GANGA RIVER BASIN MANAGEMENT PLAN
(GRBMP)

VOLUME 2

MISSION REPORTS

JANUARY 2015

cGanga

Centre for Ganga River Basin Management and Studies
Indian Institute of Technology Kanpur

National Mission for Clean Ganga (NMCG)

NMCG is the implementation wing of National Ganga Council which was setup in October 2016 under the River Ganga Authority order 2016. Initially NMCG was registered as a society on 12th August 2011 under the Societies Registration Act 1860. It acted as implementation arm of National Ganga River Basin Authority (NGRBA) which was constituted under the provisions of the Environment (Protection) Act (EPA) 1986. NGRBA has since been dissolved with effect from the 7th October 2016, consequent to constitution of National Council for Restoration, Protection and Management of River Ganga (referred to as National Ganga Council).

www.nmcg.in

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this it is also responsible for introducing new technologies, innovations and solutions into India.

www.cganga.org

Acknowledgment

This document is a collective effort of a number of experts, institutions and organisations, in particular those who were instrumental in preparing the Ganga River Basin Management Plan which was submitted to the Government of India in 2015. Contributions to the photographs and images for this vision document by individuals are gratefully acknowledged.

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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
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NIT-K
DU
NIH Roorkee
ISI Kolkata
Allahabad University
WWF India

GRBMP MISSIONS

01 AVIRAL DHARA

02 NIRMAL DHARA

03 ECOLOGICAL RESTORATION

04 SUSTAINABLE AGRICULTURE

05 GEOLOGICAL SAFEGUARDING

06 BASIN PROTECTION AGAINST DISASTERS

07 RIVER HAZARDS MANAGEMENT

08 ENVIRONMENTAL KNOWLEDGE-BUILDING AND SENSITIZATION

गजेन्द्र सिंह शेखावत
Gajendra Singh Shekhawat

जल शक्ति मंत्री
भारत सरकार
Minister of Jal Shakti
Government of India

MESSAGE

I am delighted to note that the National Mission for Clean Ganga (NMCG) with the help of the Centre for Ganga River Basin Management and Studies, Kanpur (cGanga) is releasing the print version of the Compendium of Ganga River Basin Management Plan (GRBMP) and its constituent Reports for wide distribution among various government departments, agencies, academic institutions and other stakeholders. The GRBMP and its accompanying Plan Documents (Mission Reports and Thematic Reports) are among the most insightful assessments of the state of National River Ganga that helped formulate a cogent revival strategy for the river. The documents cover a wide range of issues on the status of the river vis-a-vis various anthropogenic activities in the Ganga River Basin that have affected the river over the last many decades. The issues covered in this Compendium are of critical importance not only for the Conservation and Restoration of River Ganga and other rivers of the country, but also for many other people-centric activities in the Ganga Basin under the government's purview such as Agriculture, Fisheries, Forestry, Hydropower, Industry, Infrastructure, Municipal Services, Sustainable Water Resource Management, and Urban Development, to name a few. It is, therefore, essential that such issues that are closely interlinked with the focus areas of various ministries and departments of the government (both Central and State governments), other stakeholders and researchers, are extensively disseminated among them. I commend NMCG and cGanga in taking this initiative to print the Compendium for wide distribution among various stakeholders, academics and international agencies. This will enable them to incorporate GRBMP's views and recommendations in their forthcoming plans, programmes and activities. I also welcome further feedback from all concerned on the GRBMP framework and its recommendations.

(GAJENDRA SINGH SHEKHAWAT)

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महानिदेशक
राष्ट्रीय स्वच्छ गंगा मिशन

Rajiv Ranjan Mishra, IAS
DIRECTOR GENERAL
NATIONAL MISSION FOR CLEAN GANGA

सत्यमेव जयते

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन,
नदी विकास और गंगा संरक्षण विभाग

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

FOREWORD

India is the land of sacred rivers. Rivers, large and small, are held in deep reverence by Indians for their profound material and spiritual gifts to humankind. For rivers are not only an endless source of freshwater – a fundamental necessity for life –they also bring many other gifts for our sustenance from food such as fishes to energy in the form of hydropower, cost-effective navigation and transport, the washing away of wastes and surplus waters from the basin, supply of agricultural nutrients through irrigation waters, aesthetic beauty and, not the least, spiritual fulfilment. Among our sacred rivers, River Ganga is the most important and universally worshipped in India. In recognition of the prime importance of River Ganga in our national life the Government of India not only conferred the status of National River on the Ganga in the year 2008, it thereafter also launched the nationwide Namami Gange programme focussed uniquely on the restoration and conservation of River Ganga.

The National Mission for Clean Ganga has been at the forefront of the Namami Gange initiative ever since its launch. To understand our task in all its complexity it was necessary to harness the knowledge and understanding of a wide gamut of experts on what ails our National River and how best to redeem and preserve the river. The Ganga River Basin Management Plan (GRBMP) prepared at the behest of the Indian government by a Consortium of Seven IITs is a sterling guide for this purpose. It not only details and analyses the various anthropogenic factor that have been affecting the river over the past two centuries, but also chalks out a comprehensive roadmap for the rejuvenation of our great river. The main Plan itself is based on scores of independent studies by experts from the seven IITs and other allied institutions of learning to provide a firm foundation to its recommendations. The GRBMP is, therefore, the culmination of a many-faceted effort that synthesizes the diverse studies and perceptions of India's most knowledgeable and stimulated minds.

Being in the lead for restoring and conserving the River Ganga as a great river once again, I whole-heartedly recommend all students and scholars to peruse the GRBMP and its reports for their own subject interests as well as in the hope to get their feedback so that we can further fine-tune our knowledge and take remedial actions for improving River Ganga. In this task, we do not view the GRBMP as a static final Plan, but rather as a Plan that will evolve dynamically with our collective insights and knowledge. And such knowledge and insights can also help in the revival of our other rivers and ecosystems. I am also sure that many students and researchers will find much useful knowledge and leads in these documents to guide them in their future researches and careers. These documents are, therefore, invaluable both for individual interests as well as for reviving our rivers and water bodies for a resurgent India.

RAJIV RANJAN MISHRA

cGanga

Dr Vinod Tare
Professor & Founding Head - cGanga

CENTRE FOR GANGA RIVER BASIN MANAGEMENT AND STUDIES
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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 the 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.

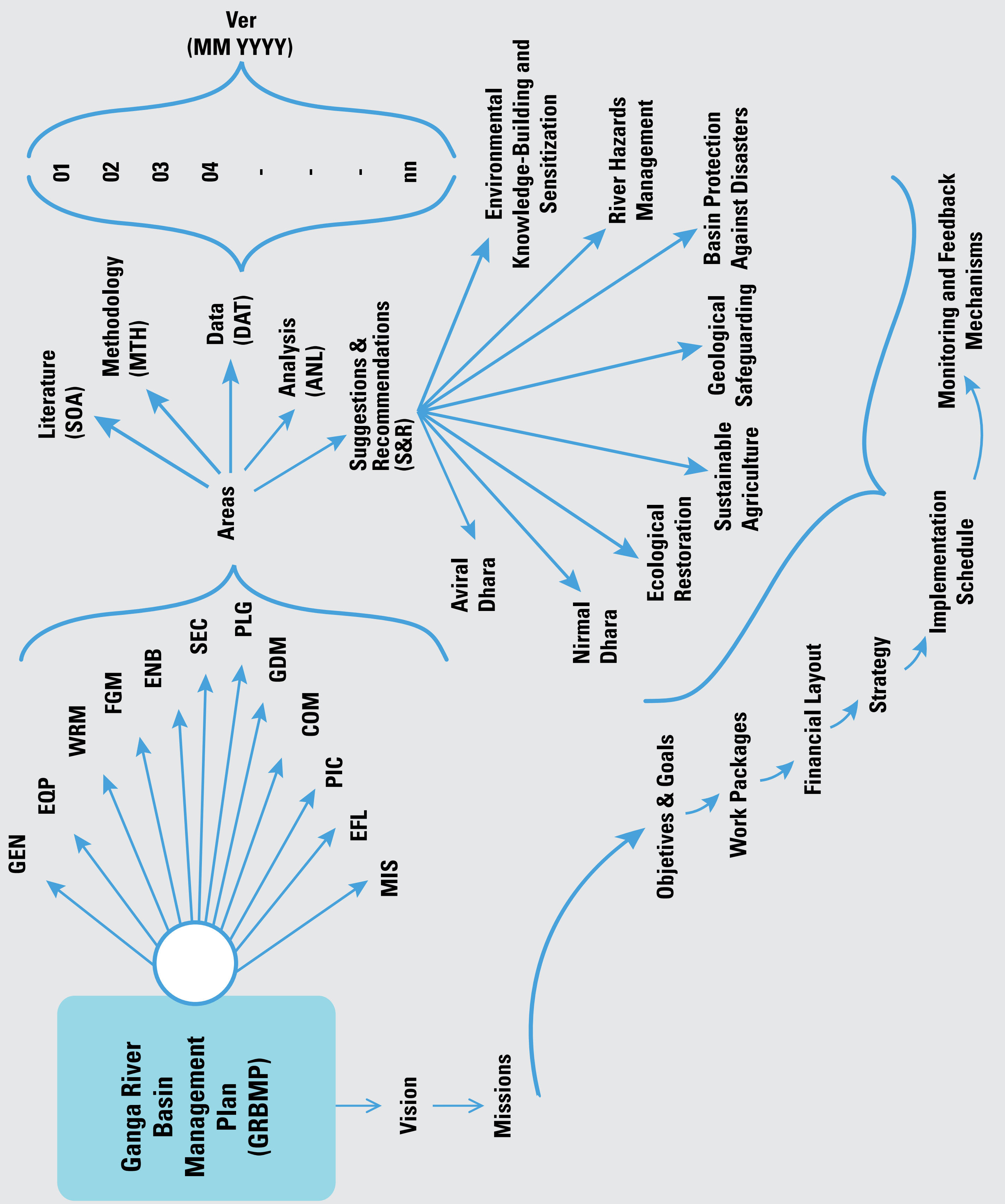
The GRBMP is presented as a 3-tier set of documents. The three tiers comprise of: (i) Thematic Reports (TRs) providing inputs for different Missions, (ii) Mission Reports (MRs) documenting the requirements and actions for specific missions, and (iii) the Main Plan Document (MPD) synthesizing background 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.

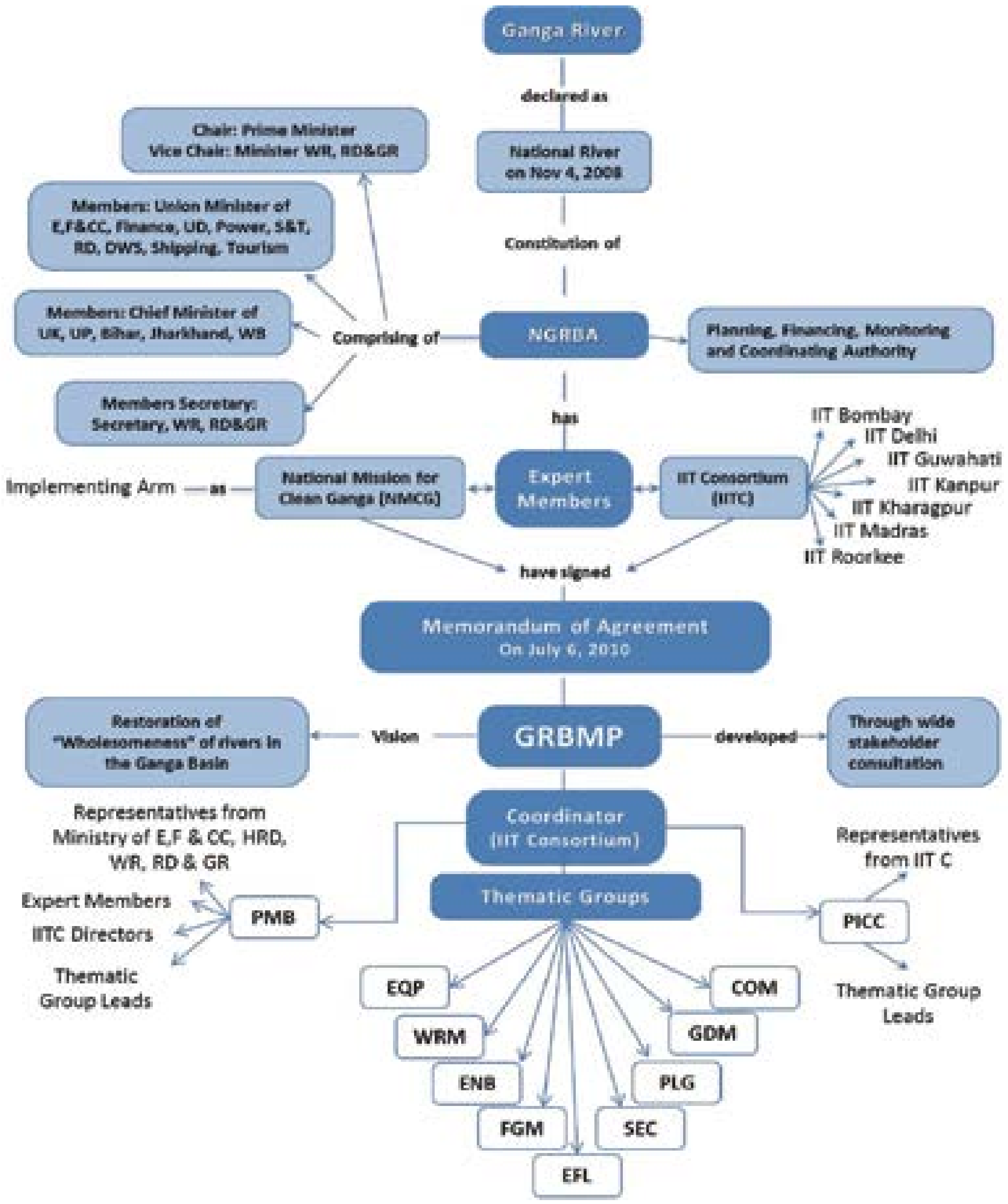
Secondly, many dedicated people spent hours discussing major concerns, issues and solutions to the problems addressed in GRBMP. Their dedication led to the preparation of a comprehensive GRBMP that hopes to articulate the outcome of the dialog in a meaningful way. Thus, directly or indirectly, many people 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.

VINOD TARE

GRBMP WORK STRUCTURE



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

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GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 1: AVIRAL DHARA

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**

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ABBREVIATIONS AND ACRONYMS

1. **BBM** : Building Block Method
2. **BCM** : Billion Cubic Metres
3. **CGWB** : Central Ground Water Board
4. **CWC** : Central Water Commission
5. **E-Flows** : Environmental Flows
6. **ET** : Evapo-Transpiration
7. **FAO** : Food and Agricultural Organization
8. **GRBMP** : Ganga River Basin Management Plan
9. **IITC** : IIT Consortium
10. **MLY** : Middle and Lower Yangtze (river)
11. **MoEF** : Ministry of Environment and Forests
12. **MoEFCC** : Ministry of Environment, Forests & Climate Change
13. **MoWR** : Ministry of Water Resources
14. **MoWR, RD&GR**: Ministry of Water Resources, River Development & Ganga Rejuvenation
15. **NCIWRD** : National Commission on Integrated Water Resources Development
16. **NGO** : Non-Governmental Organization
17. **NGRBA** : National Ganga River Basin Authority
18. **NMCG** : National Mission for Clean Ganga
19. **NRGB** : National River Ganga Basin
20. **NRGBMC** : National River Ganga Basin Management Commission
21. **ROR** : Run-of-the river
22. **UNEP** : United Nations Environment Programme

SUMMARY

The Ganga River Network was adopted in GRBMP as the primary indicator of health of National River Ganga Basin (NRGB), and human-technology-environment interactions were factored in to assess the basin's resource dynamics. While NRGB's present water status is poorly understood, a broad hydrological review indicates declining water availability in the river network due to large-scale water withdrawals from the basin's rivers and aquifers over many decades. Besides, the river network is extensively intercepted by dams and barrages into disjointed channel stretches with highly altered water, sediment and nutrient flows, thereby affecting river morphology and ecology. The depleted water availability of NRGB is borne out by hydrological modelling. The present-day sediment loads are also found to be much less than previous estimates. The main recommendations are: (1) Determination of NRGB's hydrological status more accurately and in greater detail. (2) Preparation of water resources plan for NRGB with emphasis on wetlands, forests and distributed groundwater and surface water storages rather than large impounded reservoirs. (3) Increase in water use efficiency through (i) realistic pricing of fresh water, (ii) incentives, technical assistance, and allocation of water rights and entitlements to consumers, and (iii) reuse and recycling of water. (4) Governmental policy shift to bring NRGB's water resources under natural resource management, with emphasis on resource preservation, stakeholder control, expert guidance and regulation. (5) Ensuring longitudinal river connectivity and environmental flows (of water, sediments and other natural constituents of flow) at dams, barrages and other manmade interferences, and adoption of new criteria for approving such projects. (6) Control of water withdrawals in water-depleting regions. (7) Assessment and monitoring of sediment resources of the network including assessment of quantity, quality and nutrient value of sediments trapped behind dams. (8) Research to determine the ecological limits, thresholds and interconnections of NRGB's water resources, and river flow health assessments within the framework of ecohydrology.

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 GRBMP – evolved an eight-pronged action plan, with each prong envisaged to be taken up for execution in mission mode.

The objective of Mission "Aviral Dhara" is to ensure that the flow of water – along with sediments, nutrients and other natural constituents of the flow – are continuous and adequate throughout the Ganga river network.

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 "Aviral Dhara" is to ensure that the flow of water – along with sediments, nutrients and other natural constituents of the flow – are continuous and adequate throughout the Ganga river network.

3. IMPORTANCE OF AVIRAL DHARA FOR GANGA RIVER BASIN MANAGEMENT

Climatically and geomorphologically NRGB is a large and diverse basin characterized by a network of large perennial rivers and smaller perennial or seasonal streams – the Ganga River Network – traversing from their upland sources to the sea. The basin is very fertile and has provided the natural resource needs of the basin's ecosystems and human settlements for ages. But the river network (and the basin as a whole) has seen declining water availability over the decades. In addition, there have been increasing spatial interruptions in river flows over many decades due to a host of manmade dams and barrages. The overall changes in the flow regimes of the rivers of the network have been lopsided – with greatly reduced lean season flows, but undiminished or probably even enhanced flood flows in the wet seasons – which have gone hand-in-hand with various other changes in the natural resources of rivers, notably of sediments, nutrients and biodiversity.

The above changes are found to be linked to major anthropogenic activities in the river basin rather than to natural processes. As a result, the Ganga basin and its river network are being functionally worn-out and emaciated, as reflected in the loss of biodiversity in the river network and the strain on goods and services emanating from the rivers. This underscores the urgent need to rectify or compensate for deleterious human activities in the basin in order to maintain "Aviral Dhara" in the river system.

4. STATUS OF AVIRAL DHARA IN THE GANGA RIVER NETWORK

For a given geological setting and climatic pattern, alluvial rivers – as characterized by their morphologies, drainage network and fluvial patterns – achieve stability through long-term physical balance between various dynamic parameters such as basin runoff and erosion rates, river water and sediment flow volumes, and influent/ effluent seepage rates. "Aviral Dhara" is a consequence of this long-term stability of rivers. Anthropogenic activities have violated this aspect of Ganga river's integrity in several ways – by erecting obstacles to flow, by significant water withdrawals, by increased waste disposal into rivers, and by altering the natural water recharge/ outflow rates into/ from the basin. Regarding the last point, it may be noted that, since much of the basin is hydraulically connected by groundwater flow (besides other hydrological connections), water withdrawals/ recharges are not only those directly from/ to the rivers but also those from/ to different parts of the basin. Thus, while longitudinal connectivity in the river network is an essential first step to maintain "Aviral Dhara", having adequate river flows depends much on the basin's overall water status.

Dams, barrages and other manmade structures block or constrict rivers, thereby interrupting the flow of water, sediments and aquatic species. While the short-term and local benefits of such structures can be reasonably estimated, the long-term, basin-wide environmental losses in terms of river instability, fertility of the river and its floodplains, ecological balance, nature of flood events, health effects, and other facets of basin performance are difficult to predict [UNEP, 2008; WWC, 2000]. Similar adverse effects are also caused by anthropogenic activities that significantly alter river flows or sediment loads. The UNEP document cited in Box 4.1 discusses some of these aspects in terms of *"river fragmentation"* defined as "the interruption of a river's natural flow by dams, inter-basin transfers or water withdrawal … by man." However, it is not only interruptions or changes in water flow rate that cause physical imbalance in a river; the balance may also be easily upset by alterations in sediment load and changes in seepage inflow/ outflow rates and overland inflow rates.

The two main anthropogenic factors that have increasingly dented Aviral

Box 4.1

"Damming and flood control can have negative impacts (in rivers), such as declining fish catches, loss of freshwater biodiversity, increases in the frequency and severity of floods, loss of soil nutrients on floodplains, and increases in diseases such as schistosomiasis and malaria. ... On the Mississippi River, the rising frequency and severity of flooding – attributed to local flood control structures – have reduced the river's ability to support native flora and fauna, while a dramatic increase in floods on River Rhine has been attributed to increased urbanization, engineering, and the walling off of the river from its floodplain."

UNEP [2008]

Dhara in the Ganga River Network over the past two centuries are: (i) the large number of dams and barrages that have interrupted the flow of water, sediments and nutrients in the river network, and (ii) the excessive withdrawal of water for human needs from the river network and the basin. Besides, there are other human factors (such as those causing changes in land use and land cover) that have, directly or indirectly, affected Aviral Dhara in the National River Ganga. The main factors are discussed below.

4.1 Dams and Barrages

Figure 4.1 shows major dams and barrages erected in the Ganga River Network [MoWR, 2014]. Dams and barrages often help to meet several anthropogenic needs such as water supply, hydropower generation, flood control and navigation. But these obstructions have divided National River Ganga and her tributaries into small segments, thereby interrupting the flow of water, nutrient, sediments and aquatic species in the rivers. In the Upper Ganga Basin, the obstructions include cascades of *run-of-the-river* (ROR) hydro-electric projects in the Bhagirathi and Alaknanda head streams. Many of these projects are constructed or planned end to end, i.e. the tail waters of one project are head waters of the next one, so that the river gets transformed into a series of reservoirs. Moreover, 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 [IITC, 2014a]. 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.

