Ganga River Basin Management Plan - 2015

Mission 3: Ecological Restoration

January 2015

by

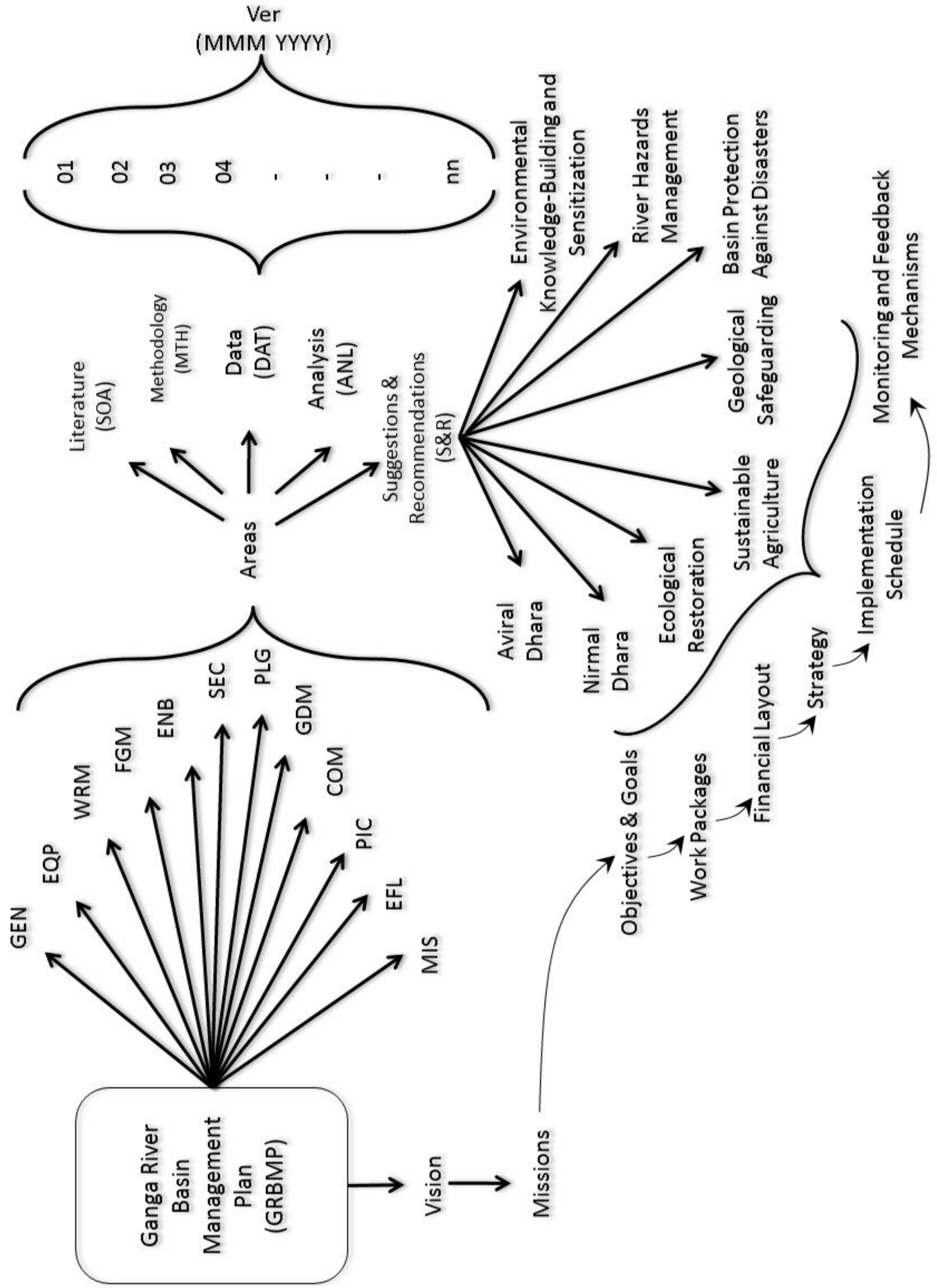
Consortium of 7 "Indian Institute of Technology"s (IITs)

IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

In Collaboration with

IIT BHU | IIT Gandhinagar | CIFRI | NEERI | JNU | PU | NIT-K | DU | NIH Roorkee | ISI Kolkata | Allahabad University | WWF India

GRBMP Work Structure



Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government constituted the National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of River Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin Management Plan (GRBMP). A Consortium of seven "Indian Institute of Technology"s (IITs) was given the responsibility of preparing the GRBMP by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. A Memorandum of Agreement (MoA) was therefore signed between the 7 IITs (IITs Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

The GRBMP is presented as a 3-tier set of documents. The three tiers comprise of: (i) Thematic Reports (TRs) providing inputs for different Missions, (ii) Mission Reports (MRs) documenting the requirements and actions for specific missions, and (iii) the Main Plan Document (MPD) synthesizing background information with the main conclusions and recommendations emanating from the Thematic and Mission Reports. It is hoped that this modular structure will make the Plan easier to comprehend and implement in a systematic manner.

There are two aspects to the development of GRBMP that deserve special mention. Firstly, the GRBMP is based mostly on secondary information obtained from governmental and other sources rather than on primary data collected by IIT Consortium. Likewise, most ideas and concepts used are not original but based on literature and other sources. Thus, on the whole, the GRBMP and its reports are an attempt to dig into the world's collective wisdom and distil relevant truths about the complex problem of Ganga River Basin Management and solutions thereof.

Secondly, many dedicated people spent hours discussing major concerns, issues and solutions to the problems addressed in GRBMP. Their dedication led to the preparation of a comprehensive GRBMP that hopes to articulate the outcome of the dialog in a meaningful way. Thus, directly or indirectly, many people contributed significantly to the preparation of GRBMP. The GRBMP therefore truly is an outcome of collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team and of the associate organizations as well as many government departments and individuals.

