch can be also be developed for eco-tourism under the purview of Arth Ganga.
2	Sisaiganj, Aligarh, Uttar Pradesh (245 km from Haridwar)	Rikera, Kasganj, Uttar Pradesh (305 km from Haridwar)	65	- This stretch has good congregations of waterbirds and turtles, and thus may be designated as a Conservation Reserve. - This site offers good habitat conditions for conservation dependent species, hence may be taken up as a potential reintroduction site. - Community based in-situ conservation of turtles and communal nesting islands of turtles as well as resident waterbirds may be carried out. - Agriculture along the river bank is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed.
3	Kaimganj, Farukhabad, Uttar Pradesh (350 km from Haridwar)	Kannauj, Uttar Pradesh (450 km from Haridwar)	105	- This stretch may be designated as eco-sensitive area (ESA) as it includes the confluence with Ramganga River, providing connectivity (corridor for movement of aquatic species) and contributing about 29% to the flow of the mainstem Ganga. - The stretch also supports a good population of waterbirds and turtles, hence may be protected as Conservation Reserve. - Flow augmentation in the Ramganga River through the restoration and revival of wetlands, and afforestation to augment riparian cover would contribute to the flow of the Ganga River. - TC increased in this stretch downstream of Ramganga confluence, hence there is an urgent need to check on wastewater inflow from point sources (drains) along the Ramganga River. - Agriculture along the river bank and in the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods.
4	Saharia Salempur Gairis, Unnao, Uttar Pradesh (485 km from Haridwar)	Ghahpur, Kanpur, Uttar Pradesh (510 km from Haridwar)	30	- This stretch has good habitat conditions except for high TC, hence there is an urgent need to check on wastewater inflow from point and non-point sources before this stretch as well as along this stretch. - The stretch is a potential rehabilitation site for key aquatic species. - Agriculture along the river bank and in the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods.

Conservation priority zones	Location		Length (km)	Prescription
	From	To		
5	Haripur, Rae Bareli, Uttar Pradesh (585 km from Haridwar)	Tanda, Fatehpur, Uttar Pradesh (610 km from Haridwar)	30	- The stretch has high habitat heterogeneity with a good combination of deep and medium pools, and hence Gangetic dolphins are frequently sighted. In view of this, the stretch may be designated as eco-sensitive area (ESA) and eco-tourism under the purview of Arth Ganga may be promoted. - TC is high in this stretch due to sewage inflow from Kanpur city, hence the wastewater inflow from point sources (drains) needs to be checked. - Agriculture along the river bank and in the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods.
6	Gospur Kachhar, Kaushambi, Uttar Pradesh (725 km from Haridwar)	Mand, Prayagraj, Uttar Pradesh (785 km from Haridwar)	65	- Yamuna and Tamas confluences provide connectivity (corridor for movement of aquatic species) and substantial flow to the mainstem Ganga in this stretch. Communal nesting islands of turtles as well as resident waterbirds along this stretch need protection. - This stretch may be declared as eco-sensitive area (ESA) and construction of any permanent structure may be prohibited and/or regulated. - TC is high in this stretch due to sewage inflow from Prayagraj city, hence the wastewater inflow from point sources (drains) needs to be checked. - Eco-tourism may be promoted under the purview of the Arth Ganga programme. - Agriculture along the river bank and in the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - This stretch falls under National Waterway 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels.
7	Revelganj, Saran, Bihar (1195 km from Haridwar)	Patna, Bihar (1255 km from Haridwar)	65	- The river confluences (Ghaghara, Son and Gandak) in this stretch provide vital ecological connectivity and is prone to monsoonal floods. In view of this, these confluences may be designated as Eco-sensitive area (ESA). - TC is high in this stretch due to high influx from Patna city, hence the wastewater inflow from point and non-point sources need to be checked. - Resource extraction in this stretch needs to be regulated through provisions of the Bihar Fisheries Policy, 2008 and Environment (Protection) Act, 1986. - Agriculture along the river bank is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - This stretch falls under National Waterway 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels.