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 environmental impact in the river sub-basins was made by the Wildlife Institute of India [Rajvanshi, 2012]. However, the study 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

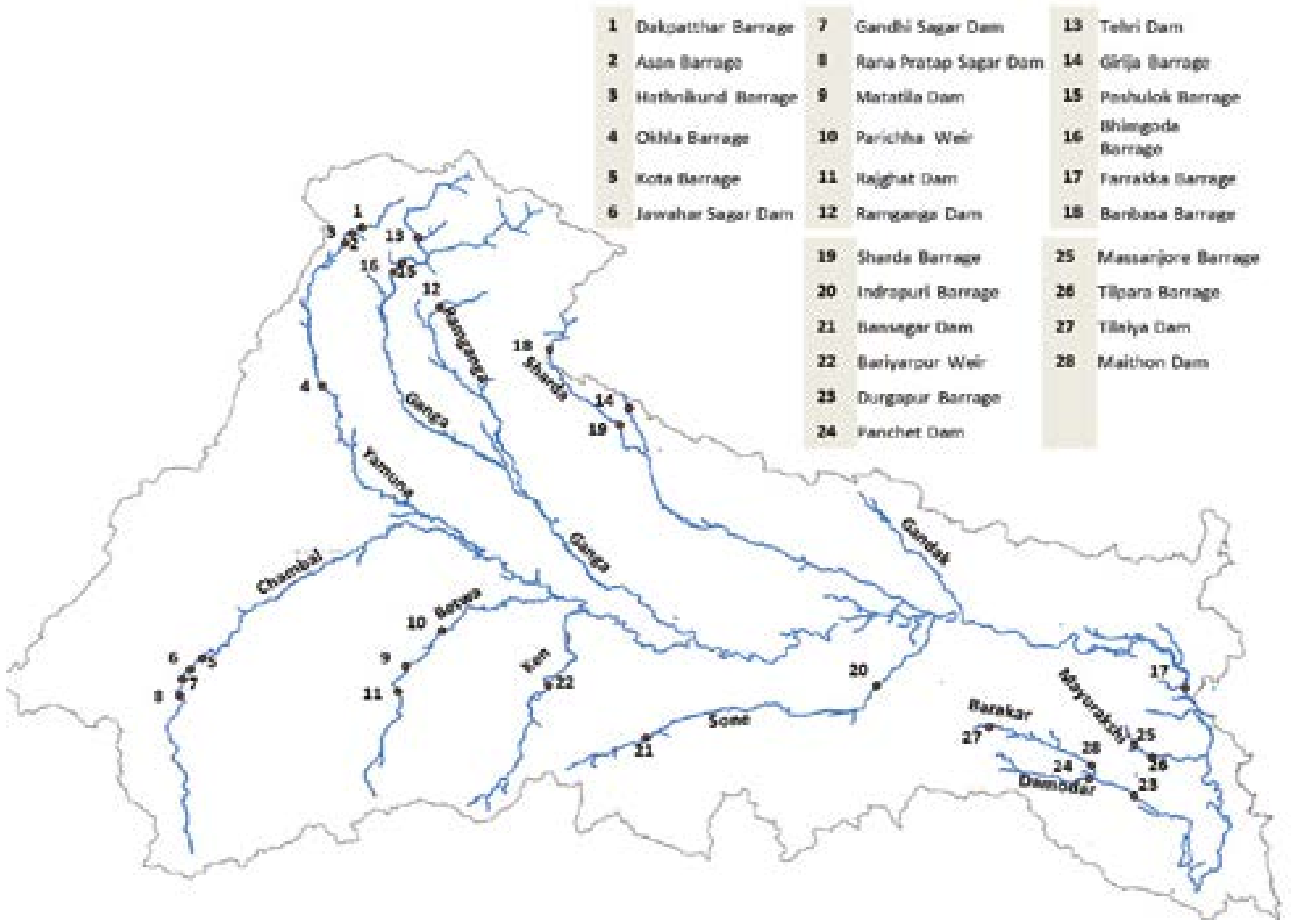

Figure 4.1: Major Structural Obstructions on River Ganga and Her Tributaries within India [MoWR, 2014]

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 essentially 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, the Asan Barrage, Dakpathar Barrage and Hathnikund Barrage (and the upcoming Lakhwar Dam) on River Yamuna, the 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 in the Ganga river network have fragmented the once unified river network into disjointed stretches of flowing and stagnant waters.

Dams and barrages trap much of the river sediments, converting the downstream river water into what is called hungry water – "hungry water 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 significantly affect the morphology of rivers and their floodplains [Graf, 2006; Gupta et al., 2012].

In addition to the direct impacts of dams and barrages on river geomorphology, the sediments trapped behind these structures may contain many mineral nutrients, thereby depriving the downstream river stretches of essential nutrients. It may be noted that, apart from carbon, hydrogen and oxygen, at least twenty five (and probably many more) elements are 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 micro-nutrient deprivation in river ecosystems may be limited, the effect of deprivation of essential macro-elements (like N and P) on river biota have been studied [refer Elser et al., 2007]. In this 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. 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, with the MLY stretch (about 2,000 km long below the Three Gorges Dam up to the estuary) getting little sediment added in the MLY reach. 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. Moreover, 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 values. Now P had already been a limiting nutrient for the Yangtze river's bioactivity before large dams came up on the river, hence its further reduction was critical for bioproductivity in MLY.

Dams and barrages trap much of the river sediments, converting the downstream river water into what is called hungry water – "hungry water gradually consumes the bed and banks of the river below the dam, resulting in entrenchment and armoring of the bed."

4.2 Water Withdrawals and Discharges

Large anthropogenic water abstractions are being effected from the Ganga River Network all over the basin, thereby dehydrating the rivers to a considerable extent. Many of the dams and barrages mentioned above are used to divert river flows for human use. After the start of the main stem of National 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 waters also occurs at different points for urban water supplies. In addition, many dams and barrages on the tributaries of River Ganga (mentioned 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 must be significantly less than what it was a century ago. Thus, large-scale water abstractions directly from the river network have contributed greatly to the mighty Ganga river becoming 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].

In addition to water withdrawals directly from rivers, there has been increased groundwater pumping in the basin in recent decades, resulting in falling water table in many places. Thus, one must take into account the additional sub-surface outflows from (or reduced base flows into) rivers due to the lowering water table in the basin.

Finally, it should be noted that water abstractions from the river network and the river basin are generally high during lean flow seasons but very low 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/ land cover 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 further pressure on its hydro-geomorphological functioning.

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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, 2014a].

4.3 Hydrological Status of NRGB

The water resources potential and water use in India (and in NRGB) have been evaluated by nodal government agencies under MoWR, GOI. Some relevant data are cited in Tables 4.1a and 4.1b [CWC, 2008; CWC, 2010; Jain et al., 2007]. The above data give an indication of the critical status of water resources in India (and in the NRGB), especially when water demands are compared with the water resource potentials. The following points, however, are pertinent with regard to these data:

Table 4.1a: Water Resources Potential (in Billion Cubic Metres) in Indian River Basins

River Basin	Catchment Area (km^2)	Total Water Resource Potential (BCM)	Total Utilizable Water Resource Potential (BCM)	
			Replenishable Ground Water Potential (BCM)	Utilisable Surface Water Resources (BCM)
Ganga	861452	525	171	250
Total Indian	3290000	1869	433	690

Table 4.1b: Projected Water Demand in India in Billion Cubic Metres (BCM)

Sector	Standing Sub-Committee of MoWR			NCIWRD		
Year	2010	2025	2050	2010	2025	2050
Irrigation	688	910	1072	557	611	807
Drinking Water	56	73	102	43	62	111
Industry	12	23	63	37	67	81
Energy	5	15	130	19	33	70
Others	52	72	80	54	70	111
Total	813	1093	1447	710	843	1180

a) How Approximate are the Water Resources Potentials? Estimates of water resources potentials made at different times and/ or by different government agencies are often very different from each other [CWC, 1986; CWC, 2008]. While the likely error margins are not indicated in the above documents, the figures have enough room for uncertainty depending on estimation methods and measurement techniques. For instance, ground water potential depends on estimating storages and yields of complex aquifer systems spread over large and diverse regions. On the other hand, surface water resource potentials do not include surface water bodies. In reviewing the government water

> **The projected water demands are evidently computed without assessing the demand trends or other factors. But given binding constraints on water availability, the growth in demand must get constrained, implying a need for demand management.**

balance estimates, Jain [2012] argued that the governmental estimates of ET (i.e. evapo-transpiration) in the Ganga basin at 23% of precipitation is too low, and suggested that it should be considered instead as 60% of precipitation as in the case for ET of most other Indian basins. The consequent estimates would reduce India's and NRGB's water resources potentials by huge amounts. In a more detailed and critical analysis, Garg & Hassan [2007] used the same government data and showed that the above water resource potentials are actually highly overestimated – by up to 88%; hence the total utilizable water resource potential of India (with the same water reservoirs deemed feasible) amounted to only 654 BCM instead of 1123 BCM, which is far short of even the present water demand of India, an issue that has already been internationally noticed [UNICEF et al., 2013].

b) The above water estimates are for very large regions, and spatial variations of water resources potentials cannot be gauged from the above data. Such variations are large in NRGB considering the diversity in physiographic and hydrological features of the basin.

c) As seen from Table 4.1a, India's surface water resources potential (1,869 BCM) as well as its "utilizable" part (690 BCM) are significantly greater than the ground water potential (433 BCM). On the other hand, government estimates show that, "more than 90% of the rural and more than 50% of urban water supply is met by ground water… with an estimated annual groundwater withdrawal of 221 BCM" [CGWB, 2012]. Thus, groundwater usage is evidently much higher than surface water usage, although surface water potential is much higher than groundwater potential. This differential usage needs to be considered in framing India's water resource management policies.

d) The information cited in the above paragraph also shows that India's estimated "water usage" is much less than half of the estimated "water demand" of 710 BCM or 813 BCM in 2010 [vide Col.5 and Col.2 of Table 4.1b], which suggests that India was already under severe water-stress/ water-scarcity in 2010. However, this conclusion seems untenable if "water-stress" is based on the premise of per capita water availability being less than 1000 m^3/year (which seems to be the government norm, vide India-WRIS, 2012, whereas the international norm for hydrological water stress is when a nation's per capita water availability falls below 1700 m^3/yr, vide FAO, 2012; UN-Water, 2013). In fact, as per CWC figures, the per capita water availability in India was 1588 m^3/yr in 2010 (the per capita water availability was significantly higher in the Ganga basin at almost 2000 m^3/yr in 2010) and is expected to reduce to 1434 m^3/yr in 2025 [CWC, 2010; India-WRIS, 2012]. Table 4.1 also shows that the "utilizable" water resources of India are only 690 BCM. Likewise, NIH states that India's "utilizable" per capita water availability reduced from 1,100 m^3/yr in 1998 to 938 m^3/yr in 2010, and is expected to further reduce to 814 m^3/yr in 2025 [NIH, 2013]. However, the terms "utilizable" and "replenishable" are not quantitatively explained, nor are the likely errors in determining them indicated, thus adding to overall confusion about the significance of the data. While clarity on these data and their interpretations are needed, it seems certain, however, that NRGB (like much of the country) is under increasing water stress, which calls for major changes in how NRGB's water resources are managed.

e) The projected water demands in Table 4.1b were evidently computed without assessing the demand trends or other factors. But given binding constraints on water availability, the growth in demand must get constrained, implying a need for demand management [UNICEF, 2013]. Moreover, the "demands" themselves are questionable. On reviewing the demand data, Jain [2011] recommended that "a detailed study to compute future water demand should be taken up." In a more detailed review of NCIWRD's estimates, Verma and Phansalkar [2007] noted, "The commission's (i.e. NCIWRD's) estimates of 'water demand' are built on the basis of minimum norms set down by various agencies … (instead of) the price at which the water is supplied and the quality of the supply." To reiterate Verma and Phansalkar's recommendation on this issue, "A refined prognosis of India's water future must account for two critical variables missed by the commission: (i) water demand (as against water requirement) as a function of price, availability and quality of supply; and (ii) coping mechanisms of the users of water." In fact, the estimated "demands" are not even "requirements"; rather they seem to be estimates of "present water use" and hypothetical "future water use".

A reliable picture of the present water status of India and NRGB or its subbasins is unavailable. Evidently, Basin's water status needs to be determined afresh and in considerably greater detail in order to estimate its true potential and its changing impact on river flows.

f) The projected water demands are for human use only, and do not give any indication of the water needed to sustain healthy functioning of the basin. Generally, in most governmental water resource assessments, no attempt is made to reliably assess this requirement and it is often ignored. Or, at best, a token value is assumed. The same is the case in the above estimates. As noted by Verma and Phansalkar [2007], "(NCIWRD) makes a 'token provision' of 5, 10 and 20 BCM for water for floods, environment and ecology (combined) for 2010, 2025 and 2050, respectively."

Thus, a reliable picture of the present water status of India and NRGB or its sub-basins is unavailable. Evidently, NRGB's (and India's) water status needs to be determined afresh and in considerably greater detail in order to estimate its true potential and its changing impact on river flows. In NRGB, as for India as a whole, it is not only natural components like ET and groundwater recharge data that may be erroneous, reliable data on water use are also scarce. Apart from industrial water use which is declared to be uncertain [MOWR, 2008], the estimated irrigation water use in India – the highest water consuming sector at 83% of national water use [MOWR, 2008] – could be highly inaccurate due to numerous un-monitored private tube-wells operating in the basin for many decades. International studies indicate that, not only are India's estimated groundwater abstraction the highest in the world, but that the uncertainty in this estimate is also the highest (± 37 km^3/yr) as shown in Table 4.2, vide Wada et al. [2012]. Wada et al.'s data also show that India's overall groundwater depletion and non-renewable groundwater abstractions for irrigation are exceedingly high, with almost 20% of the irrigation groundwater abstraction for the year 2000 being non-renewable. Other independent estimates [notably Tiwari et al., 2009] also reveal similar unsustainable trends in India's groundwater extractions.

Table 4.2: Groundwater Abstraction Rate and Depletion (with ranges of uncertainty) and Non-Renewable Irrigation Use per Country for Year 2000 [Wada et al., 2012]

Country	Abstraction (km^3/yr)	Depletion (km^3/yr)	Gross Crop Water Demand (km^3/yr)	Nonrenewable Abstraction (km^3/yr)
India	190 (±37)	71 (±21)	600	68
United States	115 (±14)	32 (±7)	203	30
China	97 (±14)	22 (±5)	403	20
Pakistan	55 (±17)	37 (±12)	183	35
Iran	53 (±10)	27 (±8)	59	20
Mexico	38 (±4)	11 (±3)	71	10
Saudi Arabia	21 (±3)	15 (±4)	14	10
Globe	**734 (±82)**	**254 (±38)**	**2510**	**234**

Notwithstanding errors and uncertainties in the water resources estimates quoted above, it is fairly certain, however, that human water demands have been increasing while dry-season river discharges and ground water levels have been falling in many parts of NRGB, which implies that the hydrological status of NRGB is shifting relentlessly towards a state of critical imbalance. To overcome this impending crisis, it is imperative that either (i) water availability in the basin is increased through increased storages, or (ii) water consumption is reduced through more efficient water use (or both options are simultaneously pursued).

5. MEASURES TO RESTORE AVIRAL DHARA OF NATIONAL RIVER GANGA

5.1 Water Storage

Human interventions promote two types of water storages, viz. concentrated (or centralized) storage and distributed (or decentralized) storage. Till date, governmental focus has been mainly on "centralized storages" in the form of dammed reservoirs on rivers. While such storage systems have the advantage of economy of scale for capital costs, they often involve significant costs for reservoir operation, transportation of water to end-users, human displacements, land inundation, ecological damage, and river mutilation. In fact the poor efficiencies of surface irrigation systems in India (about 35–40% in contrast to about 60% for groundwater irrigation systems, vide CWC, 2008) may be partly attributed to conveyance losses from reservoirs to farmlands. Moreover, evaporation losses from surface reservoirs are often high, especially in tropical climates like India's. To give an example, as per the annual water balance estimated for the Aswan Reservoir in Egypt, "10 km^3 of the entire Nile flow at Aswan, i.e. 84 km^3, would (i.e. estimated to) be lost in evaporation and seepage" [Awulachew et al., 2011]. As per UNESCO, globally more water evaporates from reservoirs than is used for industrial and domestic needs (see Figure 5.1) [UNEP, 2008]. NCIWRD assumed evaporation losses from large reservoirs at a flat rate of 15% [Verma and Phansalkar, 2007], which reflects the significant evaporation losses.

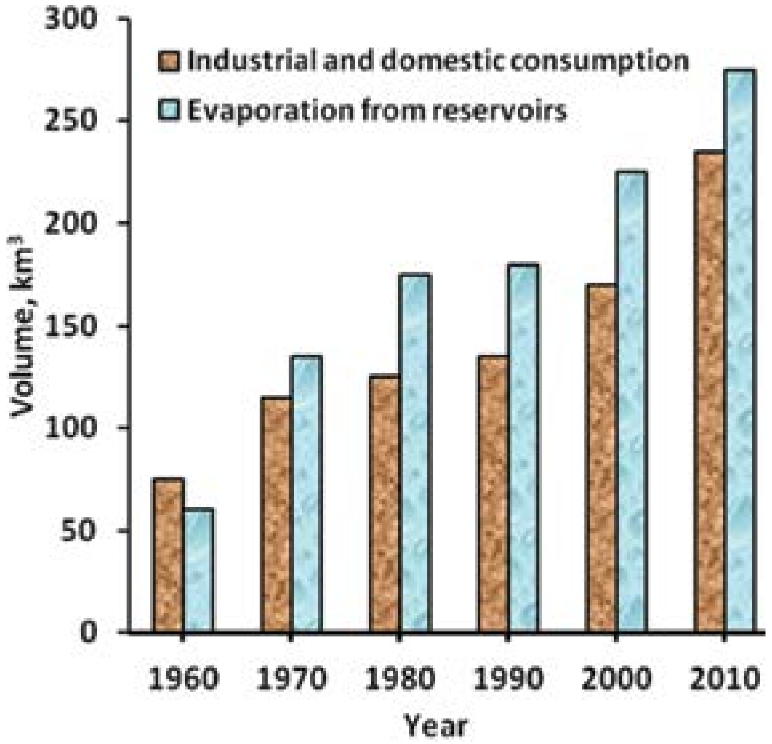


Figure 5.1: Reservoir Evaporation [UNEP, 2008]

Notwithstanding the above limitations, dams often fulfill several needs other than consumptive water use, such as hydropower generation, flood control and navigation. Thus, though dams (and other hydraulic structures that fragment, constrict or otherwise mutilate rivers) may be undesirable in free-flowing rivers, their environmental impacts need to be considered in full before adopting or discarding specific projects. Accordingly four broad categories of dams, barrages and other hydraulic structures have been worked out in GRBMP [IITC, 2014d] for environmental clearance based on their individual environmental impacts as presented in Table 5.1.

Table 5.1: Criteria for Permissibility of Dams and Other Projects on Rivers [IITC, 2014d]

Category	Type of Environmental Impact	Environmental Clearance
I	**MAJOR LONG-TERM, IRREVERSIBLE IMPACTS:** ***Break in Longitudinal River Connectivity leading to:*** (i) loss of habitat of rare or endangered species in river; and/or (ii) disruption in movement of biota along the river length; and/ or (iii) disruption in sediment transport in the river. ***Critical Flow Reductions leading to:*** inadequate Environmental flows needed to maintain river stability and ecological balance. ***Land Inundation:*** causing loss of habitat of endangered/ rare terrestrial species living in the areas inundated.	Such projects should ***NOT*** be given ***Environmental Clearance****.
II	**LONG-TERM, IRREVERSIBLE IMPACTS OF LESS IMPORT:** ***Land Inundation resulting in:*** (i) loss of terrestrial biodiversity and other ecological changes; and/ or (ii) loss of historical, religious and cultural heritage sites. ***Geological Hazards such as:*** (i) seismic hazards; and/ or (ii) landslides, land subsidence, etc.	May be given ***Environmental Clearance**** only after thorough study and review by domain experts.

Category	Type of Environmental Impact	Environmental Clearance
	POTENTIALLY REVERSIBLE LONG-TERM IMPACTS: ***Land Acquisition and Inundation, leading to:*** dislocation of human habitat, loss of livelihood, marginalization, etc. ***Construction Activities, leading to:*** ecological damage, disruption of local hydrology, human dislocation, loss of livelihood, etc. ***Inadequate downstream water leading to:*** adverse effects on livelihood, tourism (including religious tourism) and recreational activities. ***Adverse socio-economic impacts:*** Demographic changes, changes in livelihood patterns, unplanned "developmental activities", tourism and other recreational activities, etc.	May be given Environmental Clearance subject to: (i) a comprehensive socio-economic and environmental impact assessment of the project by an independent agency; (ii) formulation of a Rehabilitation/ Resettlement Plan and an Environmental Management Plan acceptable to all stakeholders; and (iii) formulation of a strong monitoring mechanism to ensure implementation of the EMP (Environmental Management Plan).
	POTENTIALLY REVERSIBLE SHORT-TERM IMPACTS: C***onstruction Activities that cause:*** noise, explosions, degradation of forests and agricultural land, pollution from debris, influx of outsiders, despoiling of nature, etc. P***otentially adverse socio-economic impacts:*** Increase in crime and other social vices, tensions between local population and outsiders, etc.	

**A project not cleared from the environmental angle may, however, be allowed on the basis of overriding national interest. Conversely, a project which has been cleared from the environmental angle, may be disallowed on the basis of overriding national interest. All such decisions must be made at the highest political level.*

The study by Zhou et al. [2013] discussed in Section 4.1 is also of relevance here. Their study showing the downstream effect of the Three Gorges Dam on phosphorous deprivation in the Yangtze river suggests that dams and barrages in the Ganga River Network may also be causing deficiencies of essential mineral nutrients in the downstream river reaches. Without adequate data of the Ganga river's nutrient levels, however, a definite conclusion cannot be drawn in this regard. Hence there is a need 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 nutrient elements are stored in the sediments trapped behind dams, and devise suitable means to release the sediments to nutrient-starved downstream reaches.

The second option of "distributed water storage" can be of much advantage in NRGB (see Figure 5.2). For NRGB has a vast groundwater storage capacity which can be annually replenished by capturing runoff and letting it percolate down to the water table through recharge pits, trenches, etc. Enhancing groundwater recharge would, however, need detailed basin surveying to identify suitable recharge zones. A recent report by CGWB [CGWB, 2014] in this regard is a suitable starting point. In addition, ponds and tanks (distributed surface storages) also need to be promoted in view of their broader environmental and socio-economic usefulness. Taken up at the level of small or micro-watersheds, these measures have the advantage of better decentralized management by local bodies and end-user communities, besides boosting groundwater levels and river base flows. However, both field-level technical help and relevant data (climatic, topographic, soil profile, water table, etc.) should be made available by government agencies to such users.

> **The "distributed storage" concept should be applied to natural ecosystems of NRGB, especially wetlands, forests and grasslands. These ecosystems contribute significantly to conservation of water and other natural resources in the basin.**

The "distributed storage" concept should also be applied to natural ecosystems of NRGB, especially wetlands, forests and grasslands. These ecosystems contribute significantly to conservation of water and other natural resources in the basin. For instance, wetlands, often referred to as "kidneys of the earth", not only help in purifying wastewaters before they reach the rivers or groundwater, but also help in nutrient cycling, flood mitigation, and providing food, fibre and fresh water during dry periods. As noted by Pegram et al. [2013] "healthy and functioning aquatic ecosystems are fundamental to rivers, in terms of the goods and services that they provide, the cultural and other social activities they support, and their inherent biodiversity value. … Experience shows that once seriously degraded, these systems become difficult and costly to return to healthy conditions. It is therefore critical for basin planning to incorporate an understanding of the ecological limits, thresholds and interconnections of the entire basin water resources." Prasad et al. [2002] had emphasized the great need to protect the existing wetlands in India, pointing out that "even a small country like UK could designate 161 wetlands as Ramsar sites, India ... so far managed to delineate a mere six sites till date." The number of Ramsar wetlands in India subsequently increased to 25 out of more than 200,000 identified wetlands in the country [SAC, 2011], but hundreds of other wetlands (including many in the NRGB) are in a state of pitiable degeneration on account of urbanization and land-use changes in their catchments, wetland encroachments, water withdrawals, and agricultural, municipal and industrial pollution [Bassi et al., 2014; Dhandekar, 2011].