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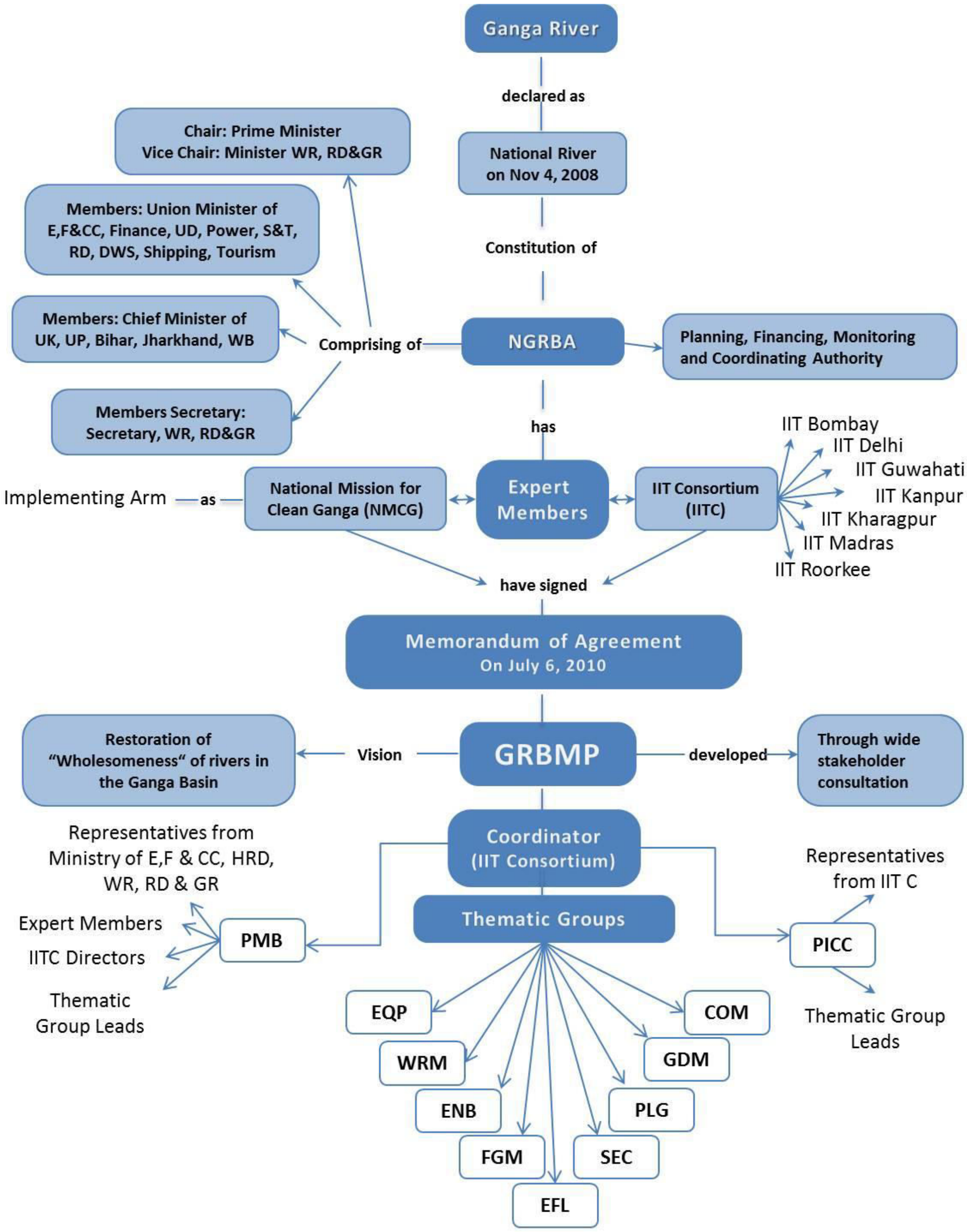
Organizational Structure for Preparing GRBMP



NGRBA: National Ganga River Basin Authority
NMCG: National Mission for Clean Ganga
MoEF: Ministry of Environment and Forests
MHRD: Ministry of Human Resource and Development
MoWR, RD&GR: Ministry of Water Resources, River Development and Ganga Rejuvenation
GRBMP: Ganga River Basin Management Plan
IITC: IIT Consortium
PMB: Project Management Board
PICC: Project Implementation and Coordination Committee

EQP: Environmental Quality and Pollution
WRM: Water Resources Management
ENB: Ecology and Biodiversity
FGM: Fluvial Geomorphology
EFL: Environmental Flows
SEC: Socio Economic and Cultural
PLG: Policy Law and Governance
GDM: Geospatial Database Management
COM: Communication

Project Management Board [PMB]

Expert Members:

- Sri Swami Avimukteshwaranand Saraswati
- Dr Madhav A Chitale
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Project Implementation and Coordination Committee [PICC]

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- Dr Purnendu Bose, Environmental Quality and Pollution (EQP)
- Dr A K Gosain, Water Resources Management (WRM)
- Dr R P Mathur, Ecology and Biodiversity (ENB)
- Dr Rajiv Sinha, Fluvial Geomorphology (FGM)
- Dr Vinod Tare, Environmental Flows (EFL)
- Dr S P Singh, Socio Economic and Cultural (SEC)
- Dr N C Narayanan and Dr Indrajit Dube, Policy Law and Governance (PLG)
- Dr Harish Karnick, Geospatial Database Management (GDM)
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8. Communication (COM)

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Members: Purnendu Bose, Rajiv Sinha, Vinod Tare (IIT Kanpur)

9. Environmental Flows (EFL)

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Abbreviations and Acronyms

1.	CF	:	Cat Fish.
2.	GRBMP	:	Ganga River Basin Management Plan.
3.	IITC	:	IIT Consortium.
4.	IMC	:	Indian Major Carp (fish).
5.	MOA	:	Ministry of Agriculture
6.	MoEF	:	Ministry of Environment and Forests
7.	MoEFCC	:	Ministry of Environment, Forests & Climate Change
8.	MoWR	:	Ministry of Water Resources (Govt. of India).
9.	MoWRRDGR	:	Ministry of Water Resources, River Development & Ganga Rejuvenation
10.	NGO	:	Non-Governmental Organization.
11.	NGRBA	:	National Ganga River Basin Authority.
12.	NMCG	:	National Mission for Clean Ganga.
13.	NRGB	:	National River Ganga Basin.
14.	RET	:	Rare, Endangered, Threatened (species).
15.	ROR	:	Run-Of-the-River.
16.	UNEP	:	United Nations Environment Programme.
17.	UPID	:	Uttar Pradesh Irrigation Department.

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Summary

The Ganga River Network was adopted as the primary indicator of health of the National River Ganga Basin (NRGB) in GRBMP, and human-technology-environment factors were considered to assess the basin's resource dynamics. Ecological restoration of National River Ganga is urgently needed since river biodiversity is being rapidly lost. Eight main factors affecting the river habitat are identified for this loss**:** (i) Habitat Fragmentation by dams and barrages; (ii) Habitat Shrinkage due to increased water diversions and withdrawals; (iii) Habitat Alterations by constructing embankments, levees, guide walls, etc.; (iv) Habitat Pollution by influx of municipal, industrial and agricultural wastes; (v) Habitat Invasion by alien river species; (vi) Habitat Encroachment by constructions in floodplains and river bed farming; (vii) Habitat Disturbances by plying of noisy vessels, dredging, etc.; and (viii) Habitat Malnutrition by the trapping of nutrient-rich sediments behind dams. Hence, the measures recommended are**:** restoration of longitudinal connectivity along with E-flows across dams/ barrages; maintenance of lateral connectivity across floodplains; restoration of unpolluted river flows; restrictions on river bed farming, gravel and sand mining, plying of vessels, dredging, and bed and bank modifications; control of alien species invasions, overfishing and fishing during spawning seasons; river nutrient assessment and release of dammed sediments into the river; bio-monitoring of Ganga river network; and synergising actions with the ongoing Dolphin Conservation Action Plan.