Conservation priority zones	Location		Length (km)	Prescription
	From	To		
8	Raghopur, Vaishali, Bihar (1275 km from Haridwar)	Barauni, Begusarai, Bihar (1335 km from Haridwar)	65	- Resource extraction in this stretch needs to be regulated through provisions of the Bihar Fisheries Policy, 2008 and Environment (Protection) Act, 1986. - Agriculture along the river bank is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - This stretch falls under National Waterway 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels.
9	Shahbegpur, Begusarai, Bihar (1380 km from Haridwar)	Bhagalpur, Bihar (1470 km from Haridwar)	95	- This stretch is located upstream of VGDS and may be designated as Eco-sensitive area (ESA) to provide a buffer to the Sanctuary from the high anthropogenic impacts along the stretch. - Agriculture along the river bank is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Resource extraction in this stretch needs to be regulated through provisions of the Bihar Fisheries Policy, 2008 and Environment (Protection) Act, 1986. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - To link livelihood of local communities with river and biodiversity conservation, eco-tourism may be promoted under the purview of Arth Ganga. - This stretch falls under National Waterway 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels.
10	Jot Talih, Katihar, Bihar (1540 km from Haridwar)	Rostampur, Maldah, West Bengal (1600 km from Haridwar)	65	- The Farraka barrage has resulted in stagnancy and sediment deposition upstream of the barrage. - Agriculture along the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Resource extraction in this stretch needs to be regulated through provisions of the Bihar Fisheries Policy, 2008, The West Bengal Inland Fisheries Act, 1984 and Environment (Protection) Act, 1986. - To link livelihood of local communities with river and biodiversity conservation, eco-tourism may be promoted under the purview of Arth Ganga. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - This stretch falls under National Waterway 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels.

Conservation priority zones	Location		Length (km)	Prescription
	From	To		
11	Amuha, Murshidabad, West Bengal (1650 km from Haridwar)	Maliapara, Murshidabad, West Bengal (1710 km from Haridwar)	65	- Agriculture along the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - High fishing intensity may pose threat to dolphin and turtle population and thus may be regulated through the provisions of the West Bengal Inland Fisheries Act, 1984. - This stretch falls under National Waterways 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels. - The stretch is part of the up-stream migratory route of the Hilsa, therefore regulation of the catch of the migrating population shall be enforced under the purview of the West Bengal Inland Fisheries Act, 1984.
12	Char Brajanathpur, Bardhaman, West Bengal (1815 km from Haridwar)	Jaluidanga, Nadia, West Bengal (1885 km from Haridwar)	75	- The stretch is downstream of confluence with Ajay river. - Agriculture along the riverbed is high that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - To link livelihood of local communities with river and biodiversity conservation, eco-tourism may be promoted under the purview of Arth Ganga. - High fishing intensity may pose threat to dolphin and turtle population and thus may be regulated through the provisions of West Bengal Inland Fisheries Act, 1984. - This stretch falls under National Waterways 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels. - The stretch is up-stream migratory route of the Hilsa, therefore regulation of the catch of the migrating population shall be enforced under the purview of the West Bengal Inland Fisheries Act, 1984.
13	Maheshtala, South 24 Pargana, West Bengal (2020 km from Haridwar)	Burul, South 24 Pargana, West Bengal (2045 from Haridwar)	30	- Agriculture along the riverbed is moderate that has the potential of conversion into an organic system, provided that linkages with agencies that build capacity for organic farming and certification of organic products are developed. - TC is high in this stretch due to sewage inflow from Kolkata city, hence the wastewater inflow from point sources (drain) needs to be checked. - Fishermen may be sensitized and involved in conservation activities and their capacities may be developed in alternate or secondary livelihoods. - High fishing intensity may pose threat to dolphin and turtle population and thus may be regulated through the provisions of West Bengal Inland Fisheries Act, 1984. - This stretch falls under National Waterways 1 and hence preventive and corrective actions may be adopted to avoid accidental mortality of key aquatic species, water pollution, wave and wake, underwater noise and sediment resuspension from the movement of large vessels. - The stretch is up-stream migratory route of the Hilsa, therefore regulation of the catch of the migrating population shall be enforced under the purview of the West Bengal Inland Fisheries Act, 1984.

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