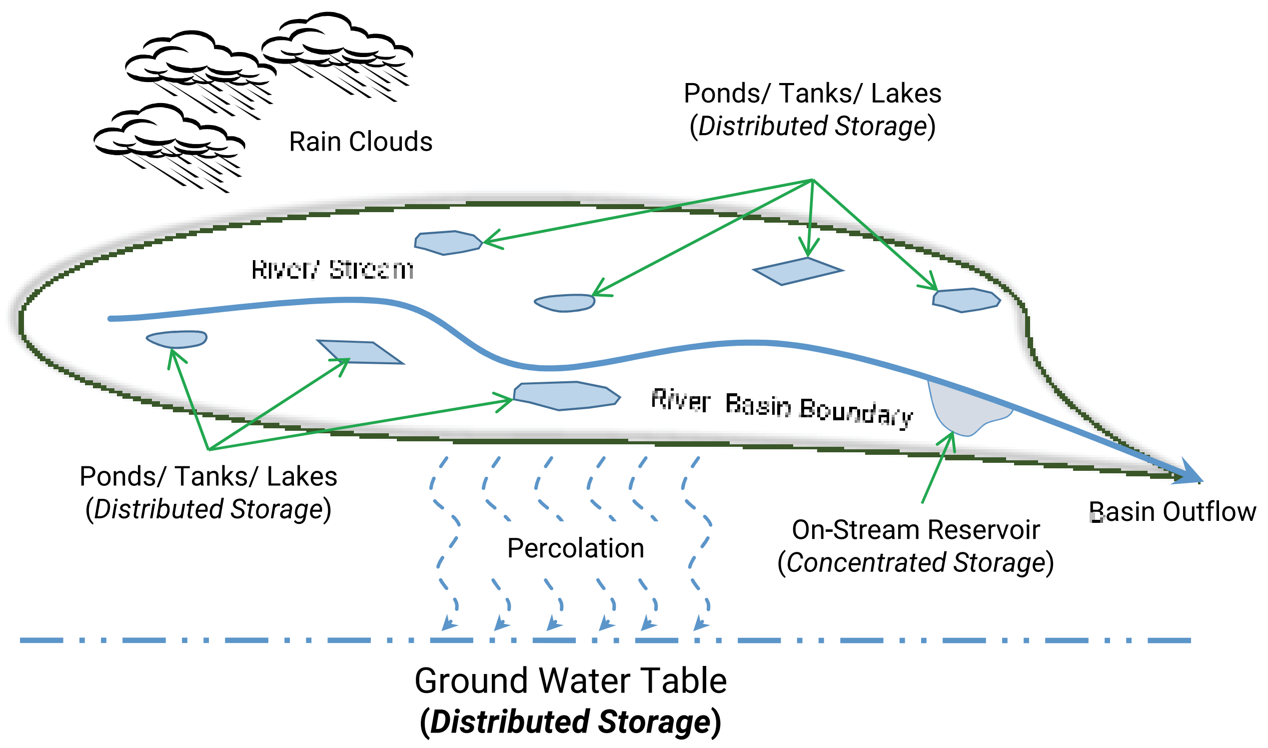


Figure 5.2: Storm-water Runoff Storage Options – Concentrated and Distributed Storages

Forests and grasslands, too, have reached minuscule proportions in the NRGB except in high altitude regions [India-WRIS, 2012]. Like wetlands, natural vegetal covers provide multiple environmental benefits including biodiversity conservation, erosion control, nutrient cycling, air and water purification, maintenance of soil health, increased groundwater recharge, flood mitigation, increased dry season flows, and increased precipitation. The last three points are particularly relevant for NRGB's water resources. The so-called sponge effect of forests – namely the ability of forests to absorb excess waters during floods and release them gradually later – has sometimes been questioned, but studies convincingly show that forests minimize flood peaks and increase dry season flows in rivers [see for example, Ogden et al., 2013]. On the last aspect concerning the effect of forests on precipitation, water resource experts typically consider forests as water-guzzling ecosystems on account of the high transpiration rates from trees; what is ignored in the water balance is the precipitation component of the regional hydrological cycle. But global field studies show that forests actually increase the precipitation in a region

[Ellison et al., 2012]. Thus, even for the purpose of water budget only, forests can play a major role in improving the hydrological status of NRGB, especially in dry seasons.

Overall, the restoration and preservation of wetlands, forests and grasslands, combined with other water and soil conservation measures, are imperative needs in NRGB.

5.2 Water Use Efficiency

While water is a renewable resource, the renewal capacity of NRGB is limited by the region's precipitation and physiographic factors. Increasing water usage has led to progressively decreasing water availability and growing water crises in parts of the basin. More significantly, that fresh water usage in the basin as a whole may be nearing the average annual water renewal capacity may not have been realized by water-users, but this is a distinct possibility. Fresh water usage or demand control is therefore of utmost importance, effective measures for which are already `pursued by many developed and developing countries. China's achievement in this regard is well-known to the Indian water establishment [Iyer, 2012], and her continuing efforts – such as 3-tiered water pricing for urban domestic supplies [Spegele & Kazer, 2014] – are worth noting. Broadly, several measures are required to ensure efficient water use, viz.:

i) Realistic pricing of fresh water (especially for urban, industrial, commercial and affluent agricultural consumers) and disincentives for wastage of water.
ii) Techno-economic assistance and incentives for poor and marginal sections (such as those engaged in subsistence agriculture) to improve water-use efficiencies.
iii) Allocation of water rights and entitlements to stakeholders.
iv) Direct reuse of water where possible, e.g. reuse of irrigation return flows.
v) Treatment and recycling/ reuse of domestic and industrial wastewaters where feasible.

5.3 Water Resource Policy

The foregoing discussions strongly suggest that the government strategy on managing NRGB's water resources needs some major changes. The desired policy changes may be stated as follows:

A) Government agencies usually deal with NRGB's water resources independently of other natural resources; but the basin waters are intimately linked with other vital resources of the basin, such as soil (and sediments), nutrients (organic and inorganic) and biotic resources. It is imperative therefore that water resource management in NRGB should be assimilated into a broader framework of natural resource management instead of the myopic water-only focus.

B) Thus far, governmental action on "water resources development" has meant extracting increasingly more water (and hydro-energy) from the basin for human use. This emphasis on water and energy abstractions has often led to the water resource systems themselves being endangered, as evident from many vanishing wetlands and streams. Thus, if "development" and "use" of water resources lead to their extinction, then it is evident that government priority must shift from "development" and "conjunctive use" of surface and ground water resources to their "conjunctive preservation".

C) In recent decades, large-scale water (especially groundwater) abstractions from the environment are being effected by water-users themselves. Other aquatic resources are also being directly tapped by users. Yet, users are not entrusted with the maintenance of water resource systems, thereby creating a contradiction between ownership and usage. The obvious need to give stakeholders the rights and responsibilities to maintain water resource systems has been advocated by many experts [e.g. ADB, 2009; Sen, 2009; Thakkar, 2012; UNICEF et al., 2013]. Broadly in line with these suggestions, it is suggested that water resources management should shift from "centralized government control" to "decentralized stakeholder control" combined with "expert guidance and regulation" for regional balance and sustainability.

5.4 Environmental Flows

Flow is one of the main drivers of biodiversity in rivers, and a river's flow regime – the variation of high and low flows through the year as well as variation over the years – exerts great influence on its ecosystem. Environmental Flows (or E-Flows) are a regime of flow in a river that mimics the natural pattern of a river's flow, so that the river can at least perform its minimal natural functions such as transporting water and solids received from its catchment and maintaining its structural integrity, functional unity and biodiversity along with sustaining the cultural, spiritual and livelihood activities of people. As per the Brisbane Declaration [2007], "Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems." In other words, E-Flows describe the temporal and spatial variations in quantity and quality of water required for freshwater and estuarine systems to perform their natural ecological functions (including material transport) and support the spiritual, cultural and livelihood activities that depend on them, vide IITC [2011].

After reviewing several different holistic methods of estimating E-Flows and in consultation with stakeholders and expert groups, the Building Block Method (BBM) was found to be robust and scientifically most suitable for rivers, as explained in the above report. But since it was found that the method results in Bigger Block governing E-Flows, BBM was considered to denote Bigger Block Method in GRBMP [IITC, 2011]. The method had been developed in South Africa through numerous applications in water resources development to address E-Flows requirements for riverine ecosystems under conditions of variable resources. Based on this method, E-Flows were computed for different sites of interest in the Ganga River System. It should be noted here that the BBM method quantifies only the lower bound on flow rates required at different times to sustain the river, and does not specify other conditions to be maintained in the river. One of these conditions is, of course, the connectivity in river flow. But maintaining the water-sediment balance is also an essential condition. In the absence of empirical data at specific sites, the required

Box 5.1

Steps for Calculating E-Flows

1. Generation of Stage-Discharge curve at the E-Flows site using river cross section and hydraulic modelling.
2. Identification of keystone species for the stretch that represents the E-Flows site.
3. Assessment of temporal variations in depth of flow required to ensure survival and natural growth of keystone species.
4. Assessment of temporal variations in depth of flow from geomorphological considerations factoring longitudinal connectivity in all seasons and lateral connectivity of active flood plain for the historically observed number of days during monsoon season.
5. Assessment of minimum ecological depth of flow (higher of steps 3 and 4 above) and generation of Minimum Ecological Flows hydrograph.
6. Determination of 10-daily Average Flows and 90% Dependable Flows from historical flow data.
7. Applying the trend of variation of 90% Dependable Flows with the estimated minimum ecological flow depths to obtain 10-daily E-Flows hydrograph for dry and wet seasons.
8. Comparison of E-Flows and Ecolgical Requirements hydrograph with hydrographs for average and 90% dependable virgin flows.

Flow is one of the main drivers of biodiversity in rivers, and a river's flow regime – the variation of high and low flows through the year as well as variation over the years – exerts great influence on its ecosystem.

sediment flux has not been computed; it is suggested that E-Flows should carry suspended load and bed load in approximately the same proportions as present in the virgin flow.

To illustrate the E-Flows results, some of the selected sites on Alaknanda and Bhagirathi rivers of the Upper Ganga Segment are shown in Figure 5.3. These sites were chosen as they are considered to have high hydropower potential. The basic procedure for computing E-Flows is summarized in Box 5.1, and the detailed procedure is described in the concerned thematic report [IITC, 2014d]. The geomorphological and biological features of the respective sites were analysed and the sites were physically surveyed to map the river cross-sections. The virgin river flows at these sites were considered for the period of data availability from CWC for the period 1972 to 1982 (prior to construction of Tehri Dam when the rivers could be considered 'virgin' or undisturbed). The virgin flows at the E-Flows sites were then estimated from the virgin flows at the nearest measuring stations.

E-Flows at the sites selected depend on ecological and geomorphological requirements and the minimum ecosystem goods and services of the river (including the cultural, spiritual and livelihood requirements). Referring to Figure 5.4, basic ecological flows corresponding to minimum depth D1 are required during all seasons for general mobility of keystone river species. For the spawning period of keystone species, minimum ecological flows corresponding to depth D2 are needed throughout the spawning season. Further, from geomorphological considerations, increased discharges corresponding to depth D3 are needed for 18 days during the monsoon season (preferably distributed over the season). To determine these requirements, the keystone species in the given river stretches were identified, and the required depths D1 and D2 were determined for these species. Since flow depths at pools are higher than at riffles, hence the critical E-Flows sites were selected at riffle sections, thus ensuring that the flow depths in the entire reach would not be less than D1 or D2. The flows corresponding to D1 and D2 were then read from the stage-discharge curves for the given sites. To determine D3, the average virgin flows that were exceeded for 18 days during the monsoon (i.e. between June and October, but generally between July and September) were computed. This corresponds to average virgin flows having 20% dependability during monsoons. The depth D3 was then read from the stage-discharge curve and checked against the available river depth at the site. The flows computed thus constitute the minimum ecological requirements of the river. The Environmental Flows were obtained by mimicking the trend of annual variation of 90% Dependable Flow using the minimum ecological requirement for non-monsoon season as the minimum environmental flow for non-monsoon. For monsoon season, the 90% Dependable Flow variation was mimicked by first deducting the flows corresponding to D3 and then adding the deducted values on the mimicked hydrograph.

It may be noted that the above procedure identifies two separate limiting flow conditions. The lower limit of Minimum Ecological Requirement may be considered essential for minimal river functioning (with survival of biota), while the higher limit of Environmental Flows would allow healthy river functioning (allowing maintenance of healthy biodiversity and production of ecosystem goods and services by the river). Thus, actual river flows above the E-Flows range would indicate a River in Good Health, while flows below this range but above Ecological Requirements would indicate a River in Marginal Health; and below the Ecological flow limit the river would be in Grossly Unsatisfactory Health. It should be noted, however, that this distinction of River Health status pertains to hydrological quantities only, and not to river water quality. For quality aspects, the flow of sediments, nutrients and other natural constituents need to be further accommodated.

The sample results for E-Flows and Minimum Ecological Requirements for a representative site at Ranari, Dharasu are illustrated below, excluding quantitative flow data (which are classified government data).

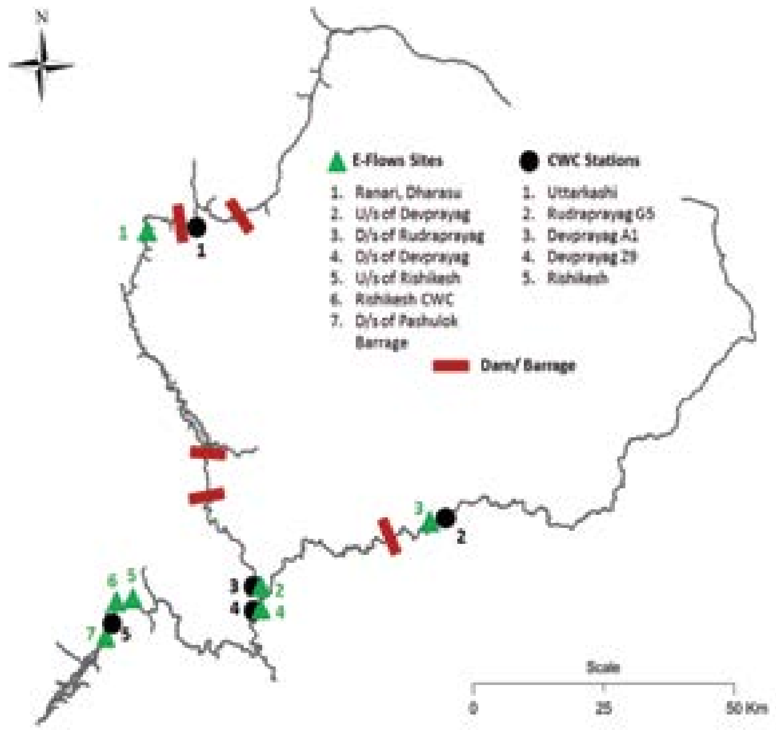
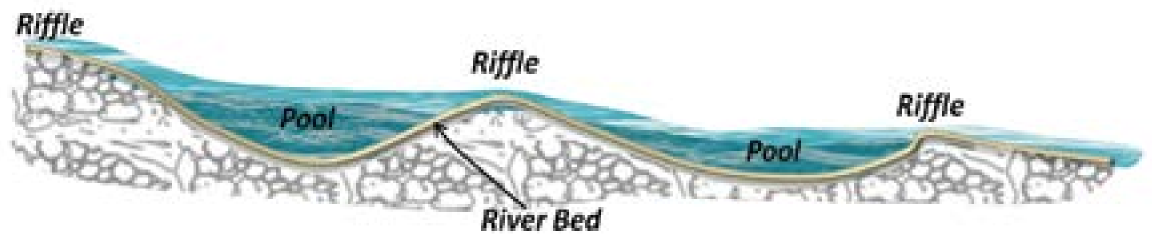
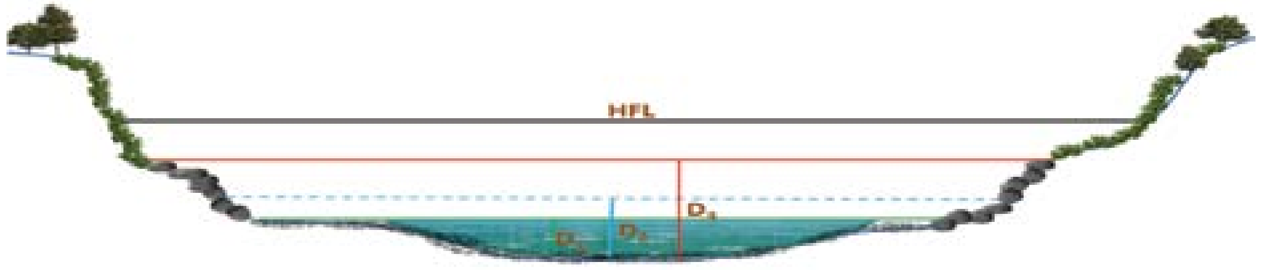


Figure 5.3: Location Map of Flow Monitoring Stations and E-Flows Sites



Riffle and Pool Locations in Longitudinal River Profile



River Cross-Section at E-Flow Site

D_1 – Depth of water required for mobility of keystone species during lean period.

D_2 – Depth of water required for mobility of keystone species during spawning period.

D_3 – Depth of water required to inundate some riparian vegetation for 18 days/year.

Figure 5.4: E-Flows Assessment – Conceptual Diagram

A. E-Flows at Site 1: Ranari, Dharasu (Lat 30°43′02″N, Long 78°21′17″E)

Geomorphic Attributes: Confined, incised river channel with coarse bed material in degradational regime in Himalayan steep valley.

Cross-Section at Site:

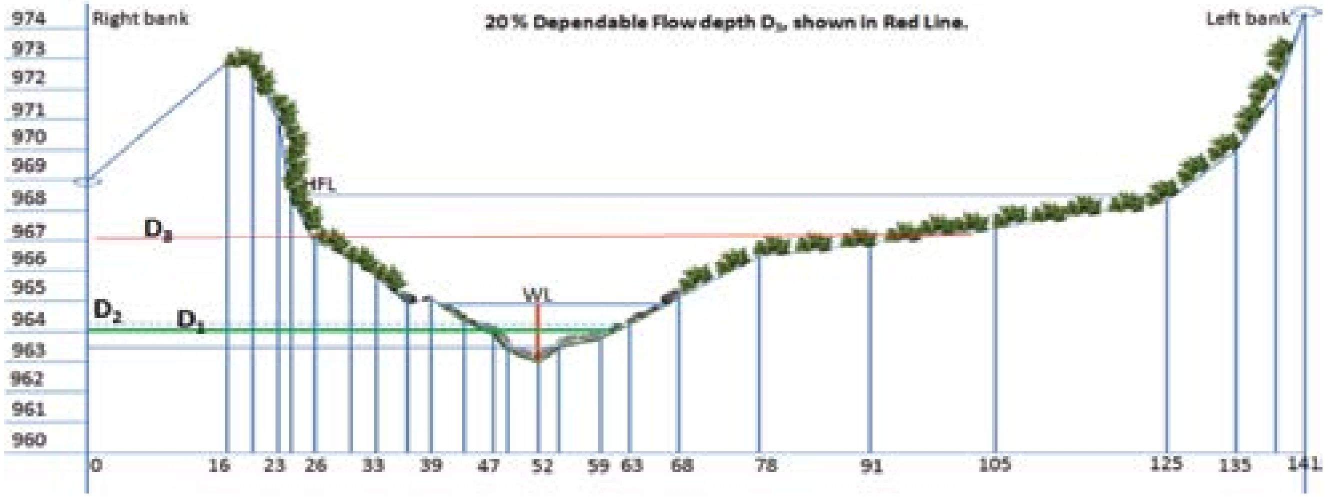


Figure 5.5: River Cross-section at Ranari, Dharasu

Keystone Species	Environmental Clearance		
	D1	D2	D3
Snow Trout (*Schizothorax richardsonii*)	0.5 m	0.8 m	3.41 m
Golden Mahseer (*Tor putitora*)			

Computed E-Flows:

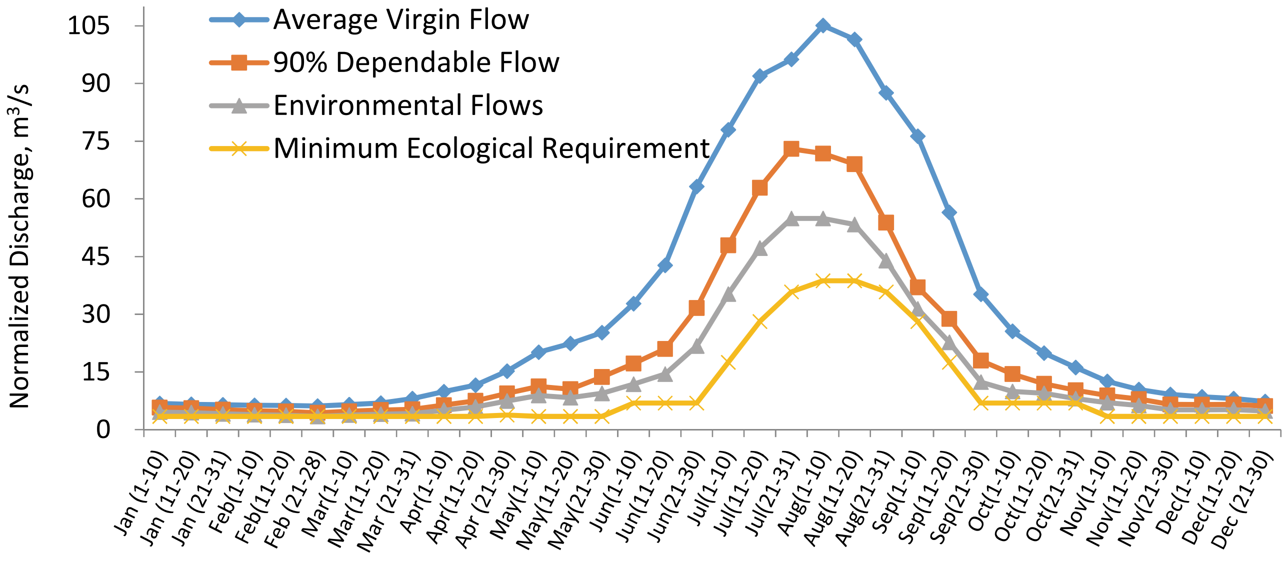


Figure 5.6a: E-Flows at Ranari, Dharasu

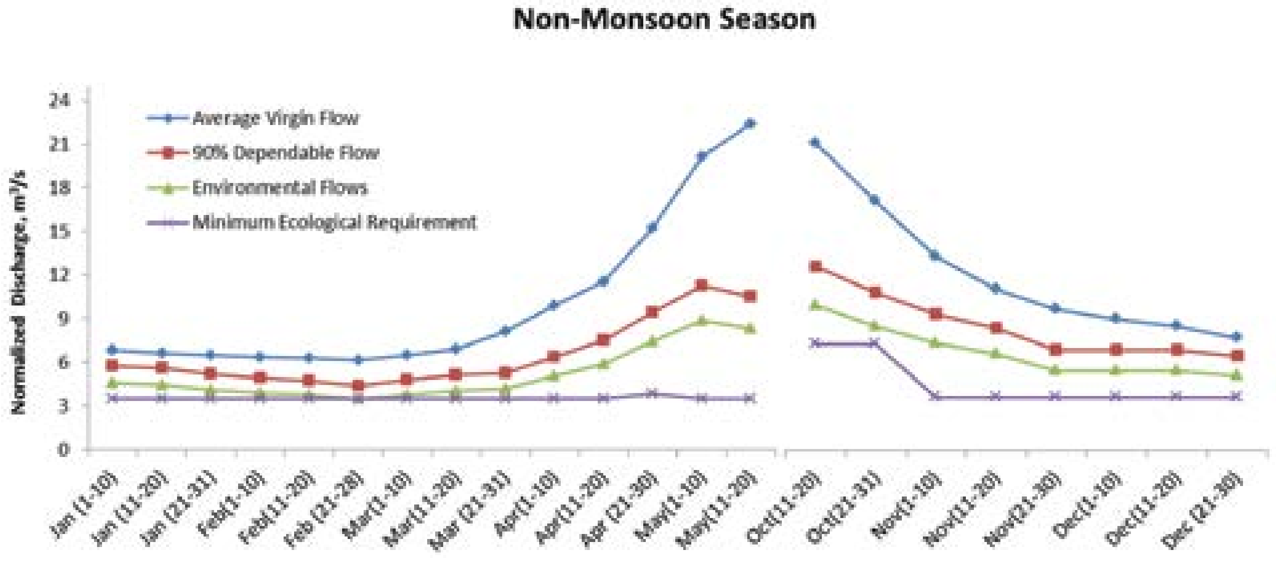


Figure 5.6b: E-Flows during Non-Monsoon Season at Ranari, Dharasu

Table 5.2: Percentage of Virgin River Flow required as E-Flows at Ranari, Dharasu

Period of Year (Season)	Wet Period	Dry Period	Annual
Minimum Ecological Requirement as percentage of Average Virgin Flow	32.59%	32.96 %	32.67 %
E-Flows as percentage of Average Virgin Flow	46.13%	53.12 %	47.54 %

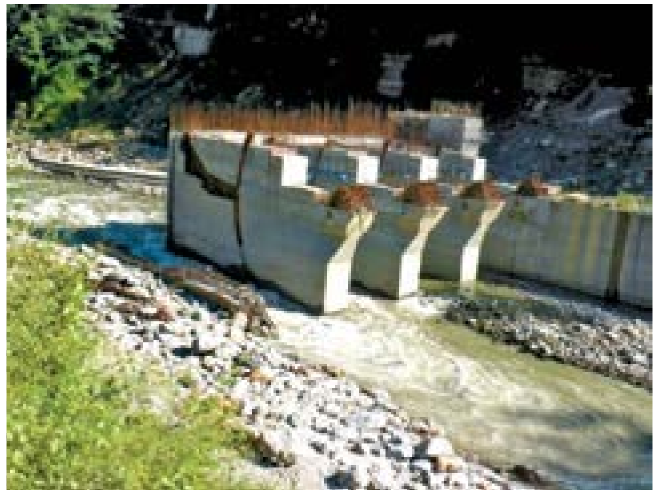
As seen from the above results, the minimum ecological flows required to maintain river integrity are about one-third of the average virgin flows of the river in both dry and wet seasons, while the E-Flows required are about half the average virgin flows. However, this fraction varies over the year and is relatively higher during dry season, river flows being minimum in winter.