1. Introduction

Indian civilization grew up under the care of River Ganga, nourished by her bounties for thousands of years. The Ganga river – along with her many tributaries and distributaries – provided material, spiritual and cultural sustenance to millions of people who lived in her basin or partook of her beneficence from time to time. To the traditional Indian mind, therefore, River Ganga is not only the holiest of rivers and savior of mortal beings, she is also a living Goddess. Very aptly is she personified in Indian consciousness as "MOTHER GANGA". This psychic pre-eminence of River Ganga in the Indian ethos testifies to her centrality in Indian civilization and her supreme importance in Indian life.

The Ganga river basin is the largest river basin of India that covers a diverse landscape, reflecting the cultural and geographical diversity of the India. It is also a fertile and relatively water-rich alluvial basin that hosts about 43% of India's population [*MoWR, 2014*]. It is fitting, therefore, that the Indian government declared River Ganga as India's **National River** in the year 2008. But the declaration was none too early. River Ganga had been degrading rapidly for a long time, and national concern about her state had already become serious in the twentieth century. It was against this backdrop that the Ministry of Environment and Forests (Govt. of India) assigned the task of preparing a Ganga River Basin Management Plan (GRBMP) to restore and preserve National River Ganga to a "Consortium of Seven IITs". The outcome of this effort – the GRBMP – evolved an eight-pronged action plan, with each prong envisaged to be taken up for execution in mission mode.

A river basin is the area of land from which the river provides the only exit route for surface water flows. For understanding its dynamics, a basin may be viewed as a closely-connected hydrological-ecological system. Hydrological connections include groundwater flow, surface runoff, local/ regional evapotranspiration-precipitation cycles and areal flooding, while ecological links are many and varied (such as the food web and transport by biological agents). These linkages provide for extensive material transfer and communication between the river and her basin, which constitute the functional unity of a river basin. Directly and indirectly, therefore, National

River Ganga (along with her tributaries and distributaries), is a definitive indication of the health of the basin as a whole. Hence, GRBMP adopted the Ganga River Network as the primary environmental indicator of the National River Ganga Basin (NRGB).

River basin management needs to ensure that a basin's natural resources (biotic and abiotic) are adequately preserved over time. The main abiotic (or physical) resources of a river basin are *soil* and *water*, along with a multitude of minerals and compounds bound up with them. Now, water is a highly variable resource. Barring variations from year to year, the water in a basin follows an annual cycle of replenishment (primarily through atmospheric precipitation and groundwater inflows) and losses (primarily through river and groundwater outflows, evaporation, transpiration, and biological consumption). In contrast to water, formation of mature soils – from the weathering of parent material (rocks) to chemical decomposition and transformation – is a drawn-out process that may take hundreds or thousands of years [*Jenny, 1994; Wikipedia, 2014*]; but, once formed, soils can be fairly durable. Thus, changes in a basin's water resource status tend to be relatively faster and easily detected, while those of soils are slow and often go unnoticed for long periods. However, soil and water are affected by each other through many biotic and abiotic processes. Being thus interrelated, degradation of either soil or water has a concurrent effect on the other, hence neither can be considered in isolation.

It is not only soil and water that are mutually interactive, living organisms also interact with them and help shape the basin's environment. The biotic resources of a basin consist of plants, animals and micro-organisms. Since biota evolve over time to achieve a stable balance in a given environmental setting, the biotic resources of a river basin depend on its constituent ecosystems – rivers, wetlands, forests, grasslands, etc. However, with significant human activity in many ecosystems (as, for example, in agro-ecosystems and urban ecosystems), the complexity of human-technology-environment systems has increased manifold [*Pahl-Wostl, 2006*]. Nonetheless, GRBMP attempts to incorporate interactive natural resource dynamics and human-technology-environment considerations in the Basin Plan. For, with human activities multiplying and diversifying in the basin, the resulting environmental consequences have also been pronounced in recent times. In sum, GRBMP focuses on the basin's overall resource environment and the major factors affecting it (especially diverse anthropogenic activities), and seeks ways and means to protect the basin and its resources against identifiable adverse impacts. For, only thus can we secure the environmental foundation of NRGB for the good of one and all.

2. Objective

The objective of Mission "Ecological Restoration" is to restore the ecological balance of National River Ganga and provide an enabling environment for endemic flora, fauna and microorganisms to thrive in the Ganga river network.

3. Why Ecological Restoration is Important for Ganga River Basin Management

Significant loss of species biodiversity in the Ganga river network has been observed over the past many decades, with many important aquatic species (fishes, dolphins, ghariyals, turtles, etc.) having dwindled or disappeared from river stretches in recent history. Now, a river ecosystem – with its intrinsic biodiversity – plays a crucial role in the functional health of the river basin and the ecosystem services provided by the river. A basic idea of the biodiversity loss in a part of National River Ganga may be inferred from Figure 1 showing the progressive loss of fish catch at Allahabad since 1950.

To grasp the biodiversity changes in National River Ganga and devise suitable means to restore her ecological balance, it is necessary to understand the dynamics of the Ganga river ecosystem and assess the possible anthropogenic and non-anthropogenic factors affecting it. Broadly, an ecosystem is a community of living organisms (plants, animals and microbes) in conjunction and interacting with nonliving components of their environment [*Wikipedia, 2014*]. The biotic and abiotic components are linked together through nutrient cycles and energy flows**:** energy and carbon enter the ecosystems through photosynthesis, while mineral nutrients are mostly recycled within the ecosystems. Now ecosystems are controlled both by external factors (or "state factors" such as climate, underlying geological material, topography and time) and internal factors (such as decomposition, periodic disturbances, species competition and human activities). Since ecosystem processes are driven by the types and number of species in an ecosystem and the relative abundance of organisms within these species, hence species biodiversity plays an important role in ecosystem functioning.