Adoption of E-Flows at Dams and Barrages:

It is evident from the preceding results that, although river flows vary significantly round the year, except for the high flows needed 18 days a year, the required ecological flows at a given site vary much less over the year if D1 and D2 are of the same order of magnitude (in the sample case presented above, D1 and D2 are 0.5 m and 0.8 m, respectively). Correspondingly, the mimicked E-Flows will also vary over a limited range. Hence, prima facie, it should be possible to allow a river passage of adequate dimensions through (or bypassing) a dam to transport sediment-laden E-flows and allowing the natural migration of aquatic species. For high flows needed 18 days a year corresponding to depth D3, passage of aquatic species is not required, and that of river sediments is not essential since their primary purpose is to flush excess river bed deposits and enable bank wetting. Hence these higher E-flows can be passed through the gates of the dam/ barrage.


Maneri Bhali–1 Barrage


Srinagar Dam


Singoli–Bhatwari Barrage


Vishnuprayag Barrage Site

Figure 5.7: Some Existing and Under-Construction Barrages in Upper Ganga

It must also be noted that in the case of discharges from hydropower plants, contrary to the conventional practice of sudden and voluminous releases of tail waters, the releases should be moderated in accordance with the river's natural flow regime. It is suggested that, in general, the maximum rate of tail water discharge should be within the maximum flows in dry and wet seasons respectively, with allowance being made for discharges corresponding to depths D1, D2, or D3 being released through the dam or river passage. The moderation of tail water discharges can be suitably achieved by use of tail-end balancing reservoirs.

To gauge the overall feasibility of the proposed scheme, photos of some existing and under-construction barrages are presented in Figure 5.7. It may be noted here, however, that while river passage through a dam/ barrage can be designed and constructed integrally with the dam/ barrage for new projects, for existing dams/ barrages the required changes may be difficult; hence alternative means may need to be explored in such cases to ensure river connectivity capable of carrying E-Flows.

River passage through a dam/ barrage may have to be designed and constructed integrally with the dam/ barrage for new projects, for existing ones alternative means may need to be explored to ensure river connectivity capable of carrying E-Flows.

6. HYDROLOGICAL MODELING OF GRBMP AND INFERENCES

In order to obtain a quantitative picture of the hydrological status of NRGB and its likely change under various scenarios, hydrological modeling was carried out for the surface water and ground water system of the combined Ganga basin area in India (i.e. NRGB) and Nepal covering 1,028,468,63 sq. km. area [IITC, 2014c]. The SWAT (Soil and Water Assessment Tool) Model was adopted to simulate the surface water response of the basin, the basin being subdivided into 1045 sub-basins for model computations. The model results were calibrated with observed river discharge data at 30 locations on the main stem and tributaries of the Ganga river network. The raw data used included static spatial data (digital elevation data, drainage network data, soil maps, soil characteristics, and land use data), dynamic hydro-meteorological data, and water demand and abstraction data. The model simulation was carried out for the period 1969–2006 (37 years) over the basin. The groundwater model was set up for the alluvium part of the basin (shown in Figure 6.1) using MODFLOW computer model.

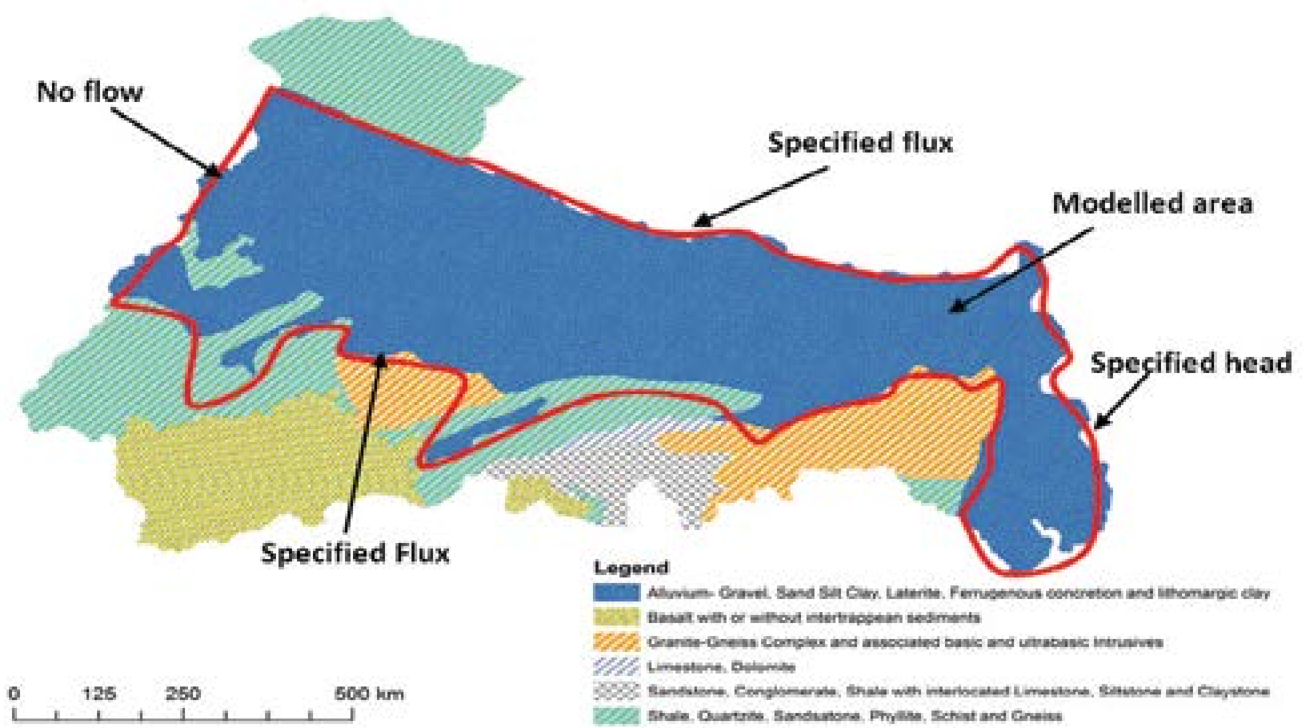


Figure 6.1: Groundwater Model Area of Ganga Basin [IITC, 2014c]

The modeling effort was constrained by data limitations such as absence of precipitation data for higher elevation areas, of canal water diversions, and of crop management (irrigation) practices. Besides, out of about 206 dams/ reservoirs in the basin, information was available on only 104 such structures, and canal command area information was also missing in some cases. Limitations are also likely on the quality of data used for other anthropogenic parameters such as land use and groundwater abstractions. Subject to such constraints, the computational model was calibrated and validated against observed streamflow data at about 24 flow measuring stations and groundwater data at about 100 observation wells. The summary outcome of surface water modeling is shown in Figure 6.2a in terms of the basin's 37-year average annual water balance components, viz.: (i) Total Streamflow (Water Yield) consisting of surface runoff, lateral and base flow, (ii) Precipitation, and (iii) Evapotranspiration. The monthly variation of the average water balance components are shown in Figure 6.2b. As evident from the figures, streamflow

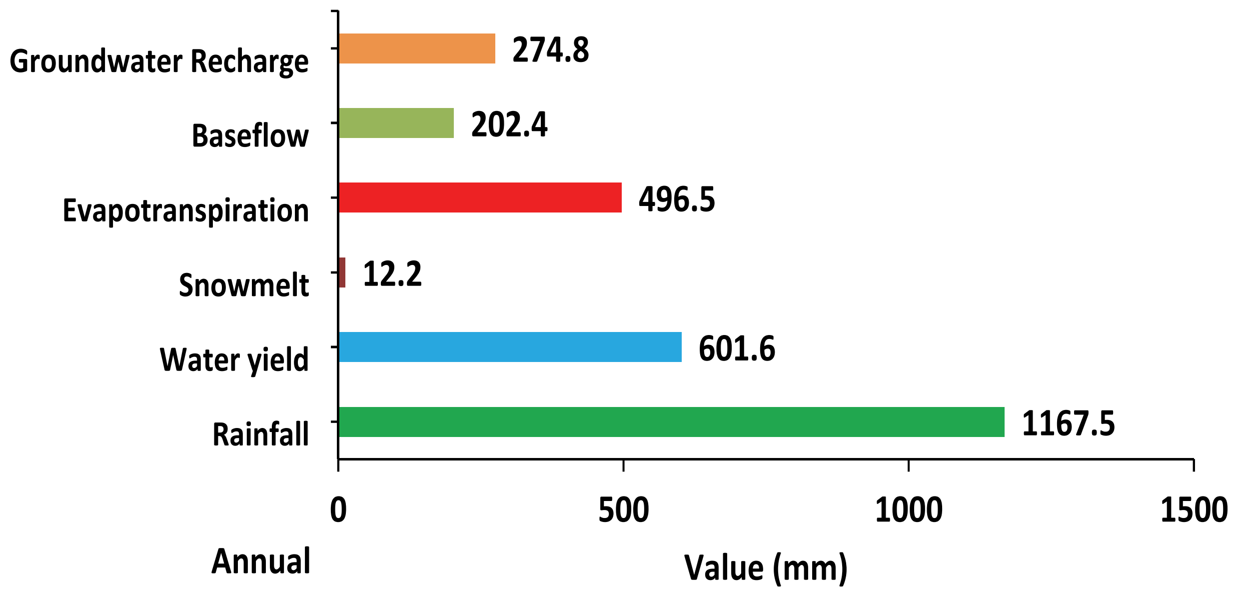


Figure 6.2a: Average (1969-2006) Annual Water Balance of the Modeled Ganga Basin

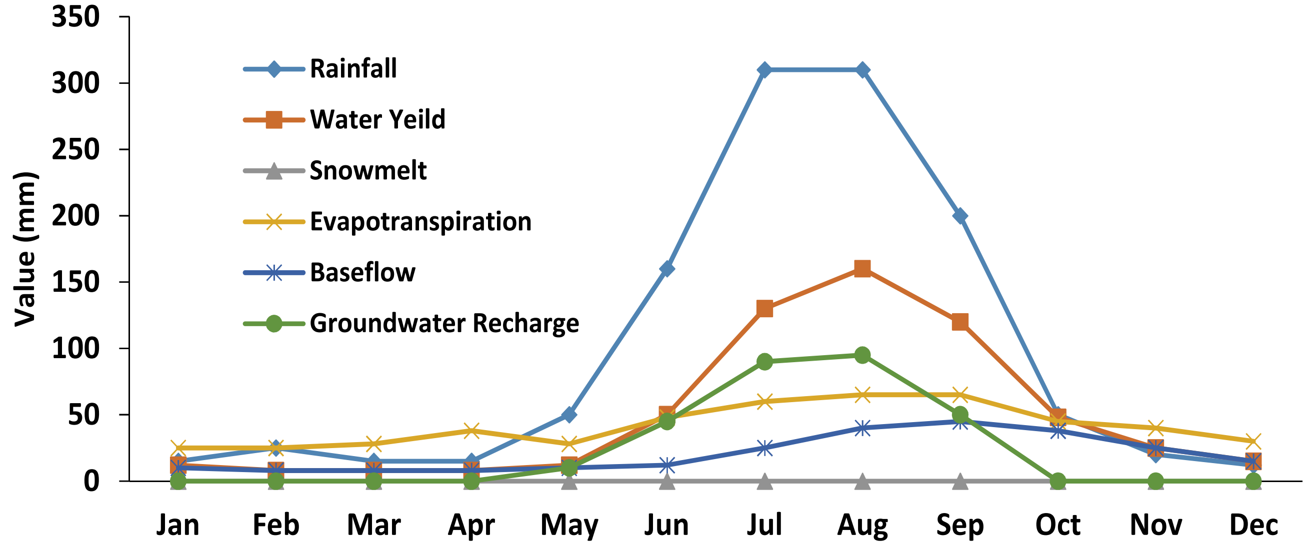


Figure 6.2b: Average (1969-2006) Monthly Water Balance Components of the Basin

and evapotranspiration are the two main components of water outgo from the modeled area. It may be noted that, on an annual basis, the average ratio of evapotranspiration to precipitation is found to be about 41-42%, which is much higher than the government norm of 23% for the Ganga basin but much lower than 60% suggested by Jain [2012] which were cited earlier in Section 4.3.

Based on the above model results, an analysis of the hydrologic flow health of the Ganga river and its important tributaries had also been carried out to obtain annual "flow health scores" of the rivers [IITC, 2014b]. In general, the study showed that the flow health scores had significantly altered in several stretches of National River Ganga and her tributaries due to the present system of river water management. However, the analysis does not cover many aspects of river health such as functional needs of ecosystems and habitats. Considering this work as a first step to understand the significance of hydrology on the health of National River Ganga, it is envisaged that a more comprehensive assessment including ecological and geomorphological considerations of river health can be developed in future within the broader framework of ecohydrology.

The hydrological model was also run to simulate the hypothetical virgin river flows under the present climatic and land-use conditions by switching off all water resource projects and considering no groundwater abstraction in the basin. The "virgin flows" of different rivers of the network and their contributions to the main stem of the river were thus obtained for the hypothetical virgin conditions over a 30-year period of model run to enable quantitative comparison with actual flows over this period. The main tributaries of the Ganga river network (and some important flow and water quality measuring stations of CWC) are shown in the line diagram of Figure 6.3. Based on the model results, Figure 6.4a shows the estimated changes in annual flows of the major tributaries of the network. The results indicate that, while the changes in flow volumes are very small in the headstreams of National River Ganga, river flows are considerably reduced in her major tributaries such as Yamuna, Ghaghra, Gandak, Kosi, Chambal, Sone, etc., thereby reducing the flow in the main Ganga river through most of her reach. Figures 6.4b and 6.4c show the comparisons of average virgin flows and actual flows for the wet season (mid-June to mid-October) and dry season (mid-October to mid-June of following year), respectively. As evident from the figures, the differences between virgin and present flows in most rivers are much more pronounced in the dry season than the wet period, with dry season flows having drastically reduced in some rivers such as Ramganga, Chambal, Yamuna and Damodar. Thus, it can be definitively concluded that anthropogenic hydrological interventions have significantly curtailed the annual flows in the Ganga river network below the Himalayan Upper Ganga Region, especially in the dry season. Further anthropogenic uses must be immediately curtailed in critical sub-basins, and corrective measures applied where possible.

The model simulation results were also analysed in further detail to compare the average hydrographs of maximum 10-daily flows, average 10-daily flows and minimum 10-daily flows under virgin and present conditions, respectively in the major sub-basins. Appendix 1 presents figures showing the comparative changes, and their significance is self-evident from the figures.

> **The flow health scores have significantly altered in several stretches of National River Ganga and her tributaries due to the present system of river water management.**

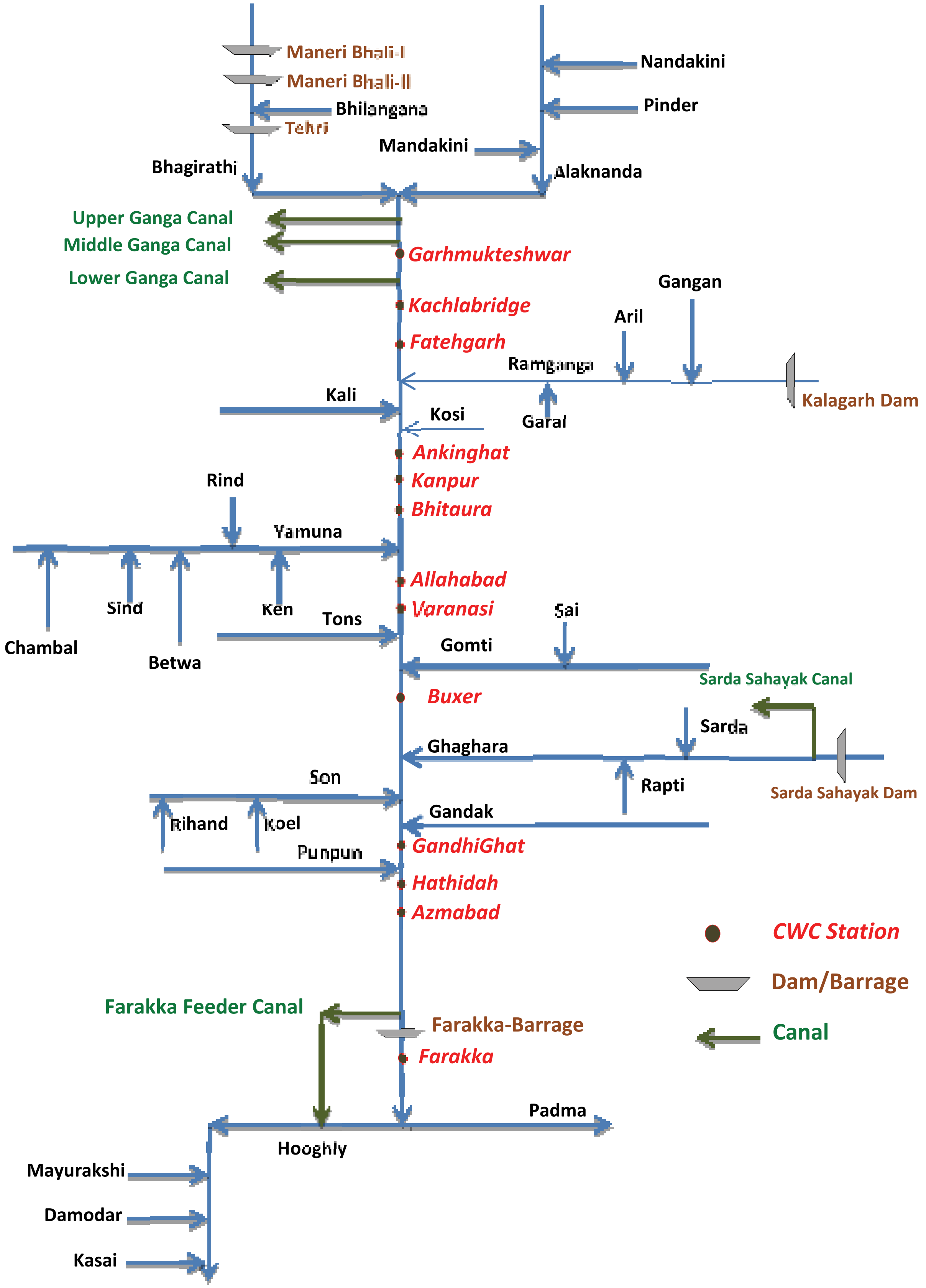


Figure 6.3: Line Diagram of Ganga River Network (with major dams/ barrages, canals, and flow and water quality measuring stations)

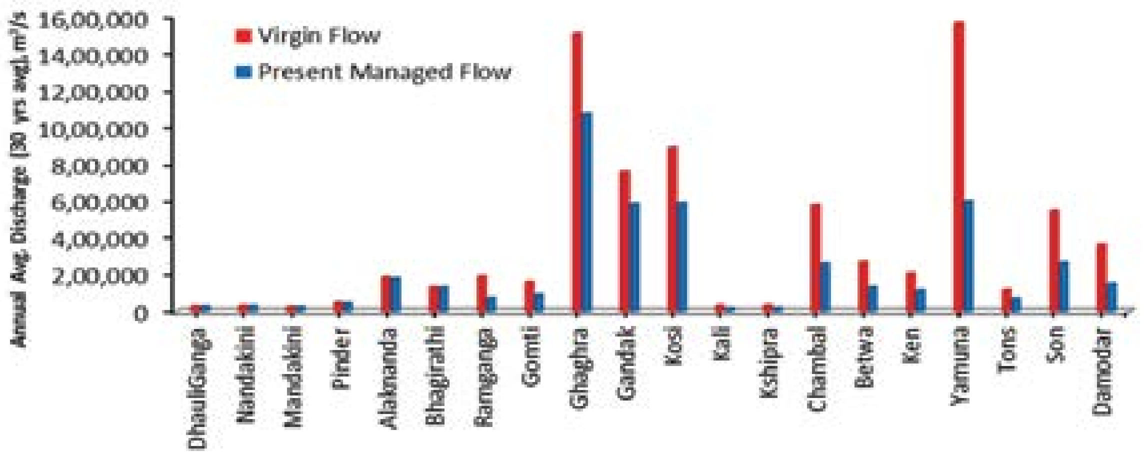


Figure 6.4a: Annual Flow Contributions of Different Tributaries (sub-basins) to National River Ganga under Present Flow Conditions and under Virgin Flow Conditions

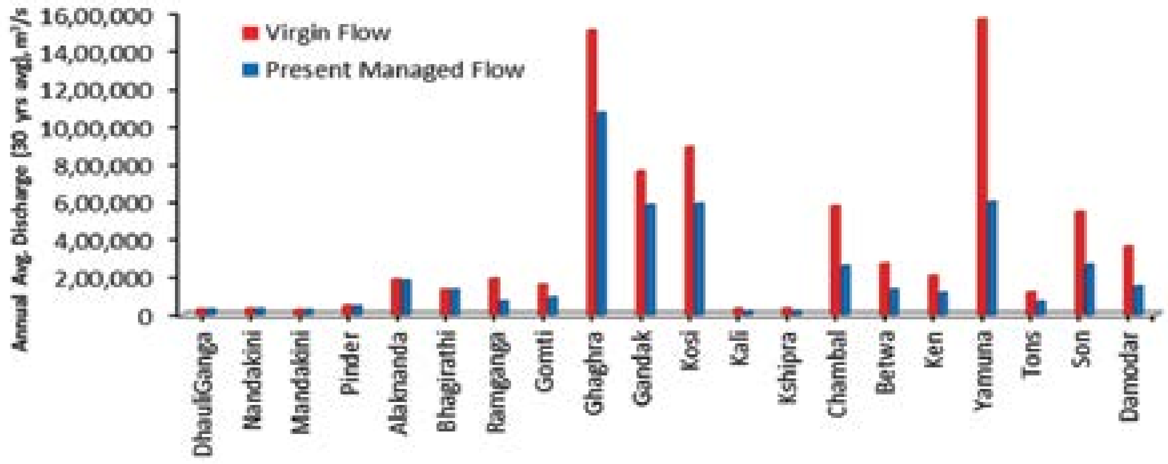


Figure 6.4b: Wet Season Flow Contributions of Different Tributaries (sub-basins) to National River Ganga under Present Flow Conditions and under Virgin Flow Conditions

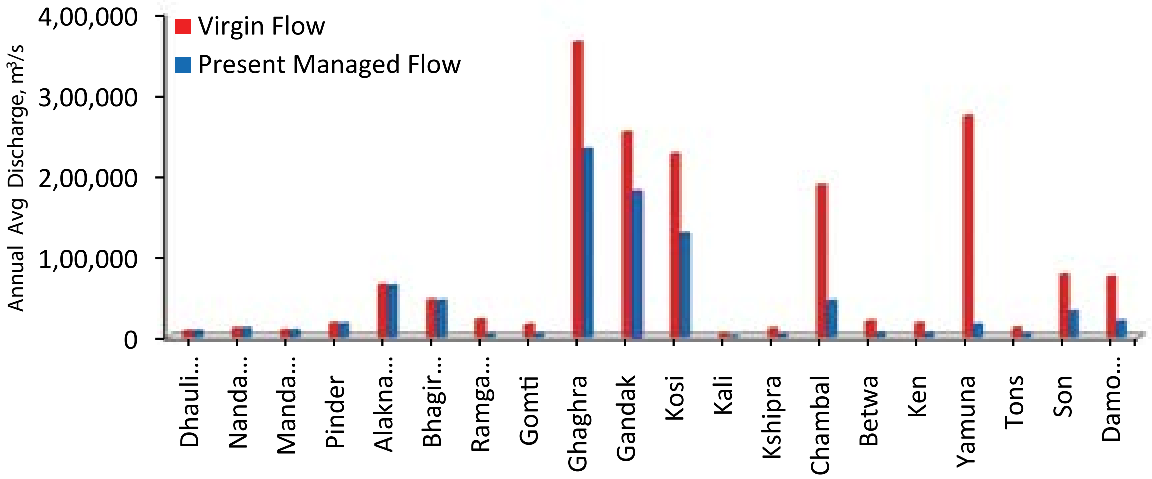


Figure 6.4c: Dry Season Flow Contributions of Different Tributaries (sub-basins) to National River Ganga under Present Flow Conditions and under Virgin Flow Conditions

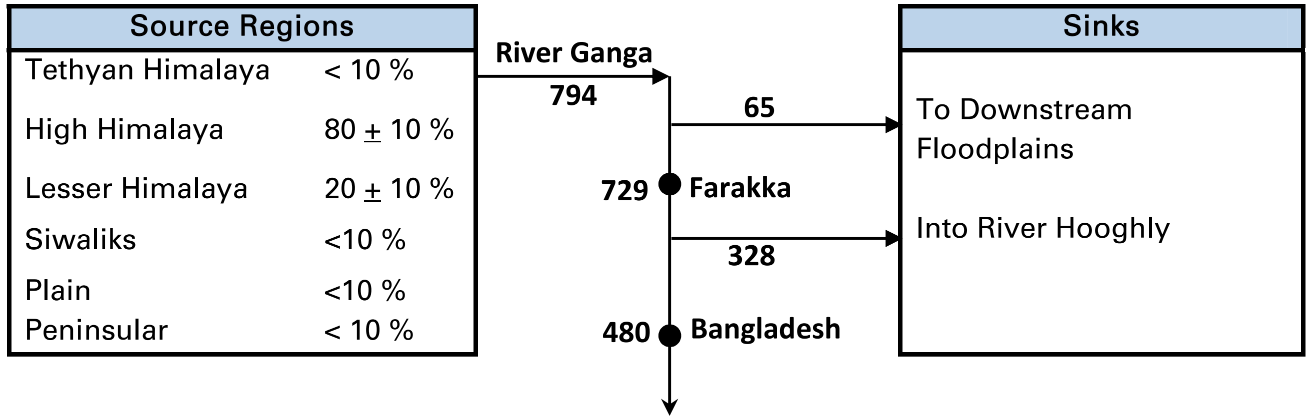
7. SEDIMENT RESOURCES OF NATIONAL RIVER GANGA

Water-borne sediments play a vital role in the dynamics and ecology of the Ganga River Network. The river's suspended sediment load – generally estimated at between 500 to 800 million T/yr (e.g. 524 million T/yr vide Tandon et al., 2008; 729 million T/yr vide Abbas & Subramanian, 1984) – is probably the third highest among the world's rivers, after the Yellow and Amazon rivers' loads [Milliman & Meade, 1983; Singh et al., 2003]. The total sediment load estimated at 2400 million T/yr [IITC, 2012] is also very high for any river, but since bed load measurements are few in the river network, the figure is very uncertain. Wasson [2003] reasoned that the long-term average of total sediment load of the combined Ganga-Brahmaputra rivers is between 1600 to 3500 million T/yr, which suggests that the total sediment load of National River Ganga could be much less than 2400 million T/yr. Nonetheless, the sediment load is exceptionally high, and it evidently plays a key role in maintaining the network of rivers in dynamic equilibrium from their sources to the delta.

Apart from their geomorphological significance, river sediments deposited on plains during floods replenish soils lost from the plains through erosion. Besides, sediments are also a potentially major source of key nutrient elements such as phosphorous as well as most of the micro-nutrient elements discussed in Section 4.1. These elements provide long-term fertility to the rivers and the delta (for maintaining healthy biota) as well as to the plains by flood deposits [Dixit et al., 2008]. The possibility of heavy metals being present in harmful proportions in the sediments has also been studied in the field, but their concentrations in sediments from upland sources are generally found to be benign in the Ganga river network [Jha et al., 1988; Purushothaman & Chakrapani, 2007; Singh et al., 2003]. In fact, considering the sediment load at 744 million tons/ year, Singh et al.'s [2003] estimate includes significant annual transport of many sedimentary micro-nutrients to the Bay of Bengal (e.g. 1.3 x 106 tons Mn, 30.0 x 106 tons Fe, 110 x 103 tons Cr, 14 x 103 tons Co, 35 x 103 tons Ni, 41 x 103 tons Cu, and 78 x 103 tons Zn). Given the known deficiency of many of these micro-nutrients in agricultural soils in NRGB (vide Mission Report on Sustainable Agriculture), the sediments deposited on flood plains would be a natural mechanism to replenish such nutrients.

Wasson [2003] conducted a sediment budget analysis and estimated that most of the long-term sediment load in the Ganga river system derives from the Himalaya mountain range (especially from the High Himalayas), with probably less than 10% coming from the Siwaliks, plains and peninsular regions of the basin, vide Figure 7.1. While the exact figures may be uncertain, the Himalayas – on account of their litho-tectonic characteristics – undoubtedly contribute the major sediment load in the river network. Thus many of the Himalayan tributaries of National River Ganga (such as the Kosi, Ghaghra, and Gandak) are known to carry enormous sediment loads, some of which tend to deposit on the plains during floods. The Himalayan ranges are therefore important not only for the hydrological regime, but also for the geomorphological stability and fertility of the basin.

Apart from their geomorphological significance, river sediments deposited on plains during floods replenish soils lost from the plains through erosion.



Source Regions	
Tethyan Himalaya	< 10 %
High Himalaya	80 ± 10 %
Lesser Himalaya	20 ± 10 %
Siwaliks	<10 %
Plain	<10 %
Peninsular	< 10 %

Figure 7.1: A Sediment Budget (in 106 tons/yr) for Ganga River Basin [Wasson, 2003]

In view of the above available information, it is first and foremost necessary to estimate the correct sediment loads in the Ganga River System. To this end, river discharges and suspended sediment concentrations measured continually at 13 measuring stations along the main stem of the National River Ganga for varying periods were availed from CWC. The said measuring stations and the period of sediment data availability are given in Table 7.1 below. Data were also available for 3 measuring stations on tributaries, but these stations have not been used here since such stations are too few. Based on data of the preceding 13 stations, the average sediment loads at different stations for the common period of data availability (1999–2006) were computed for annual, wet season and dry season sediment loads respectively, and are shown in Figures 7.2, 7.3 and 7.4. However, it may be noted that at Garhmuketswar data were available only up to 2003, so the average of the 1999-2003 period was used for this station. For further reference, the annual sediment load data for different stations are shown in Appendix II.

Table 7.1: Sediment Measuring Stations and Periods of Data Availability

Station No.	1	2	3	4	5	6
Station Name	Garhmukteshwar	Kachlabridge	Fatehgarh	Ankinghat	Kanpur	Bhitaura
Data Period	1981–2003	1981–2010	1981–2010	1981–2010	1981–2010	1981–2010

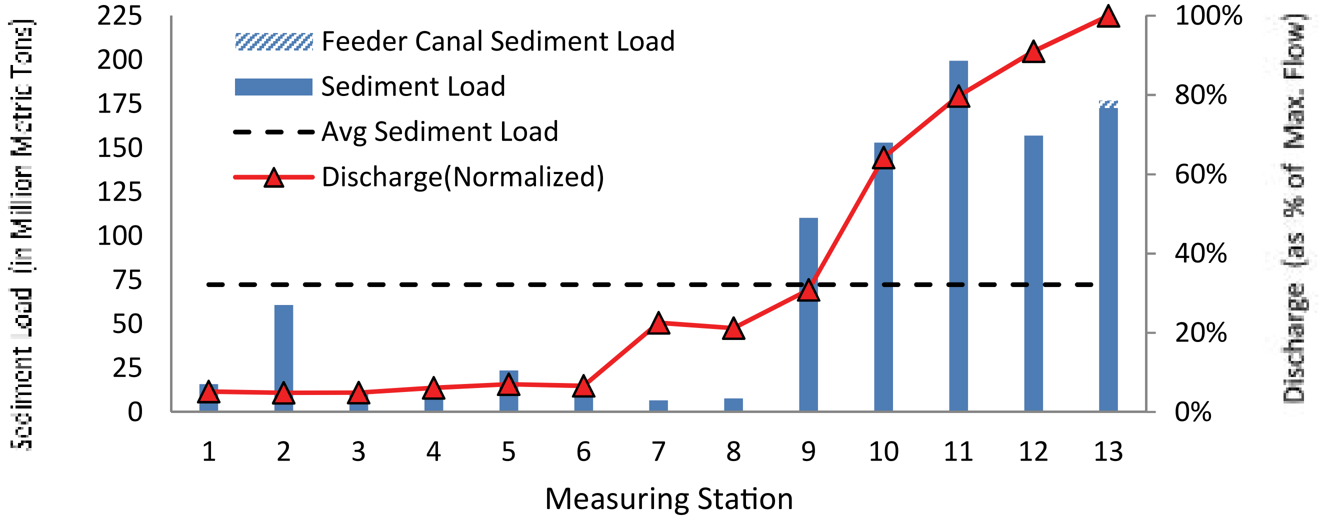


Figure 7.2: Comparison of the Annual Average Sediment Loads (for period 1999-2006) at Different Locations of National River Ganga

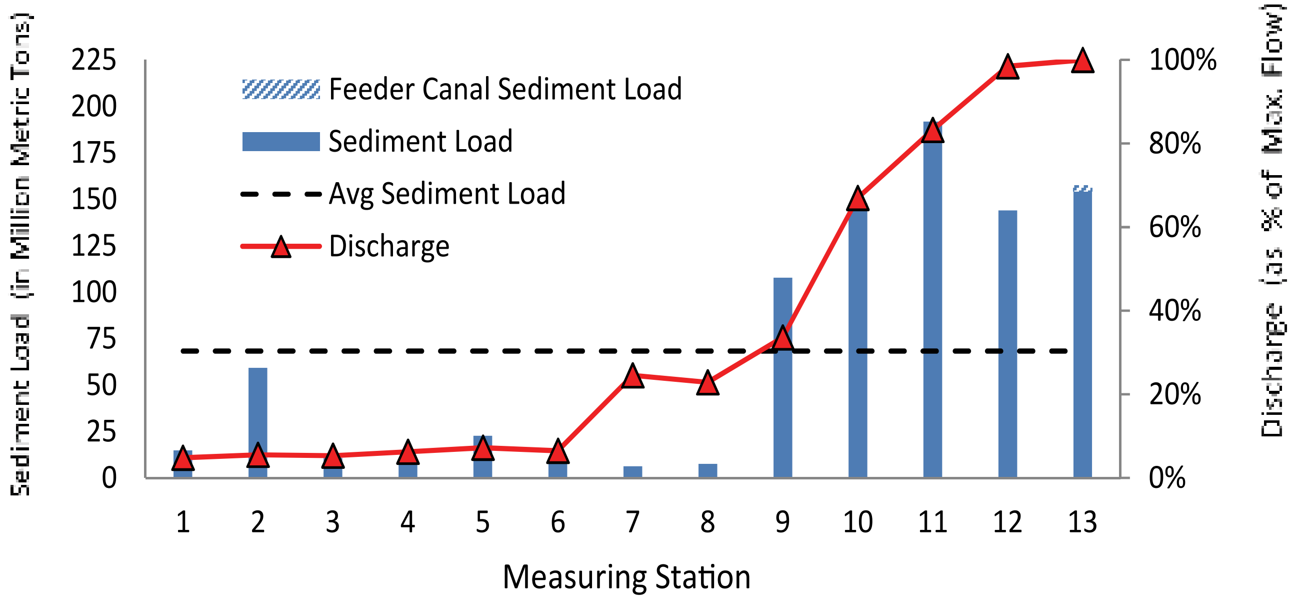


Figure 7.3: Comparison of the Average Wet Season Sediment Loads (for period 1999-2006) at Different Locations of National River Ganga

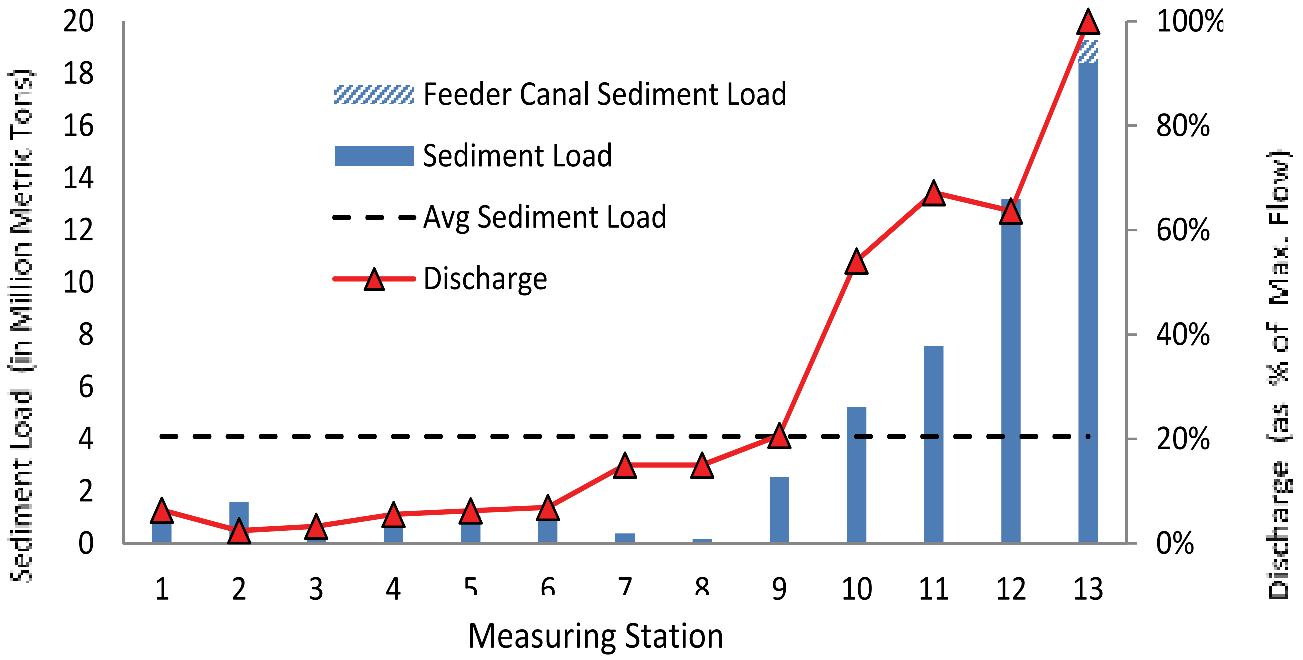


Figure 7.4: Comparison of the Average Dry Season Sediment Loads (for period 1999-2006) at Different Locations of National River Ganga

Overall, it may be noted that the common period of data availability is very limited, hence the computed results are of limited significance. But some provisional conclusions can be drawn from the figures. Firstly, the average suspended sediment load at Farakka (i.e. passing the Farakka Barrage into the Ganga/ Padma river as well as flowing into the canal feeding River Bhagirathi/Hooghly) during the period 1999–2006 is only about 177 million T/year which is much less than values between 500 to 800 million T/year commonly cited in literature. But, in consonance with observations cited in literature, most of the sediment load carried by the river occurs during the wet season.

Secondly, the sediment load variation along the main river stem is somewhat intriguing, and they suggest varying aggrading–degrading stretches along the length of the river. Generally the load increases downstream, but it jumps sharply between Garhmukteswar and Kachla bridge (despite the Lower Ganga Canal taking off in this zone) and drops at Fatehgarh, suggesting a degrading river stretch before Kachla bridge and an aggrading stretch after it. Between Kanpur and Varanasi, the river stretch again appears to aggrade to some extent with the sediment load reducing downstream (despite the Yamuna river joining below Allahabad). After Varanasi, the sediment load increases steeply at Buxar (probably due to significant sediment inflows from the Tons and Gomti rivers) and increases progressively up to Hathidah (with major tributaries like Ghaghra, Sone, Gandak and Punpun joining National River Ganga). But the sediment load decreases before Azimabad (except in the dry season), again suggesting channel aggradation in this zone. Finally there is some further increase in load at Farakka (presumably with sediment inputs from River Kosi.) It may be also seen that most of the sediment outflow from Farakka barrage carries over to the Ganga/ Padma river, with only a very small fraction entering the feeder canal of the Bhagirathi-Hooghly river.

In summing up, the above discussions throw up many questions regarding National River Ganga's sediment resources. At the minimum, they underscore the need for long-term monitoring of sediment loads in the Ganga river system including all her major tributaries, sediment budget assessments of her major sub-basins, understanding the dynamics of sediment flow in the network, and sediment quality estimates.

A major policy shift in NRGB's water resource management should bring it under the ambit of natural resource management in the basin with emphasis on resource preservation before exploitation, decentralized stakeholder control, and expert guidance and regulation.

8. SUMMARY OF RECOMMENDED ACTIONS

The main recommendations of the mission are summarized below:

1. While water withdrawals from rivers and aquifers have affected the basin's water status and accentuated the rivers' hydrological extremes, NRGB's present hydrological status is very inadequately known, especially in terms of water availability and usage. The hydrological status needs to be determined afresh and in much greater detail in order to estimate its true potential and its changing impact on different regions of the basin.
2. Considering the significant costs of land inundation, human displacements, ecological damage, operation, transportation, and evaporation losses of large in-stream reservoirs, NRGB's water resource management plan must adopt distributed water storage in the basin's groundwater, lakes, tanks and ponds, and promote wetlands and forests.
3. Increasing anthropogenic water usage needs to be checked by increased water use efficiency through realistic pricing of fresh water, incentives, technical assistance, allocation of water rights and entitlements to stakeholders, and promotion of water reuse and recycling.
4. A major policy shift in NRGB's water resource management should bring it under the ambit of natural resource management in the basin with emphasis on resource preservation before exploitation, decentralized stakeholder control, and expert guidance and regulation.
5. Dams and barrages have altered or disrupted the flow of water, sediments, nutrients and biota in the Ganga river network, severely affecting the morphology and ecology of rivers, floodplains and river valleys. Hence, all dams/ barrages must ensure longitudinal river connectivity and environmental flows (of water, sediments and other natural constituents), and new projects should be approved or rejected on the basis of a set of 4 categories of their environmental impacts as detailed in Table 5.1.
6. Hydrological model studies show significant anthropogenic effects in many sub-basins of NRGB and

NRGB as a whole. Increasing water withdrawals must be checked on a priority basis in critical regions.

7. The sediment resources of the Ganga river system need monitoring on a long-term basis and assessed comprehensibly in terms of both quantity and quality. The quantity and nutrient value of sediments trapped behind dams also need to be assessed, and nutrient-rich sediments need to be delivered to downstream river stretches and floodplains.
8. Major research needs include the determination of ecological limits, thresholds and interconnections of water resources in NRGB, and river flow health assessments within the framework of ecohydrology.