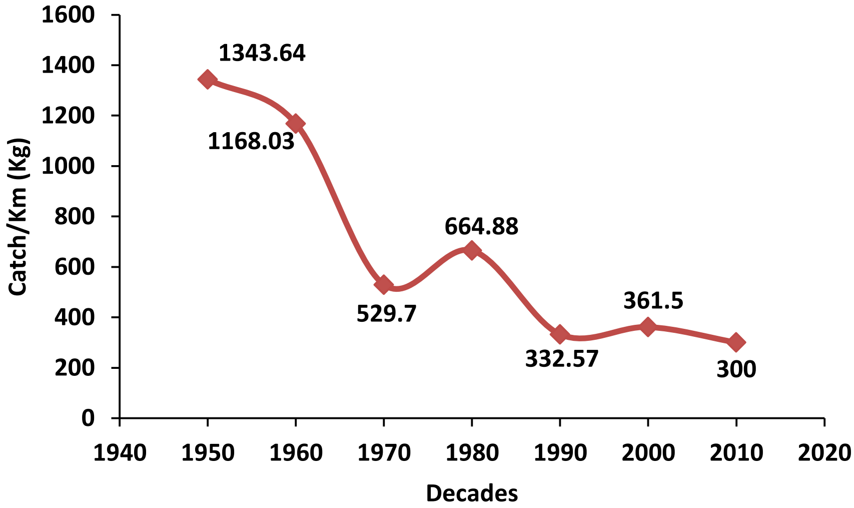


Figure 1: Decline of Fish Catch per km at Allahabad between 1950 to 2010 [IITC, 2014]

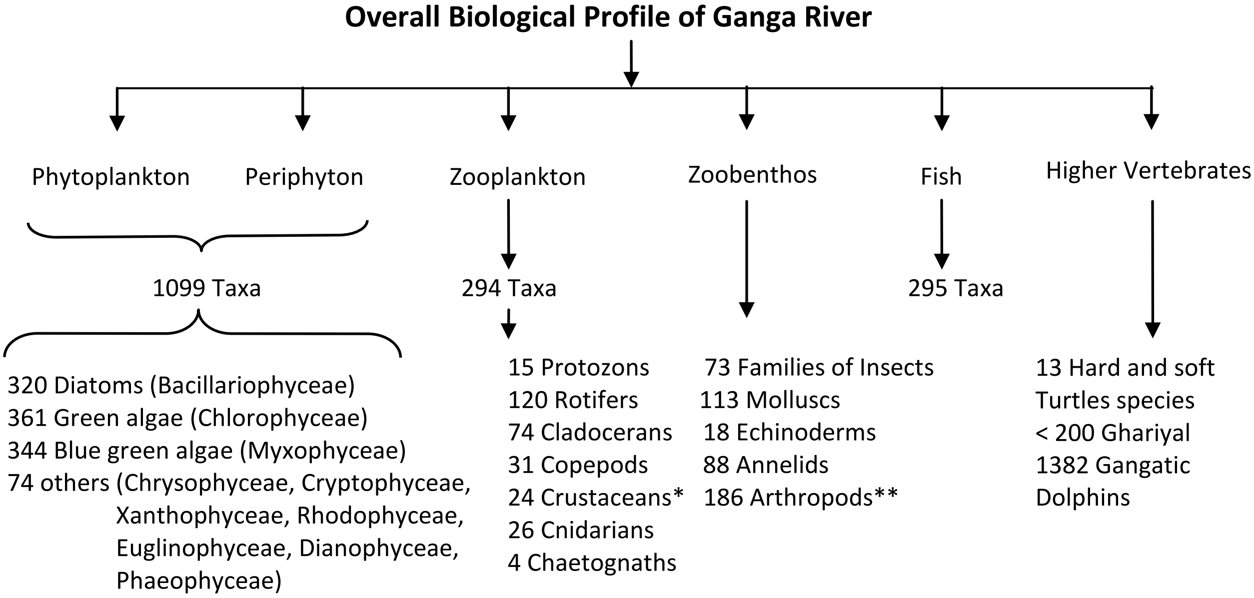
In general, ecosystems can be assessed either in terms of the services (or goods and services) they provide to humans, or in terms of "ecosystem structure" (i.e. measurable attributes of a least impacted or reference state of the ecosystem). However, as noted by Palmer and Febria [*2008*], the former as indicator of ecosystem health is an oversimplification of the ecosystems services concept; on the other hand universally applicable structural metrics of river health are yet to be developed. Nonetheless, the latter approach is more prevalent, and the taxonomic composition of aquatic biota – from microbes that influence decomposition to aquatic animals that shred leaf litter – is an important structural metric for ecosystem health assessment [*Palmer and Febria, 2008*]. Thus, the species biodiversity of a river is an important indicator of the functional health of river ecosystems. Restoring the Ganga river's biodiversity to its earlier state is therefore of critical importance for the ecological balance of the river network.

The Ganga river being a diverse landscape-scale ecosystem, it is not easy to decipher her ecology in detail. To start with, the river traverses three distinct climatic-geographical zones from the snow-clad and alpine Himalayan reaches to the tropical alluvial plains until she enters the estuarine zone and meets the sea. Ecologically, the diversity of the basin within each climatic zone plays an overarching role on River Ganga. For while a river's ecosystem boundary may be nominally demarcated by the river banks, there are varying degrees of (but often close) biotic and abiotic interactions of the river with her riparian zones, flood plains and drainage basin. The saturated sub-surface zone under the river bed also forms a unique habitat (termed "hyporheic biotope") for a diverse group of fauna, which also provides temporary refuge for aquatic organisms in times of adversity and plays an important role in the processing of river nutrients and interacting with groundwater [*Gopal and Chauhan, 2013*]. Without detailed primary studies of these components and the interactive processes in the river basin, only a general understanding of the river's ecological balance is possible from available historical data.

4. Ecological Status of National River Ganga

National River Ganga and her tributaries are home to a wide variety of aquatic organisms (from microscopic flora and fauna to higher invertebrates and vertebrates) and visited periodically by many other creatures from far and near. The status of flora and fauna of River Ganga and her riparian zones has been documented in several Thematic Reports of GRBMP [IITC, 2011*;* IITC, 2012a-g; IITC, 2014.]. Basic information culled from these documents is presented here to inform the specific eco-restoration measures needed for the river. The overall biological profile of River Ganga is depicted in Figure 2. The biodiversity of River Ganga is unique, as it synthesizes three major eco-regions of India situated along different climatic gradients, namely**:** the Himalayan mountainous region in the upper reach, the Gangetic plains in the middle reach, and the estuarine region (including the Hooghly-Matlah delta) in the lower reach. These regions – apart from differing climatically – also have different geologic characteristics and evolutionary histories. Thus, while the overall biological profile of the river covers a vast spectrum, the biota differs significantly in different reaches.

It should be noted here that Figure 2 is based on secondary information obtained from published and unpublished literature (including technical reports and academic theses) which generally do not pertain to the present-day river but to National River Ganga at different times and in different places. Therefore, not only are the data fragmentary, but many investigations may have missed out the identities of some species (especially small organisms in sediments and/or sediment water interface) due to procedural and instrumental limitations then prevalent. Thus the above information may not be complete, but can only be considered as an approximate representation of the ecological profile of River Ganga before the construction of dams/ barrages in the upper Ganga region.



* Other crustaceans; ** Arthropods including (Crustacea, Ostracoda and Arachnida)

Figure 2: Biodiversity of River Ganga at a Glance

On the basis of available data, the present ecological scenario for four stretches of the main Ganga river are presented in Table 1, with distinctive characterization of biotic species in the stretches. The ecological parameters which are conspicuous by their presence or absence have been examined. And, though comparative historical data are not available, reasonable desired levels of the main river species are indicated in the table.