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Appendix I

Hydrographs of 30-Years' Maximum, Average and Minimum 10-Daily Flows Under Virgin and Actual (Present) Conditions for Sub-Basins of NRGB

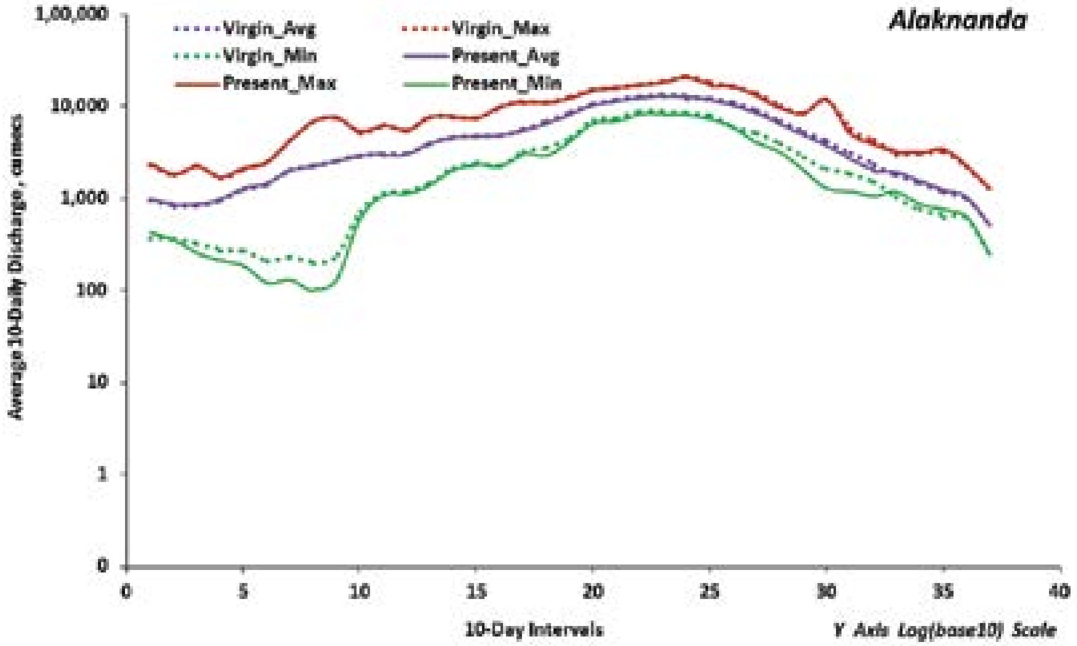

Figure A1.1: 10-Daily Hydrographs for River Alaknanda

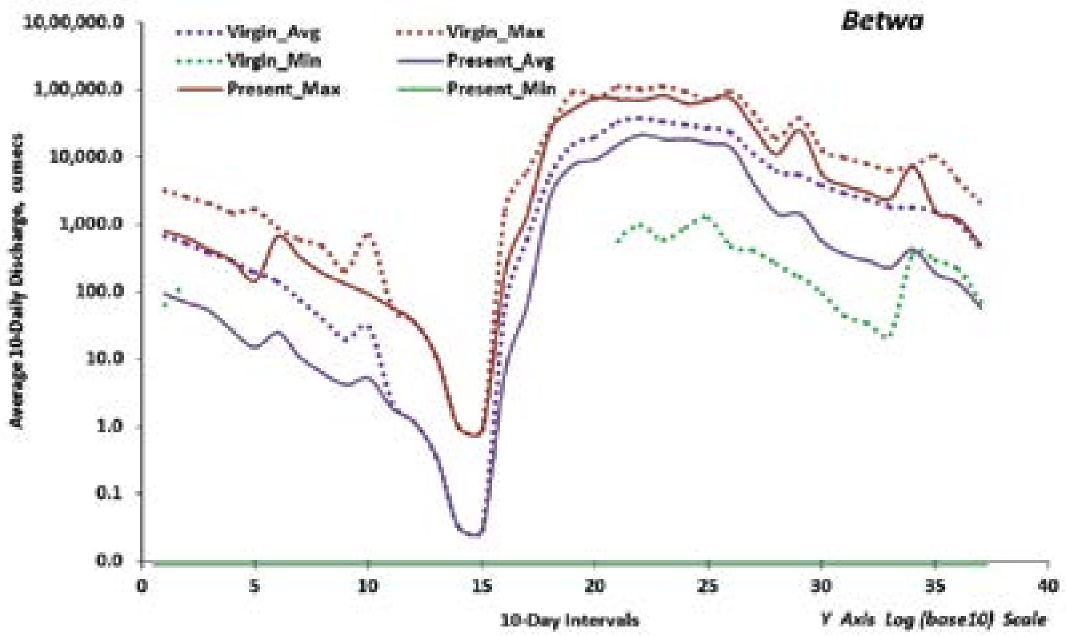

Figure A1.2: 10-Daily Hydrographs for River Betwa

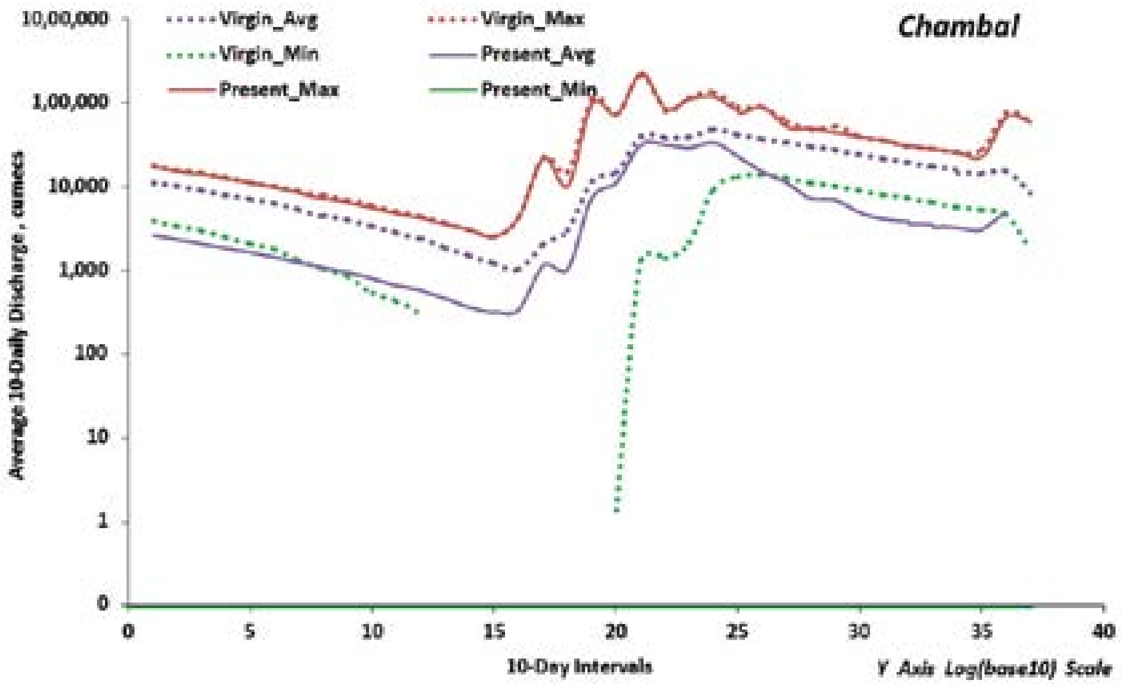

Figure A1.3: 10-Daily Hydrographs for River Chambal

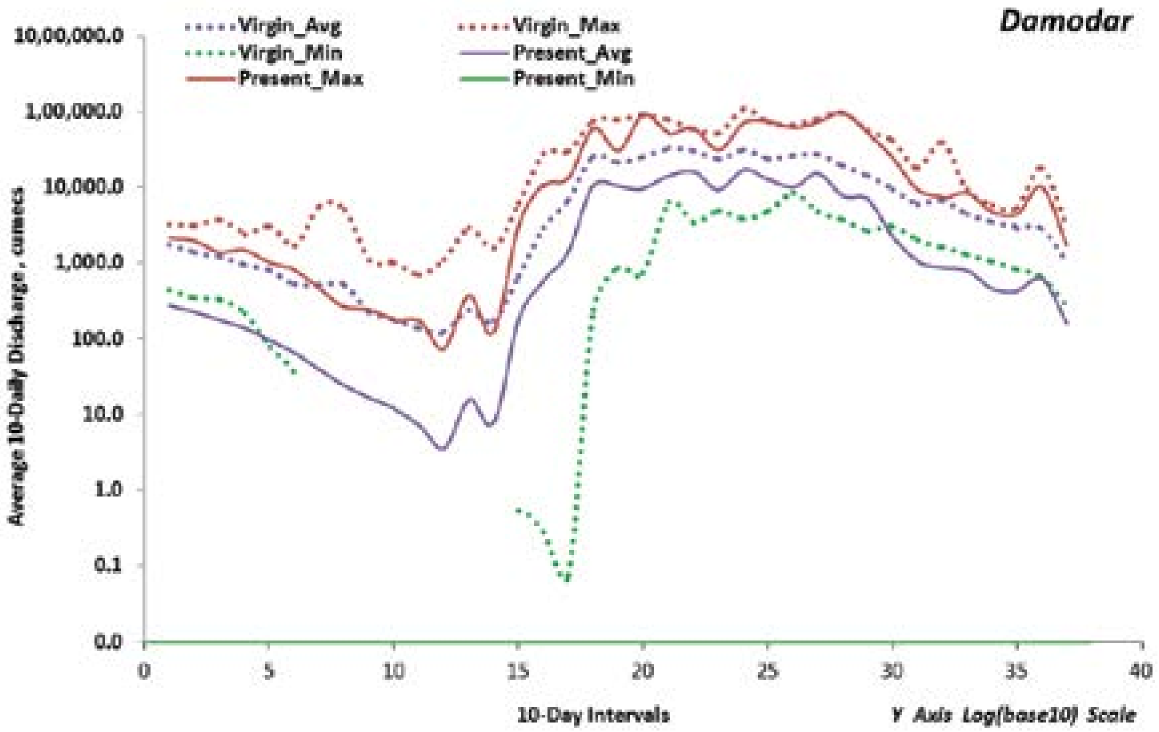

Figure A1.4: 10-Daily Hydrographs for River Damodar

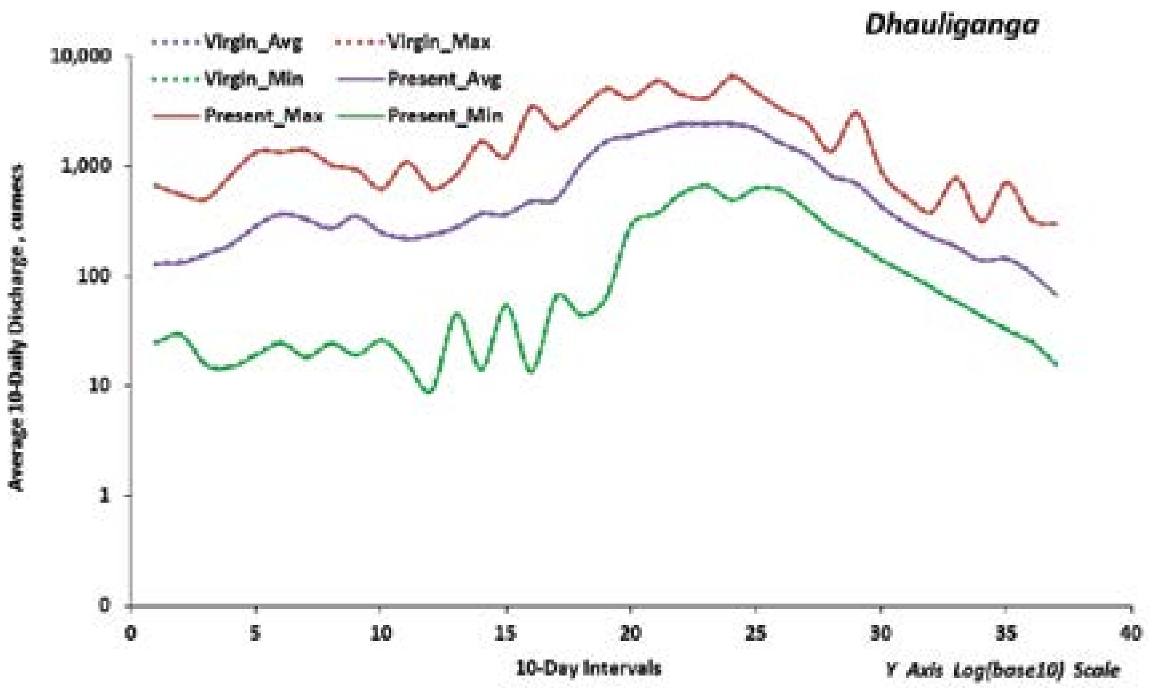

Figure A1.5: 10-Daily Hydrographs for River Dhauliganga

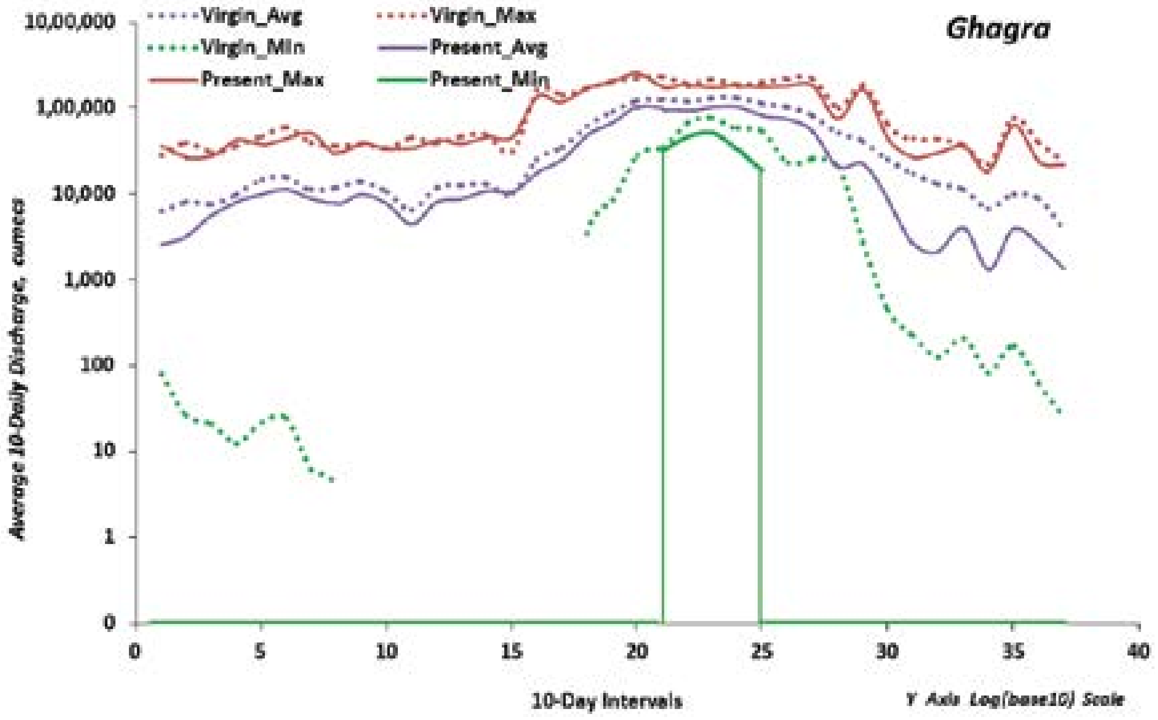

Figure A1.6: 10-Daily Hydrographs for River Ghagra

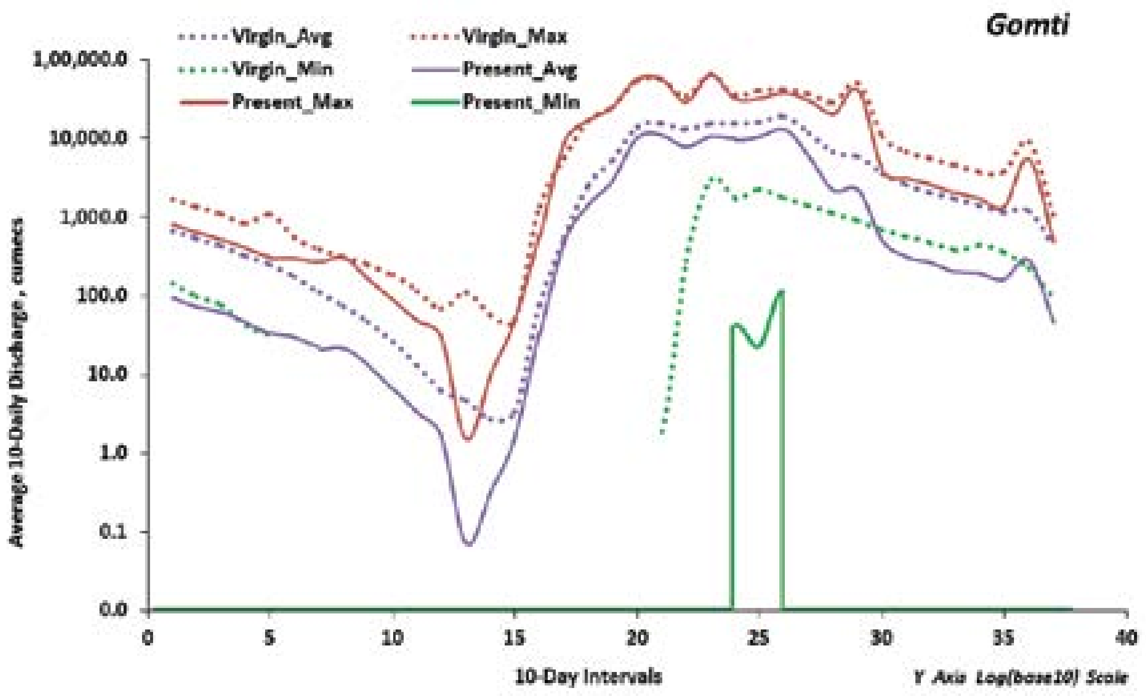

Figure A1.7: 10-Daily Hydrographs for River Gomti

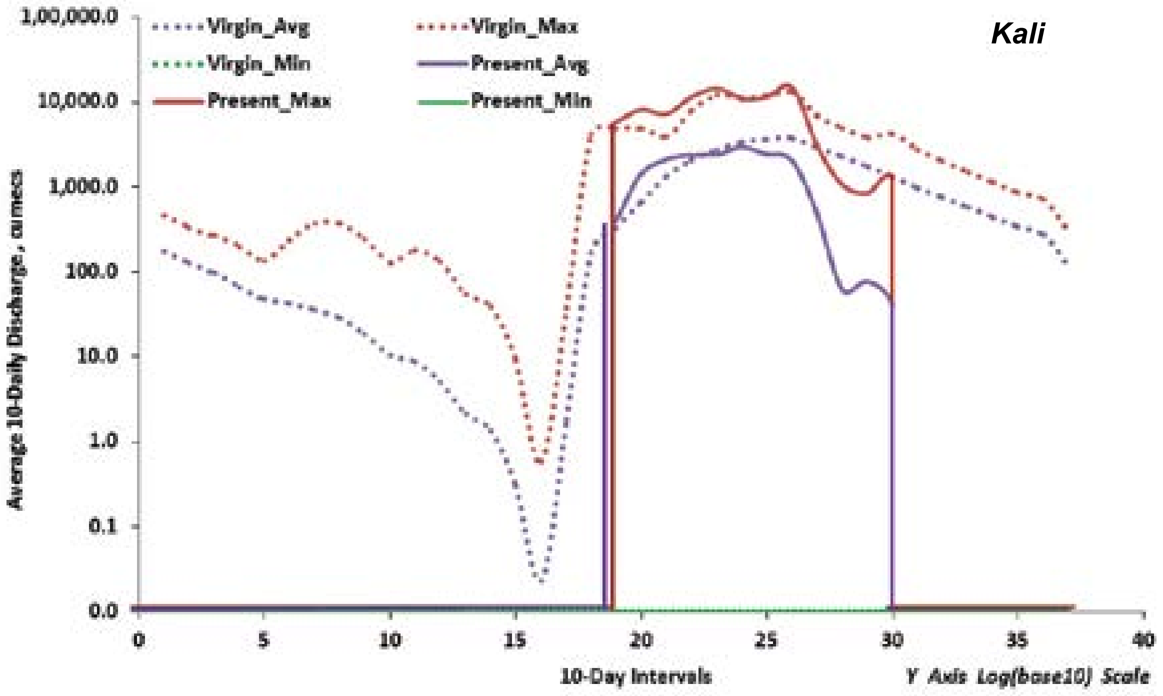

Figure A1.8: 10-Daily Hydrographs for River Kali

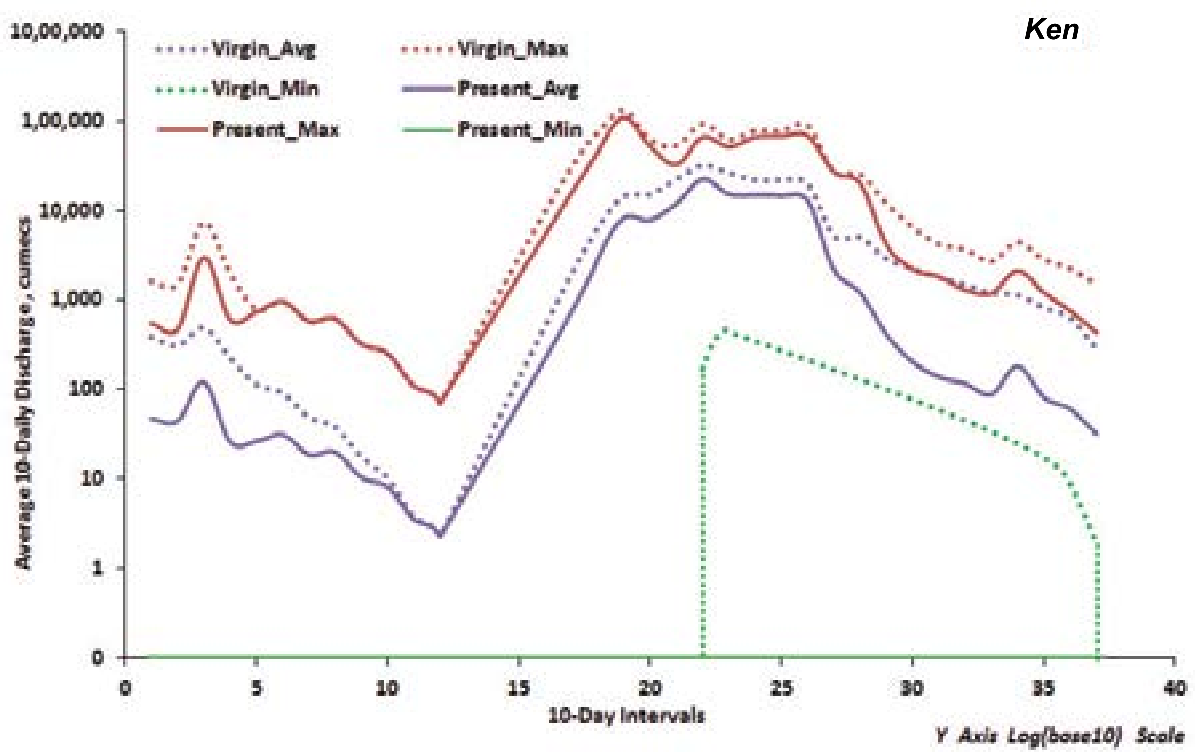

Figure A1.9: 10-Daily Hydrographs for River Ken

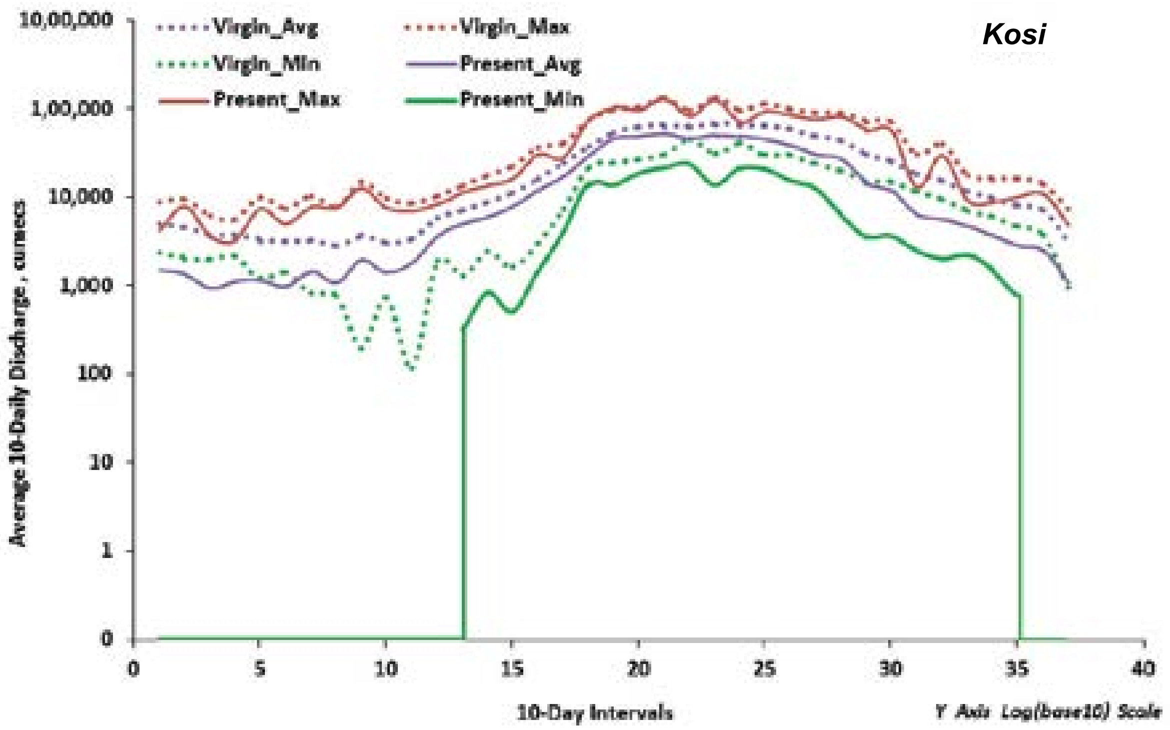

Figure A1.10: 10-Daily Hydrographs for River Kosi

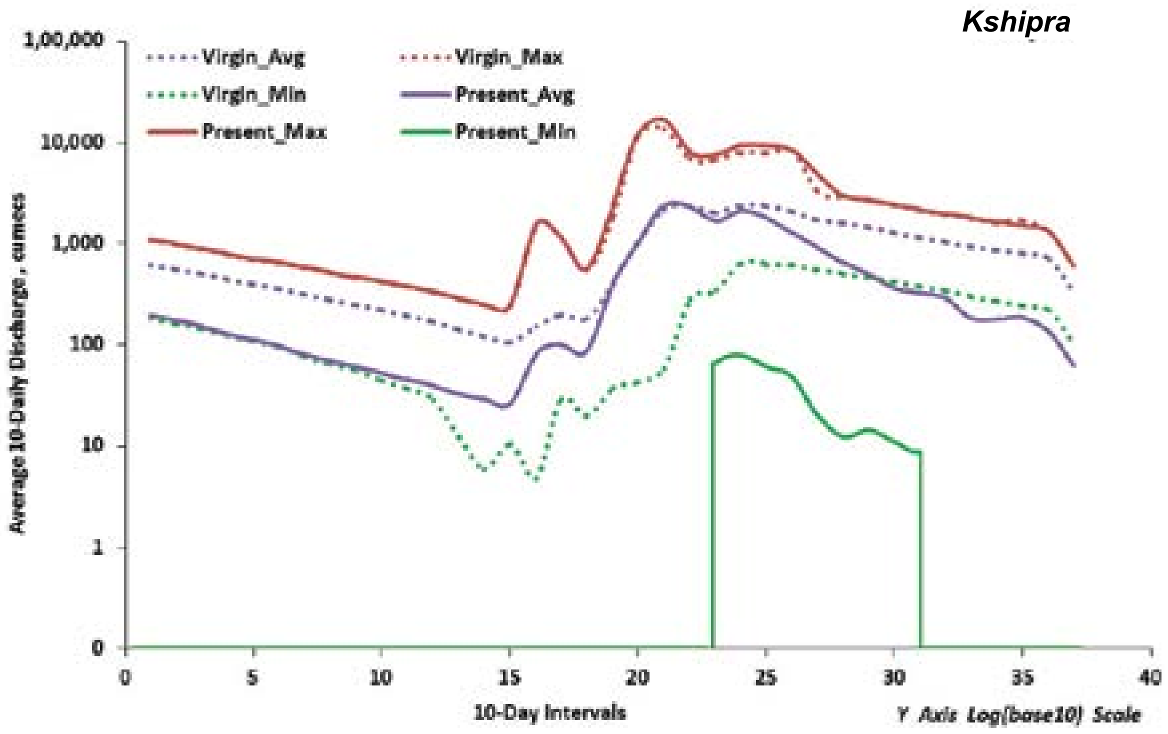

Figure A1.11: 10-Daily Hydrographs for River Kshipra

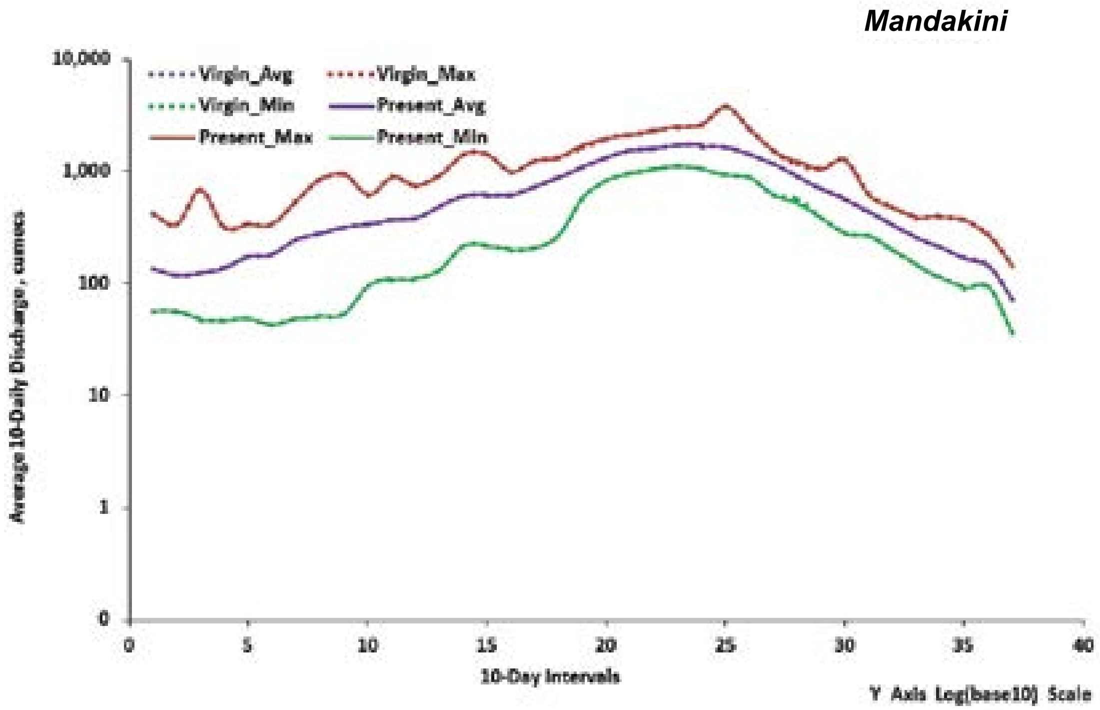

Figure A1.12: 10-Daily Hydrographs for River Mandakini

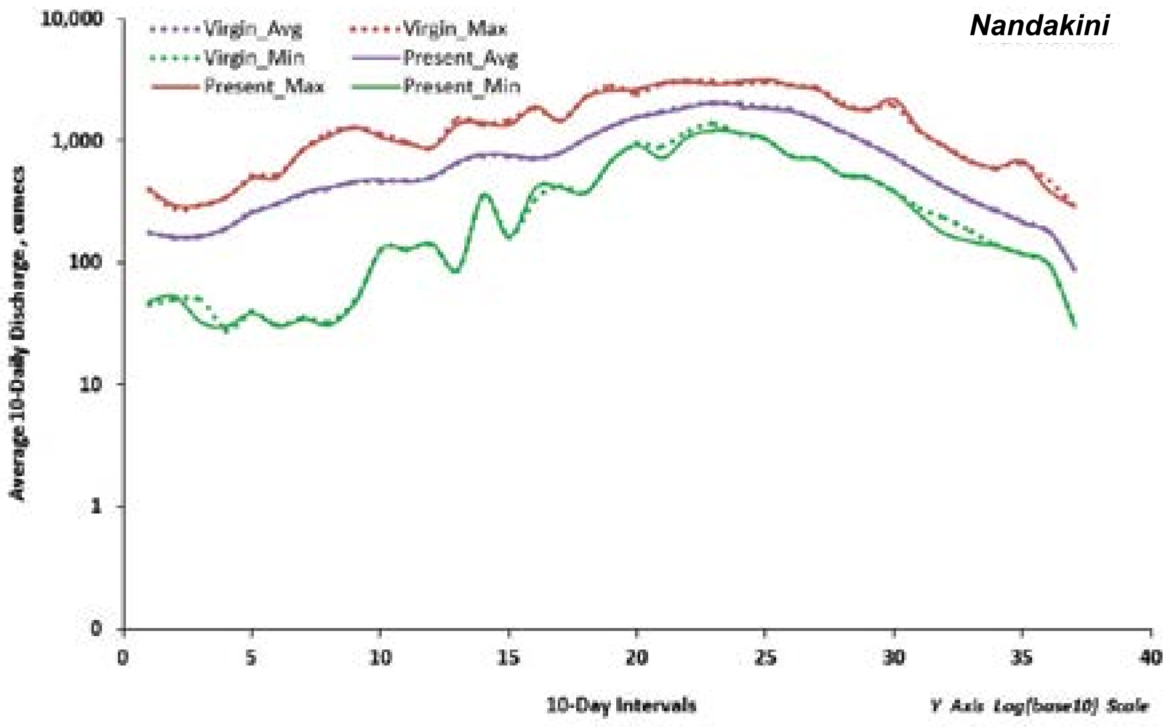

Figure A1.13: 10-Daily Hydrographs for River Nandakini

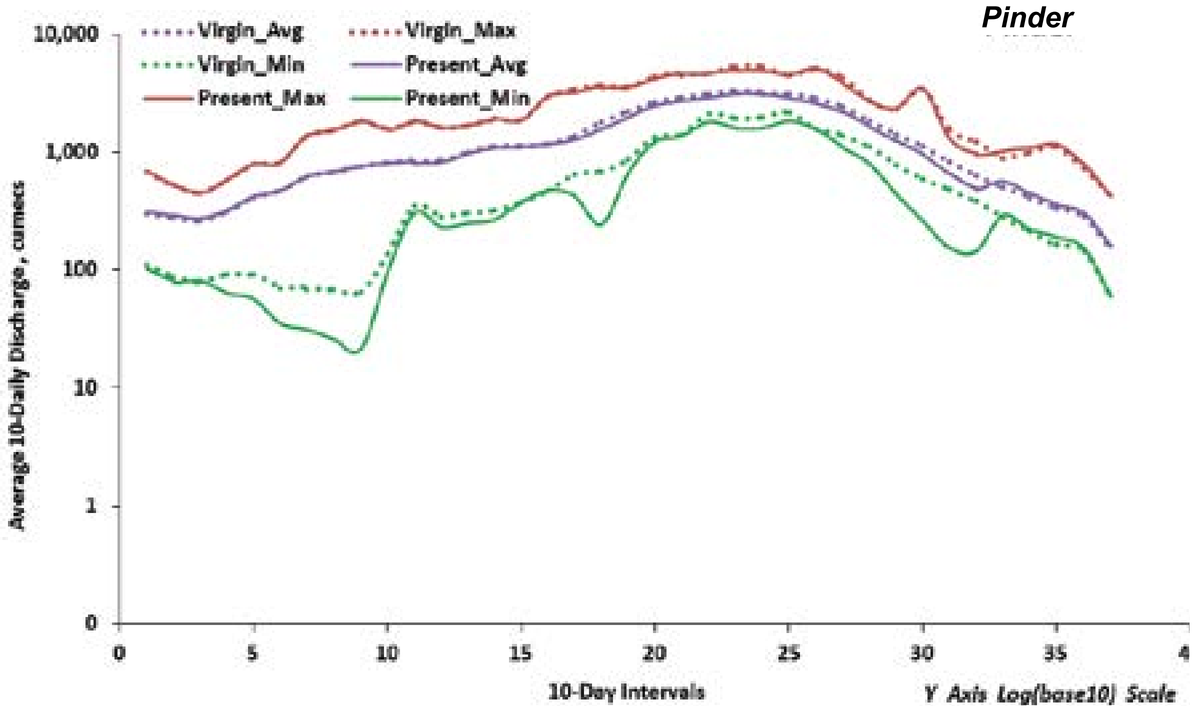

Figure A1.14: 10-Daily Hydrographs for River Pinder

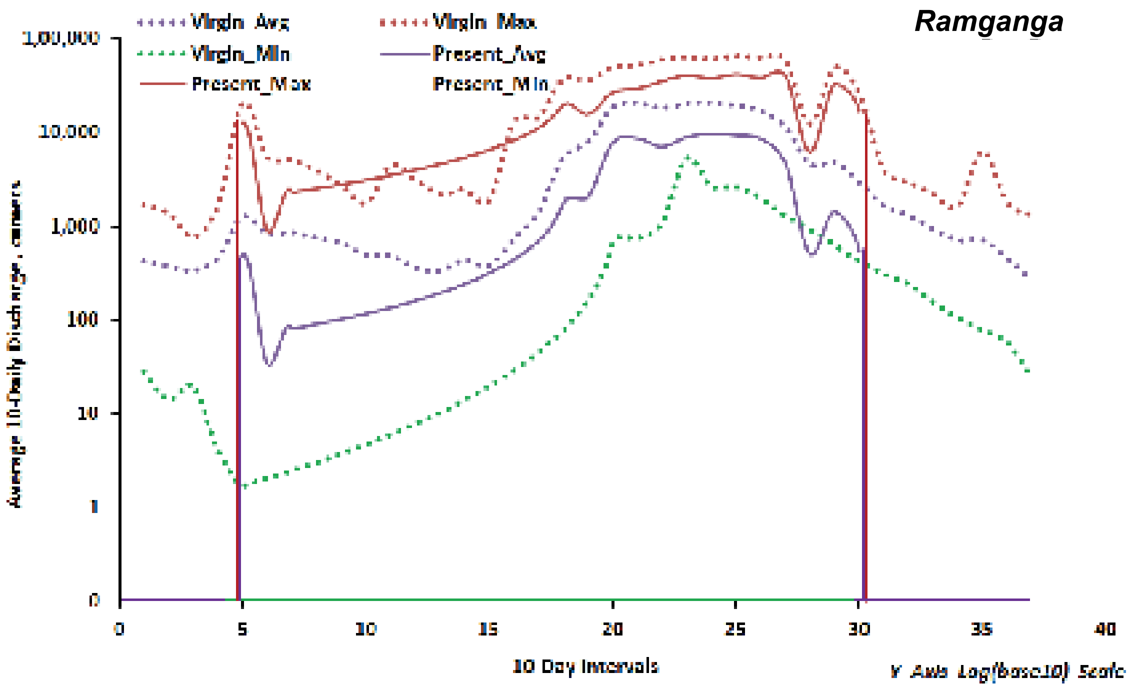

Figure A1.15: 10-Daily Hydrographs for River Ramganga

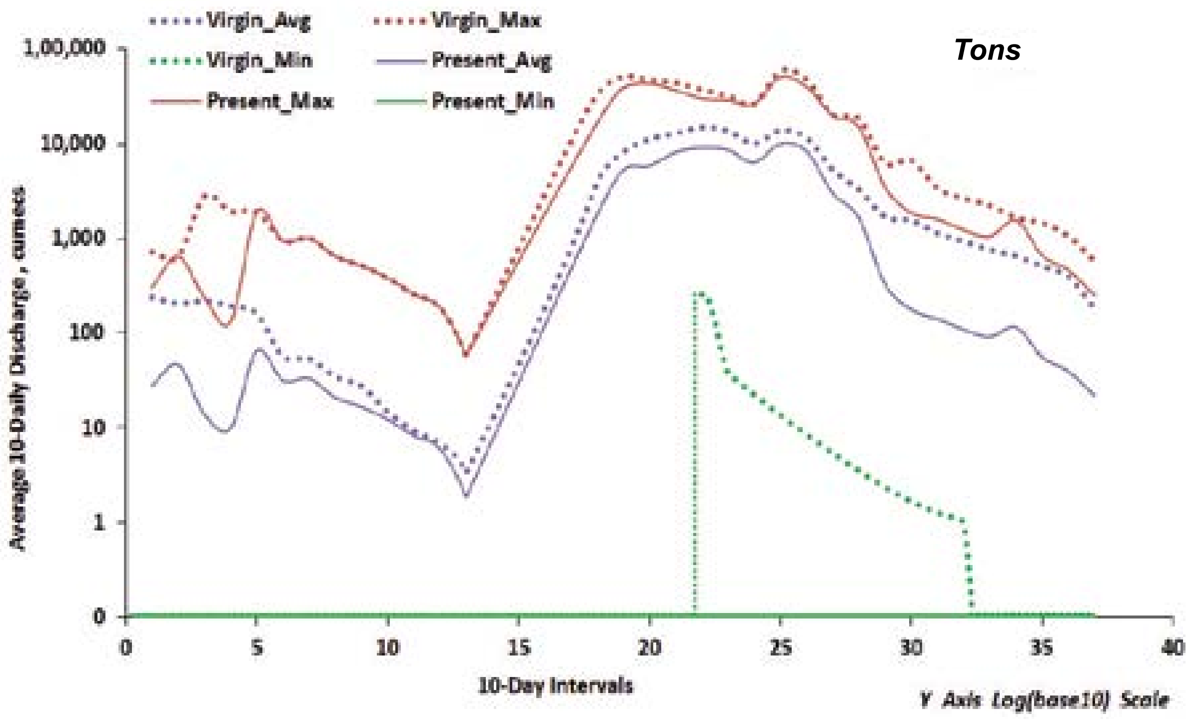

Figure A1.16: 10-Daily Hydrographs for River Tons

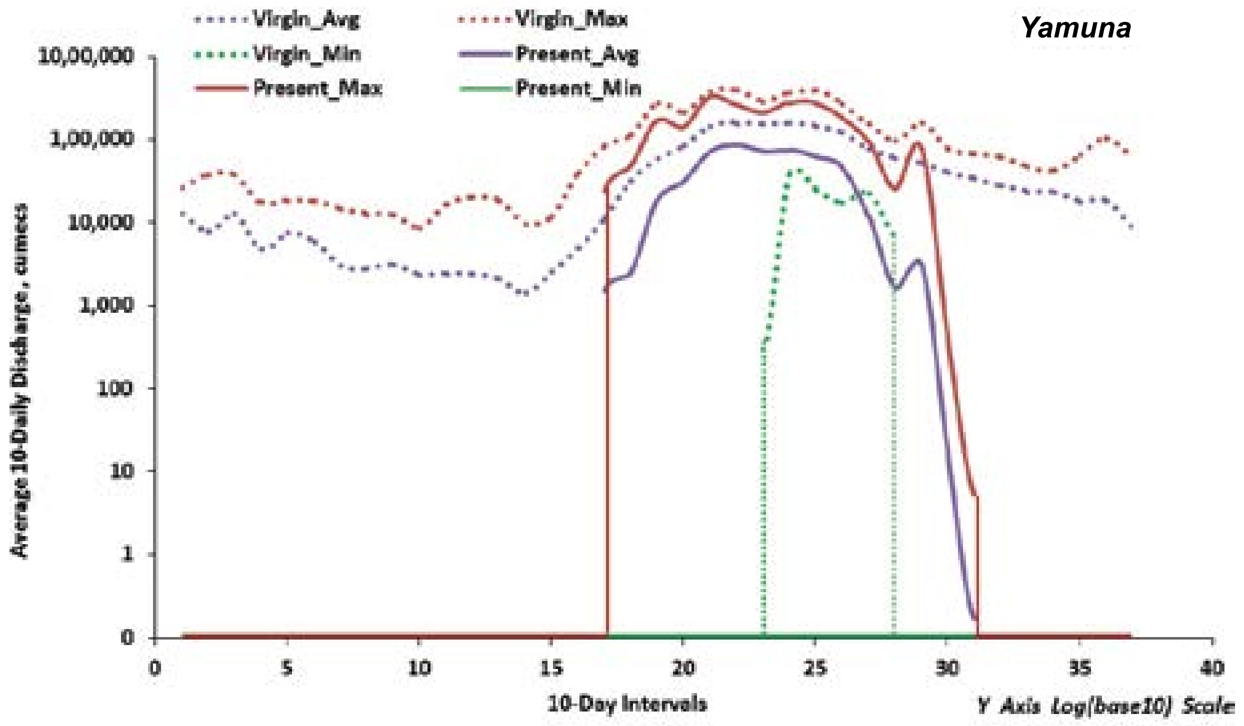