Table 1: Indicative Biological Profile of Different Stretches of River Ganga

River stretch	Algal ratio D* G* BG*	Specific Zoobenthos	Fish Families/ RET species	Carps/ Cat fishes / All Fish taxa	Characteristic fish species	Higher vertebrates
Upper Ganga **UG1 (Gangotri to Gangnani)**	100:6:0 (33, 2, 0) Total: 36 Other: 1	Plecoptera, Tricoptera, Ephemeroptera, Diptera	❖/ ❖	❖	❖	No Vertebrates
UG2 (Gangnani to Devprayag)	100:17:5 (123, 21, 6) Total: 151 Other: 1	Plecoptera, Tricoptera, Ephemeroptera, Diptera, Coleoptera	4/ 14	(23/6/35)	Snow Trout (*Schizothorax richardsonii*)	No Vertebrates
UG3 (Devprayag to Haridwar)	100:14:13 (95, 13, 12) Total: 123 Other: 3	Tricoptera, Ephemeroptera, Diptera, Odonata	12/ 8	(25/7/42)	Golden Mahseer *(Tor putitora)*	No Vertebrates
Middle Ganga MG1-MG3 (Haridwar to Fatehgarh)	100:36:15 (100,36, 15) Total: 154 Other: 3	Tricoptera, Ephemeroptera, Diptera, Odonata	25/ 15	(46/14/109)	Indian Major carps, Catfishes	Turtles, Ghariyals, Gangetic Dolphins
MG4-MG5 (Fatehgarh to Varanasi)	100:67:36 (149, 100, 54) Total: 322 Other: 119	Tricoptera, Coleoptera	24/ 12	(34/28/92)	Indian Major Carps, Catfishes	Gangetic Dolphins, Turtles
Lower Ganga **LGA (Varanasi-Farakka)**	100:118: 105 (81, 96, 85) Total: 285 Other: 23	Tricoptera, Ephemeroptera, Diptera, Coleoptera, Annelids, Mollusca	35/ 16	41/31/121)	Indian Major Carps, Catfishes	Dolphins, Turtles
LGB (Farakka-Ganga Sagar)	100:161: 220 (127, 205, 279) Total: 652 Other: 41	Thysanura, Collembola, Annelids, Mollusca, Echinoderms	37/ 12	(16/27/172)	IMC, Catfishes, Hilsa, *Polynems paradiseus*, *Liza parsia*, *Harpodon neherus*	Turtles, Ghariyals, Gangetic Dolphins, Porpoises, Crocodiles

❖ A couple of brown trout *Salmo trutta fario* were cited by Nautiyal (2007); D* G* BG*= Diatoms, Green algae, Blue green algae; RET= Rare, Endangered, Threatened; IMC= Indian major carps; CF= Cat fishes

5. Threats to Biodiversity of National River Ganga and their Remediation

Many factors affecting the ecological integrity of National River Ganga have been identified through GRBMP studies [*vide* IITC, 2014]. Together with additional information available for rivers the world over, seven critical factors – all of them anthropogenic – are of particular concern for National River Ganga's biodiversity. These factors – and the envisaged means to alleviate them – are described below.

5.1 Habitat Fragmentation

Throughout the world, many rivers have been affected in modern times due to direct manmade structural interferences in them. Over the past two centuries, the Ganga river network has been considerably fragmented by dams and barrages. Figure 3 shows major dams and barrages erected in the Ganga River Network [*MoWR, 2014*]. These obstructions slice the rivers into pieces, thereby interrupting the flow of water, nutrient, sediments and aquatic species in the rivers. In the Upper Ganga Basin, the obstructions include several *run-of-the-river* (ROR) hydro-electric projects in the Bhagirathi and Alaknanda head streams. The completed dams that are under operation are given in Table 2. In addition to these, a cascade of six more dams on River Alaknanda and four on River Bhagirathi are under construction, while many more projects on these rivers are proposed. Many of these projects are planned end to end, i.e. the tail waters of one project are head waters of the next one. The water stored behind a dam is sent through tunnels to turbines and released as tail waters at downstream points of the rivers. Thus, long stretches of rivers between dams and tail-water releases are almost devoid of water. Overall, an estimated 86 km length of River Bhagirathi is thus without any flow whatsoever. Besides, sediments get trapped behind the dams, thereby disrupting the downstream river's water-sediment balance and affecting nutrient flow and fertility of the downstream river.

Table 2: Major Hydro-Electric Projects on National River Ganga's Head-Streams [*IITC, 2014*]

Project	Installed capacity (MW)	Status	River
Vishunprayag	400	On	Alaknanda
Maneri Bhali I	99	On	Bhagirathi
Maneri Bhali II	304	On	Bhagirathi
Tehri	1000	On	Bhagirathi-Bhilangna confluence
Koteshwar	400	On	Bhagirathi

More than 70 hydropower projects (large and small dams) have been conceived in the Upper Ganga Basin, many of which are still in the planning stage. While there have been environmental impact studies of some individual dams, the only comprehensive study of their cumulative impact on aquatic and terrestrial biodiversity in the river sub-basins was attempted by the Wildlife Institute of India. However, the study had its shortcomings [*Rajvanshi, 2012; SANDRP, 2012*]. Moreover, it was limited in scope**:** for instance, its focus did not extend beyond the Bhaghirathi and Alaknanda sub-basins, so that the impact of the dams over the downstream river's ecology remained unexplored. It may be also noted here that, while many of these dams are small, the common notion that small dams have relatively insignificant impacts on river ecosystems is a misconception. In some cases, the cumulative impact of small dams may be more damaging to river ecosystems than those of large dams of equivalent power generation capacity [*Kibler and Tullos, 2013*].

Downstream of the hydroelectric projects in the Bhagirathi and Alaknanda basins, the Pashulok barrage on River Ganga near Rishikesh diverts nearly all the dry-weather flow of main Ganga river into the power channel of Chilla Power Station. The tail water of this power station joins the Ganga river near Bhoopatwala. Thus, a distance of about 15 km from Pashulok barrage to the junction of the tail waters with the river has no flow. Further downstream, Bhimgauda Barrage, Madhya Ganga Barrage and Narora Barrage intersect the river successively to divert water to the Upper, Middle and Lower Ganga Canals. Further downstream, River Ganga is again clipped at Kanpur by the Lav-Kush Barrage. Finally, as the river heads for the estuarine reach, it is again bifurcated by the Farakka Barrage in West Bengal, which diverts part of the flow into a canal to feed the Bhagirathi-Hooghly river.