Figure A1.17: 10-Daily Hydrographs for River Yamuna

Appendix II

Annual Sediment Load Variation in National River Ganga

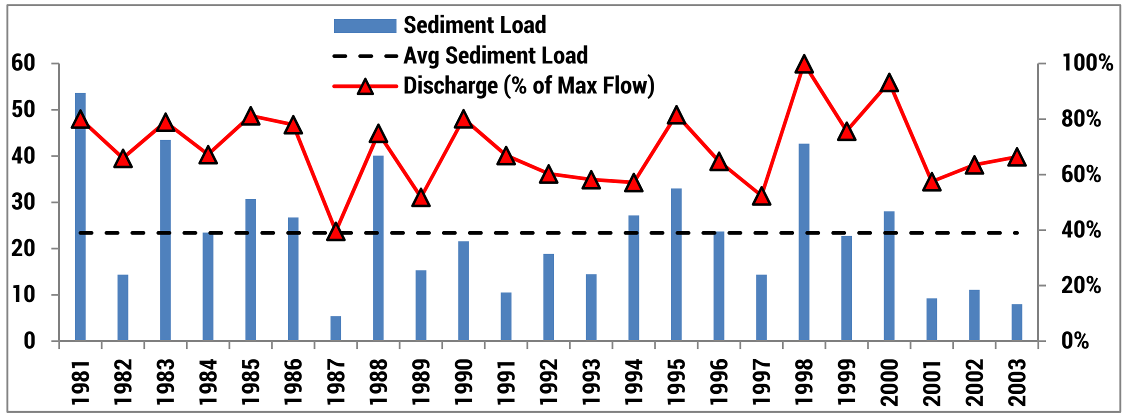

Figure A2.1: Annual Sediment Loads (in million metric tons) at Garhmukteswar

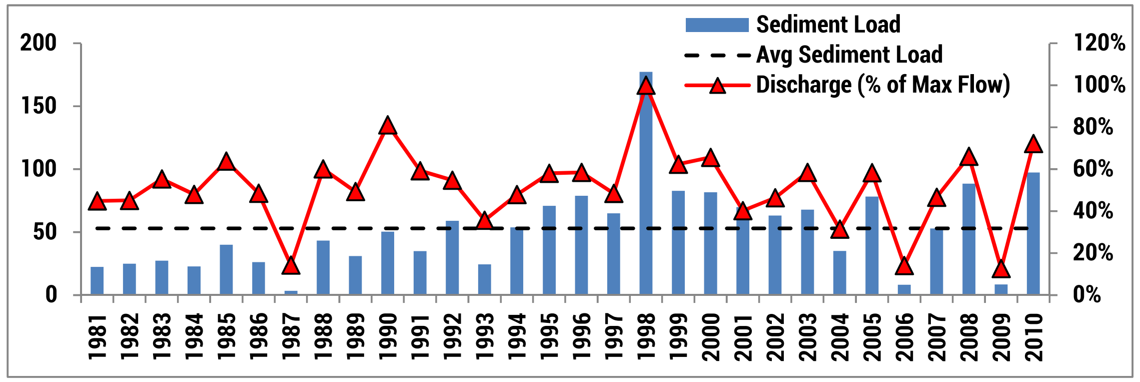

Figure A2.2: Annual Sediment Loads (in million metric tons) at Kachlabridge

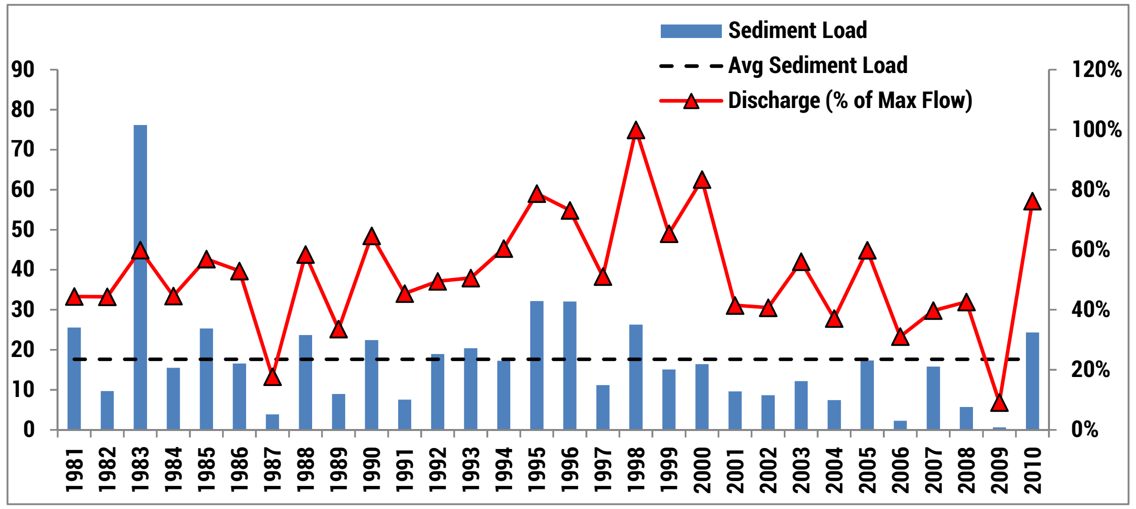

Figure A2.3: Annual Sediment Loads (in million metric tons) at Fatehgarh

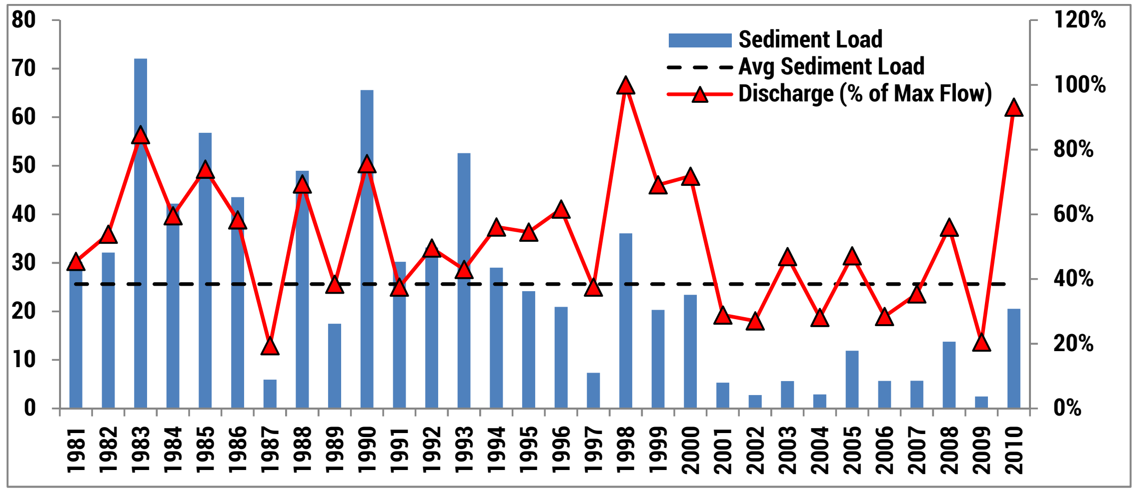

Figure A2.4: Annual Sediment Loads (in million metric tons) at Ankinghat

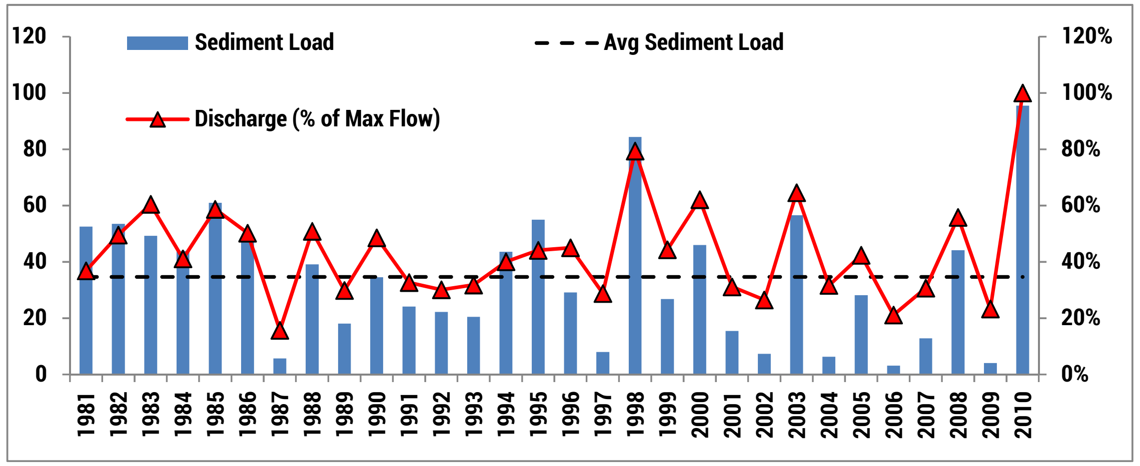

Figure A2.5: Annual Sediment Loads (in million metric tons) at Kanpur

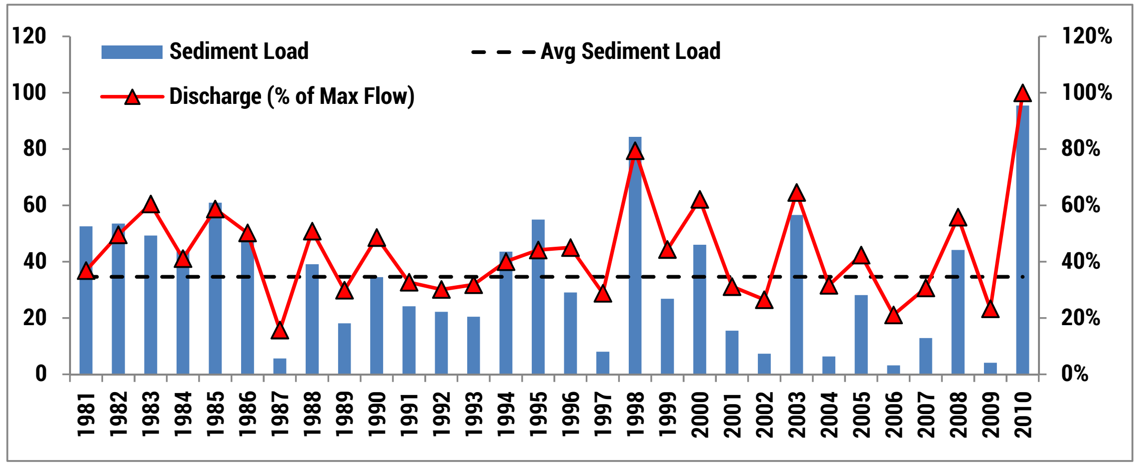

Figure A2.6: Annual Sediment Loads (in million metric tons) at Bhitaura

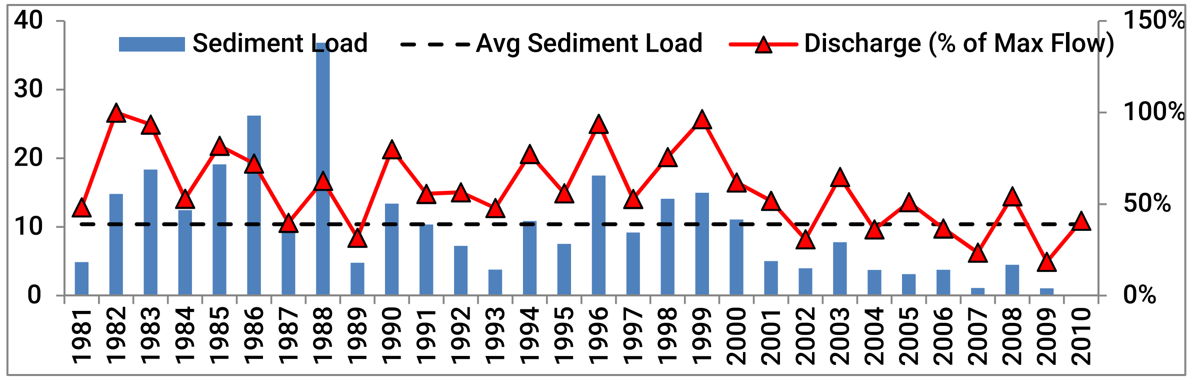

Figure A2.7: Annual Sediment Loads (in million metric tons) at Allahabad

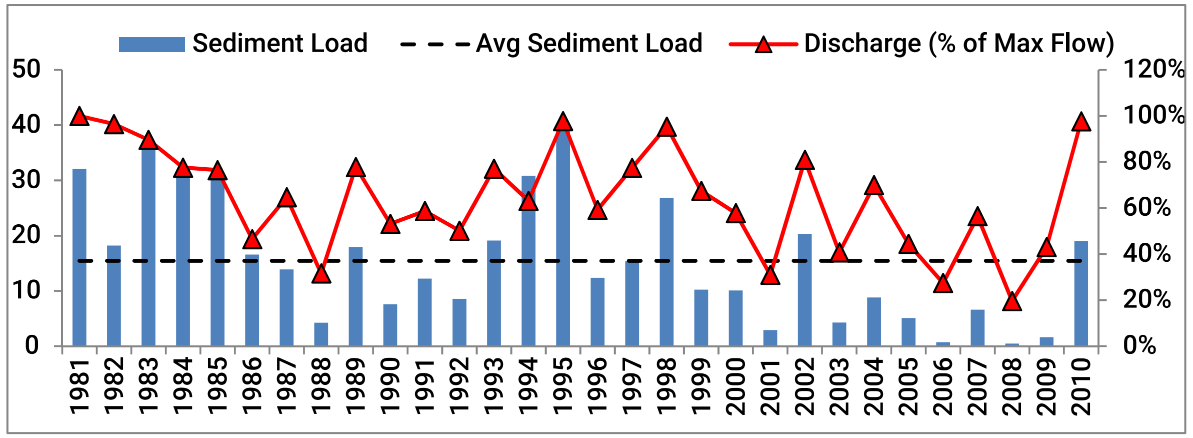

Figure A2.8: Annual Sediment Loads (in million metric tons) at Varanasi

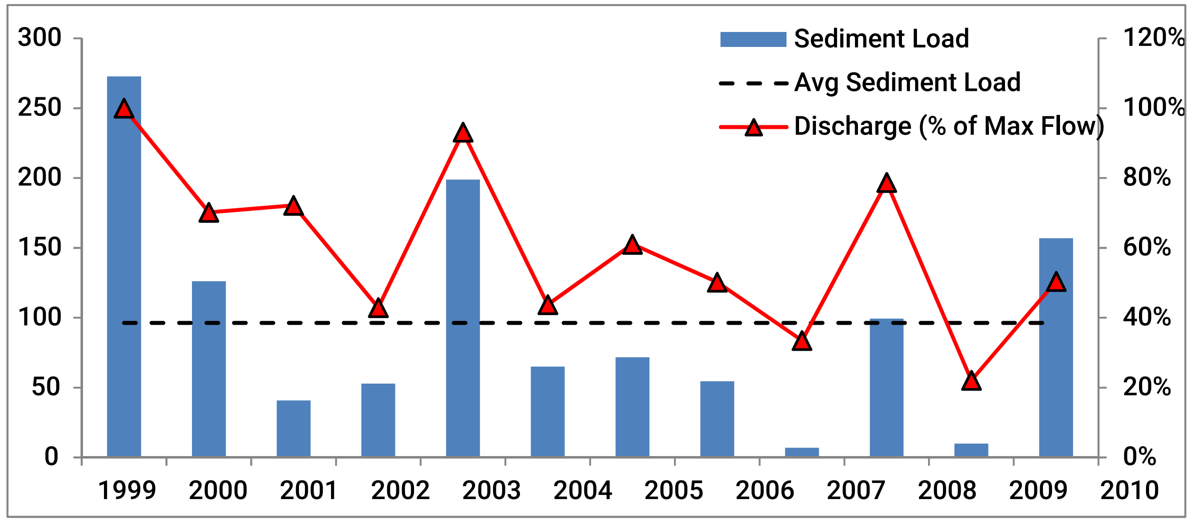

Figure A2.9: Annual Sediment Loads (in million metric tons) at Buxar

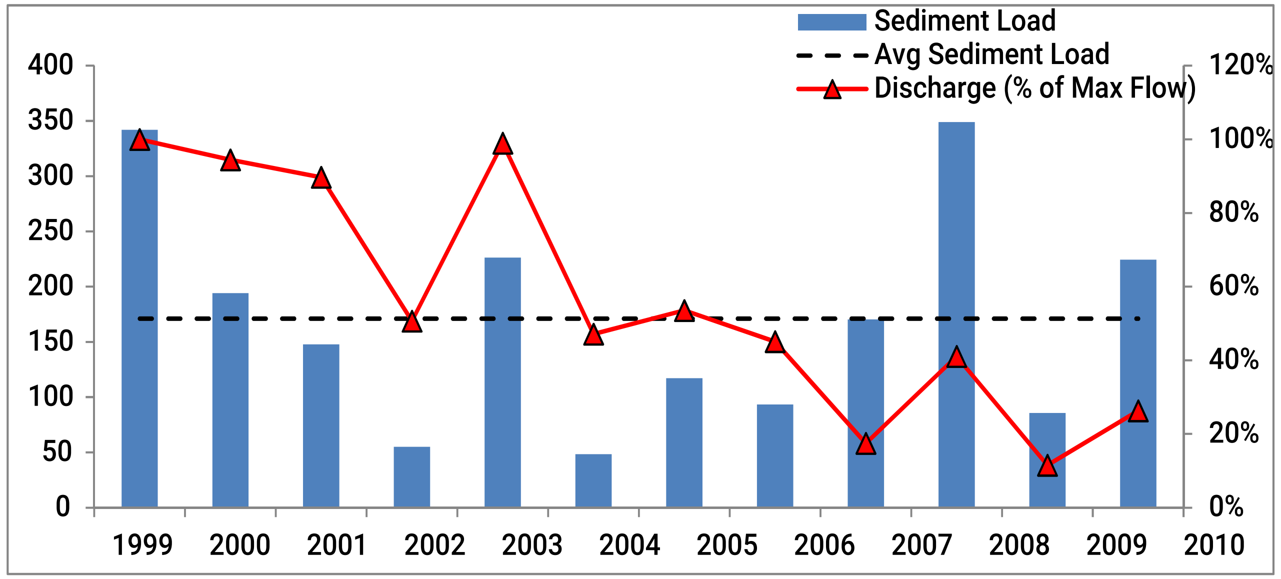

Figure A2.10: Annual Sediment Loads (in million metric tons) at Gandhighat

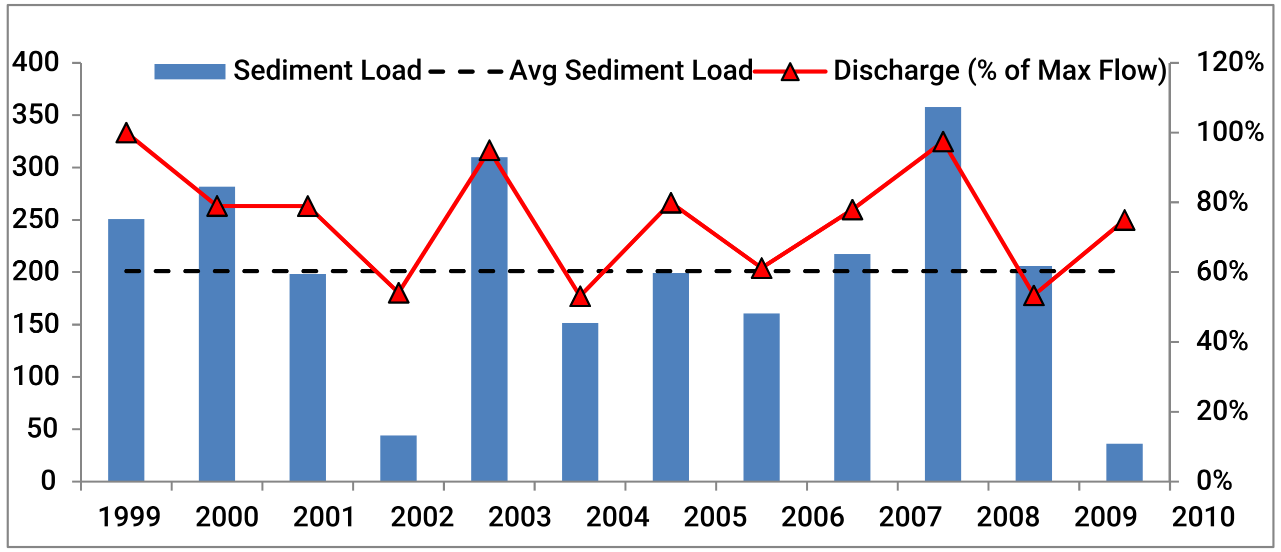

Figure A2.11: Annual Sediment Loads (in million metric tons) at Hathidah

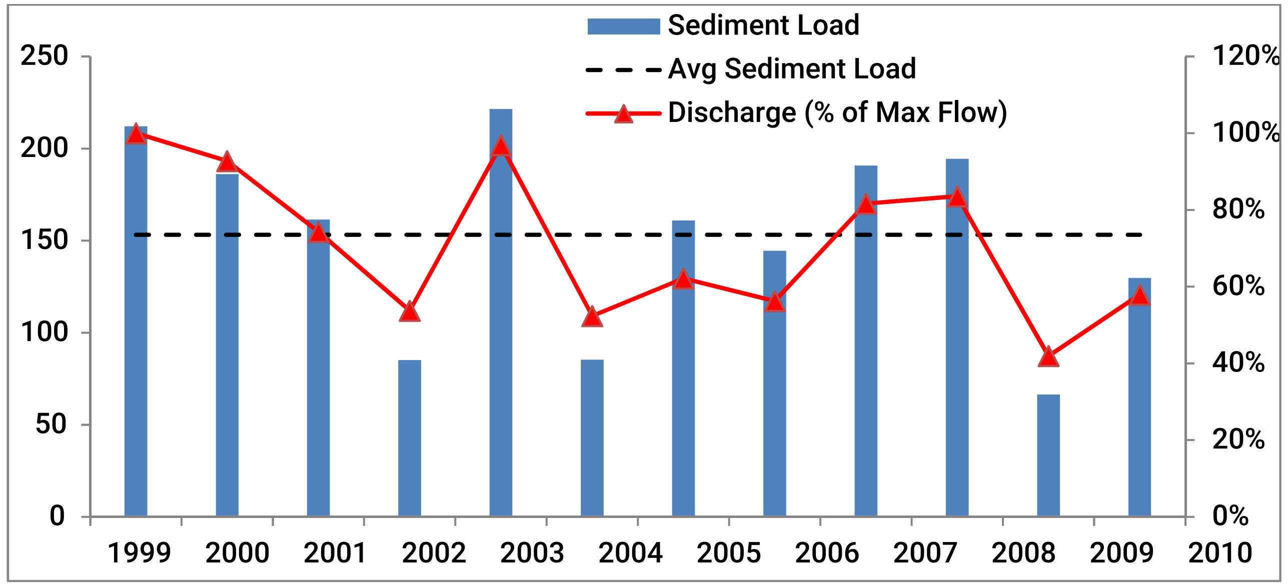

Figure A2.12: Annual Sediment Loads (in million metric tons) at Azimabad

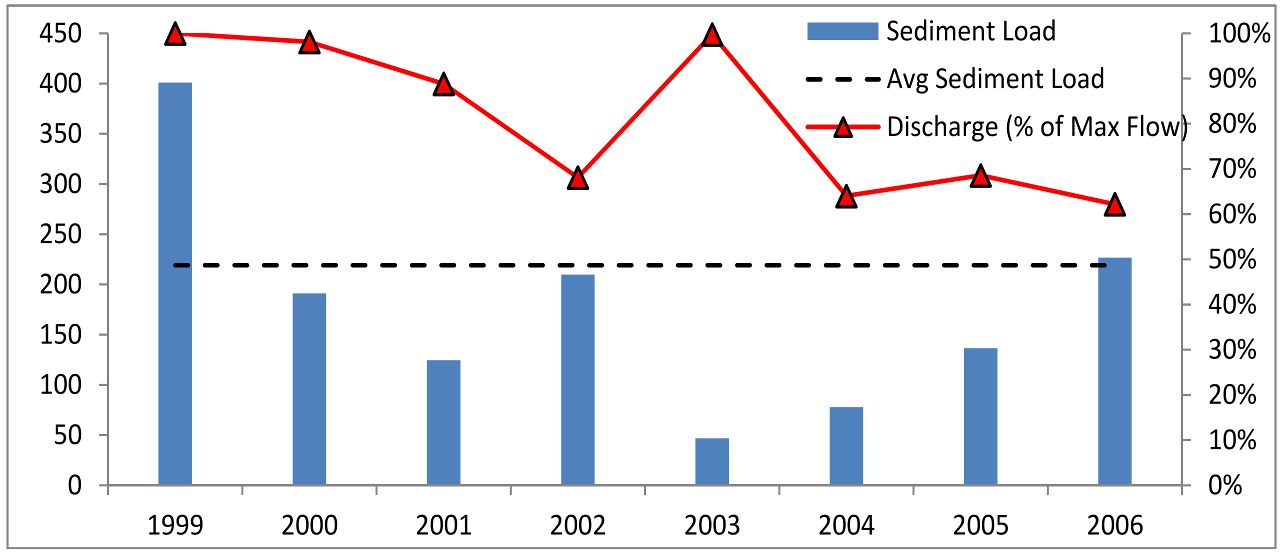

Figure A2.13: Annual Sediment Loads (in million metric tons) at Farakka (including Feeder Canal)

GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 2: NIRMAL DHARA