Besides the above operations on the main Ganga river, major dams and barrages on her tributaries include the Ramganga Dam on Ramganga river in Uttarakhand, Asan Barrage, Dakpathar Barrage and Hathnikund Barrage (and the upcoming Lakhwar Dam) on River Yamuna, Ichari Dam and Tons Barrage on River Tons, the Dhandhraul Dam on Ghaghra river, Gandhi Sagar Dam on Chambal river, the Rajghat, Parichha and Matatila Dams on Betwa river, the Rihand Dam on Rihand river in Uttar Pradesh, the Bansagar, Jawahar Sagar and Ruthai Dams on Kali Sindh, the Chandil, Tenughat, Maithon, Panchet and Tilayia dams on the Suvarnarekha and Damodar rivers in Jharkhand, and the Durgapur Barrage on River Damodar in West Bengal [*NIH, 2014*]. Needless to say, the innumerable intercepts on the Ganga river network have fragmented the once unified river habitat into disjointed ecological stretches. Attempts to provide ecological connectivity by means of fish passages is also often ineffective [see e.g. *Brown et al., 2013*]. Dams and barrages are also notable for trapping high quantities of river sediments, thereby converting the downstream river water into "*hungry water* because it has sufficient energy to transport sediment but the sediment has been captured behind the dam. The *hungry water* gradually consumes the bed and banks of the river below the dam, resulting in entrenchment and armoring of the bed" [*Wampler, 2012*]. The long-term effects of this process are significant not only for river morphology [*Graf, 2006; Gupta et al., 2012*], but also for the benthic and hyporheic biota as well as aquatic creatures that depend on river bed and bank sediments for spawning, shelter, scavenging or other needs.

In view of the above problems, it is necessary to ensure longitudinal connectivity – along with adequate water and sediment flows – throughout the Ganga river network.

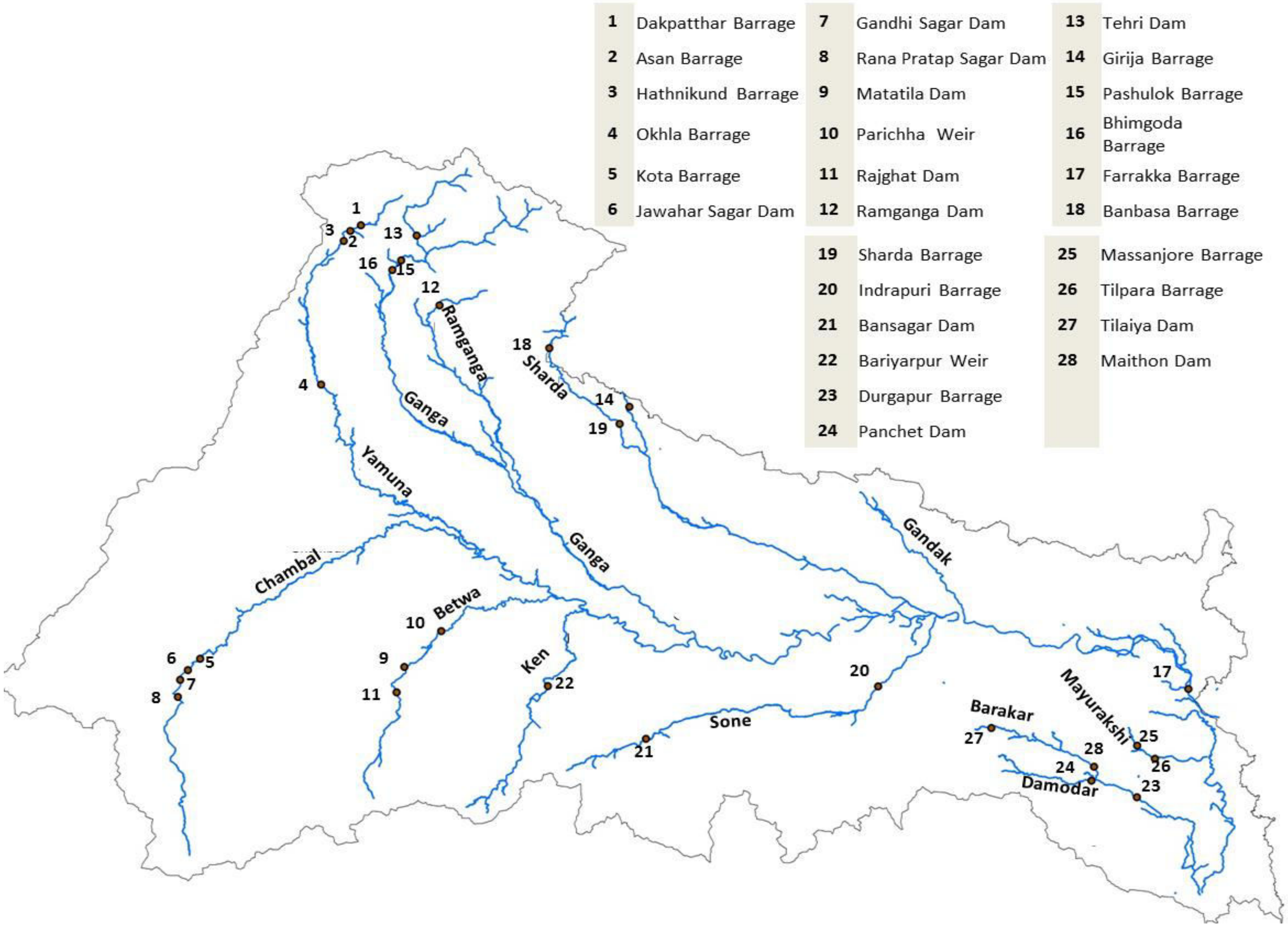


Figure 3: Major structural obstructions on River Ganga and her tributaries within India [*MoWR, 2014*]

5.2 Habitat Shrinkage

Large anthropogenic water abstractions are being effected from the Ganga River Network all over the basin, thereby considerably shrinking the aquatic space of river species. Many of the dams and barrages on the rivers are used to divert river flows, which includes the Tehri reservoir that supplies significant amounts of River Bhagirathi's water for urban needs. After the start of the main stem of River Ganga, the Bhimgauda Barrage diverts nearly all the river water to the Upper Ganga Canal (having head discharge capacity of about 300 cu.m/s) at Haridwar[1]. Large water abstractions occur thereafter at Bijnor and Narora to divert river water into the Middle and Lower Ganga Canals respectively. Abstraction of river water also occurs at different points for urban water supplies. In addition, many dams and barrages on the tributaries of River Ganga noted in the previous section are coupled with water diversion into irrigation canals (such as the Yamuna, Sarda, Ramganga, Kosi and Sone canal systems). Thus, even after the confluence with River Yamuna near Allahabad, the Ganga river flow is low and significantly less than what it was a century or two ago. Thus, large-scale water abstractions from the river network have milked the mighty Ganga river to an emaciated stream during most of the lean season ever since the Upper Ganga Canal System was made operational in the mid-nineteenth century [*UPID-FAO, 2008*].

While the effect of water abstractions from National River Ganga on her biota may not have been extensively studied, similar studies elsewhere indicate the serious threat they pose to riverine species. To cite, studies on the Indus River System in Pakistan show that water abstraction is the single most important cause for the decline and extirpation of the Indus River Dolphin (biological name "*Platanista gangetica minor*") in many stretches of River Indus [*Braulik et al., 2014*]. It may, therefore, be easily surmised that shrinkage of the Ganga river habitat due to river water abstractions may also have had dire consequences for various aquatic species of National River Ganga. If one considers the additional sub-surface outflows from (or reduced base flows

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[1] Note**:** The flow diverted into the Upper Ganga Canal is regulated at Mayapur head works. During lean seasons, only a little water is led back into the Ganga river downstream at Kankhal, with the stretch from Hardwar to Kankhal being nearly dry [*IITC, 2012a*].

into) rivers due to increased groundwater pumping in the basin, the shrinkage of the riverine habitat over the past one-and-a-half centuries is likely to have been grievous for the biodiversity-rich Ganga river that existed earlier. In fact, the extirpation of the Gangetic Dolphin from the Middle Ganga Stretch up to Allahabad may also be due to the diminished dry season flows in this stretch [*Sinha et al., 2010*].

Finally, it should be noted that river water abstractions are generally high during lean flow seasons but low (or nil) during the wet seasons. This results in the river channel carrying extremely low flows during the dry season but with the original high flows of the wet season almost intact. In fact, peak runoff rates from the basin into the rivers may have increased in many places due to urbanization and land-use changes over the past one or two centuries, thereby increasing the river flood peaks from their earlier levels. Overall, the extremes of the river's natural hydrological regime have certainly accentuated, thus exerting considerable further survival pressures on the biota. Restoring National River Ganga's flow regimes to states comparable to their original (undisturbed) flow regimes is, therefore, an essential need for ecological revival of the river.

5.3 Habitat Alterations

While dams and barrages have much altered the Ganga River Network, the river morphologies have undergone other anthropogenic alterations too. Notably, unrestrained gravel and sand mining from river beds combined with the dumping of construction wastes in rivers have altered river forms drastically in places, besides also probably contributing to river pollution. Other alterations include those caused by manmade structures such as river constriction through levees, embankments, guide walls and even bridges[2]. Many of these alterations in river morphologies adversely affect benthic flora and fauna, fish breeding sites and the egg laying sites of soft and hard shell turtles. A complete end to any further anthropogenic alterations to river habitat is therefore a prime requirement for ecological restoration in the Ganga river network.

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[2] Bridges are generally considered benign, but ill-designed bridges *can* interrupt the natural flow pattern, e.g. as reported for bridges on River Mandakini in Chitrakoot, M.P. [*Mishra, 2013*]

5.4 Habitat Pollution

Pollution from domestic and industrial wastes is extensive in the Ganga river downstream of Haridwar, and it assumes alarming proportions below Kannauj (after the confluence of Ramganga and Kali rivers) at least up to Varanasi. As noted in GRBMP Thematic Reports on Water Quality, the discharge of treated and untreated municipal wastes from many Class I and Class II towns of NRGB in the river is rampant, resulting in high levels of organic pollutants and pathogens (like fecal coliforms) and probably some emerging pollutants. Added to these are untreated or semi-treated industrial wastes from various manufacturing units. Thus, residues of organochlorines including DDT (dichlorodiphenyltrichloroethane), HCH (hexachlorocyclohexane), endosulfan and their metabolites are common in the river water. Presence of organophosphates and heavy metals are also reported in water and sediments. These pollutants can be largely attributed to anthropogenic sources – domestic wastes, industrial wastes and agricultural runoff. The high levels of such pollutants in the river have their own fatal effects on river biota. A rigorous check on anthropogenic pollution of the Ganga river system is therefore of urgent need for the river's ecological revival.

5.5 Habitat Invasion by Alien Species

Exotic species of fish, notably the common carp (*Cyprinus carpio*) and Tilapia (*Oreochromis niloticus*), have invaded River Ganga's waters downstream of Allahabad, after having swamped the Yamuna river. Downstream of Allahabad they have greatly populated the river, largely displacing Indian Major Carps (IMC) and other indigenous fishes of River Ganga. In all, seven species of exotic fish have been reported in river Ganga including the Thai magur, (*Clarias gariepinus*) and Grass carp (*Ctenopharyngodon idella*). But it is not only the middle and lower reaches that have been invaded. The sighting of another exotic fish – the brown trout (*Salmo trutta fario*) downstream of Jhala – is an important signal of the presence of invasive species reaching up to Bhagirathi.

Now, invasion of ecosystems by alien species can occur only after their introduction into the ecosystem, which is often anthropogenic. But, even after their introduction, alien species have to out-compete the native species in the ecosystem. Often, this competitive advantage in river ecosystems accrues from manmade changes in rivers to which indigenous species are not well adapted. As shown by Leprieur *et al*. [*2008*], globally, the biogeography of alien fish invasions in rivers correspond to the impact of enhanced human activities in the respective river basins. Hence, habitat invasion of the Ganga River Network by alien species is also essentially of anthropogenic origin. The adverse consequences of such invasions include the propagation of new diseases and parasitic organisms, and disruption of the river's ecological balance. It is, therefore, imperative that exotic species that have invaded the river network be eliminated and appropriate control measures be devised against introduction of any new alien species.

5.6 Habitat Encroachment

Human beings have been encroaching upon rivers since long ago especially by occupying much of the flood plains and parts of river banks for various purposes. In modern times, however, the encroachments have become extensive – with widespread construction activities on floodplains and even farming on river beds during lean flow seasons. On the one hand, the increased constructions on flood plains have led to altered runoff patterns into rivers, increased pollution inflows with runoff, reduced groundwater recharge and, hence, decreased base flows in rivers, and curtailed ecological linkages between the river, its floodplains, and floodplain wetlands. On the other hand, river bed farming together with modern chemical pesticides such as DDT and HCH [*Hans, 1999*], have polluted the river bed, thus affecting the health of aquatic creatures, especially the hyporheic biota, and disturbing the breeding sites of higher aquatic animals. Hence anthropogenic habitat encroachments of the Ganga river network must be curbed at the earliest.

5.7 Habitat Disturbances

Frequent disturbance of the Ganga river habitat by humans has received little attention, but this is a definitive threat to riverine creatures. In particular, dredging and plying of noisy ships, especially in the Hooghly river stretch of the Lower Ganga, have evidently affected major aquatic animals such as the Gangetic dolphin so significantly that they have vanished from these reaches

[*Sinha et al., 2010*]. With the possibility of commercial navigation in much of the Middle and Lower Ganga stretches in future, the issue is of considerable importance. In this regard, the recent invasion of the upper reaches of the Danube river in Europe by the round goby fish (plus other exotic goby species, snails, mussels and amphipods) is a pointer**:** the increased frequency of passing ships combined with the straightening, deepening and reinforcing of riverbanks are believed to be major factors for the invasion by round goby, which is not really an alien fish in the Danube river but was earlier confined to only the lower reaches [*TUM, 2013*]. Evidently, the native fishes of the Upper Danube region were not as well adapted to the river disturbances as the round goby and other exotic goby fishes. It is clear that similar possibilities exist in the Ganga river network too. And, besides the passage of ships, frequent or intermittent dredging of the river bed (usually done to improve navigability in the river) is also harmful as it disrupts not only the benthic and hyporheic flora and fauna, but also aquatic animals that depend on the river bed and bank sediments for spawning, shelter, scavenging or other needs.

In view of the problems discussed above, anthropogenic disturbances of the Ganga river network must therefore be completely stopped (or at least minimized).

5.8 Habitat Malnutrition

While anthropogenic pollution – or increase of harmful substances – in the Ganga river habitat is a matter of grave concern, the reverse phenomenon of anthropogenic nutrient deprivation in the river has received little attention. The general notion of anthropogenic effects on nutrient concentrations in rivers is that of nutrient enrichment, i.e. increased concentrations of nitrogen (N), phosphorous (P) and other nutritional elements commonly present in agricultural, domestic and industrial wastewaters. But the opposite phenomenon of nutrient depletion is often overlooked. In particular, dams, as noted earlier, trap large quantities of river sediments that may contain many mineral nutrients, and the reduced sediment flux can starve the downstream river stretches of essential nutrients. Now, apart from Carbon, Hydrogen and Oxygen, at least twenty five (and probably many more) elements are known to be essential for plants and animals [*namely, N, P, K, Ca, Mg, S, Na, Cl, B, Zn, Cu,* *Mn, Fe, Co, Ni, Mo, Li, I, Se, Cr, V, Si, F, As, and Sn, vide Graham, 2008*]. While knowledge of the effects of the deprivation of micro-nutrient elements in river ecosystems may be limited, many studies have been conducted on deprivation of essential macro-elements (like N and P) and synergistic co-limitation of multiple elements on primary producers in freshwater ecosystems [*Elser et al., 2007; Harpole et al., 2011*]. Thus, the effect of dams on nutrient availability in downstream reaches of rivers is of obvious significance.

In the above context, a report by Zhou *et al*. [*2013*] on the effects of the Three Gorges Dam on phosphorus depletion in MLY (i.e. Middle and Lower Yangtze river) deserves mention. The study is relevant not only for its quantification of P deprivation due to the Three Gorges Dam, but also because – like National River Ganga – the Yangtze river of China (originating from Tibetan glaciers) also carries significant upland sediments with its flow. Now, until major dam constructions begun on River Yangtze in the 1990s, the river discharged about 940 km^3/yr water and 478 Mt/yr of sediment into the East Sea. The MLY stretch (below the Three Gorges Dam) up to the estuary is about 2,000 km long but gets very little sediment added in the MLY reach. The Three Gorges Project (with several large dams constructed in the upland river basin) began operating since 2003. Zhou *et al*.'s study reveals that by 2011 (i.e. within 10 years of operation of the Three Gorges Project) the total sediment load in MLY reduced to only 6% of its previous long-term average (thereby resulting in extensive scouring of the river channel), while nutrient-rich fine sediment load reduced to only 8% of its long-term average. As a result, the Total P and Particulate P loads delivered to the MLY reduced to only 23% and 16.5% of their long-term averages. Now P had already been a limiting nutrient for the Yangtze river's bioactivity, hence its further reduction was a matter of grave concern. Zhou *et al*. concluded**:** "When P is trapped with sediment in upstream reservoirs and depleted from riverbed resuspension, the nutrient regime in the MLY is altered. Extremely high and further elevated ratios of nitrogen to P can reduce the bioproductivity and promote unusual algal blooms in downstream waters."

It is evident from the above that the trapping of sediments behind dams in the upland reaches of the Ganga River Network may also be starving the downstream river reaches of some essential mineral nutrients. Without comprehensive data of the river's nutrient levels, a definite conclusion cannot be drawn in this regard. But, in the light of the above study, there is a distinct possibility of nutrient imbalance in the Ganga river system due to dammed sediments. Moreover, in the Ganga river network, while macronutrients like N and P may actually get compensated (or even more than compensated) due to their increased influx from anthropogenic wastewaters, the same may not be true of the many essential micronutrients if their main supplier to the river ecosystem are sediments from upland reaches. In the absence of quantitative data, the threat of nutrient deprivation to National River Ganga's biodiversity can only be guessed. Hence the imperative need is to**:** (i) assess the availability of essential nutrient elements in different branches and stretches of the Ganga river network and identify the nutrient-starved stretches; and (ii) assess what essential nutrient elements reside in the sediments trapped behind dams, and devise suitable means to release the sediments to nutrient-starved downstream river reaches.

6. Summary of Recommended Actions

Based on the above threat assessment, the following essential actions are envisaged to restore the ecological balance of National River Ganga:

i) Restoration of longitudinal connectivity along with maintenance of environmental flows and sediments throughout the Ganga river network.

ii) Maintenance of lateral and vertical connectivity across rivers and floodplains is also needed to provide breeding sites of fish and other aquatic/ amphibious animals as well as the periodic exchange of river biota with floodplain wetlands.

iii) Restoration of unpolluted flow in the river by appropriate measures to control anthropogenic pollution as envisaged under Mission Nirmal Dhara.

iv) Restrictions on anthropogenic alterations of river morphology by gravel and sand mining as well as by river bed and river bank modifications by structural measures.

v) Elimination of alien invasive species from the Ganga river network and establishing norms to prevent future introductions of exotic species.

vi) Control of habitat encroachment by humans for riverbed farming, riparian activities and permanent constructions in floodplains.

vii) Restrictions on anthropogenic disturbances of river habitat by frequent plying of vessels, dredging of river bed, etc.

viii) Control of overfishing and fishing during spawning seasons, ban on commercial fishing, and protection of the spawning and breeding grounds of fish.

ix) Assessment of essential nutrient elements available in different river stretches and in sediments trapped behind dams, and devising suitable means to release the trapped sediments into downstream river reaches.

x) Continuous bio-monitoring of the entire Ganga river and her important tributaries, and dissemination of information in public domain.

xi) Synergising the eco-restoration measures proposed above with the Dolphin Conservation Action Plan initiated by MOEF in 2010.

Finally, it needs to be stressed that the ecology of large rivers is globally inadequately understood. While the amount of descriptive information is large, comprehensive studies that integrate hydrology, bio-geochemistry, and community ecology are rare [*Melack, 1987*]. Hence, In addition to the above actions, it is desirable to conduct comprehensive research to understand the ecological dynamics of National River Ganga.

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