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

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ABBREVIATIONS AND ACRONYMS

1. **CGWB** : Central Ground Water Board
2. **CWC** : Central Water Commission
3. **DBFO** : Design-Build-Finance-Operate
4. **E-Flows** : Environmental Flows
5. **IITC** : IIT Consortium
6. **FAO** : Food and Agricultural Organization
7. **GRBMP** : Ganga River Basin Management Plan
8. **MND** : Mission Nirmal Dhara
9. **MoEF** : Ministry of Environment and Forests
10. **MoEFCC** : Ministry of Environment, Forests & Climate Change
11. **MoWR** : Ministry of Water Resources
12. **MoWR, RD&GR**: Ministry of Water Resources, River Development & Ganga Rejuvenation
13. **NGO** : Non-Governmental Organization
14. **NGRBA** : National Ganga River Basin Authority
15. **NIH** : National Institute of Hydrology (India)
16. **NMCG** : National Mission for Clean Ganga
17. **NRGB** : National River Ganga Basin
18. **NRGBMC** : National River Ganga Basin Management Commission
19. **PPP** : Public-Private Partnership
20. **SRI** : System of Rice Intensification
21. **UNEP** : United Nations Environment Programme
22. **URMP** : Urban River Management Plan

SUMMARY

The Ganga River System consists of all rivers in the NRGB, including the main stem of river Ganga and all its tributaries/ distributaries. The health of the Ganga River System is an important indicator of the overall condition of NRGB. The water quality of Ganga River System has been significantly impacted by disposal of wastes from anthropogenic sources into the rivers. This includes solid and liquid wastes of both hazardous and non-hazardous types from domestic, industrial and agricultural sources.

The objective of Mission Nirmal Dhara (MND) is to ensure that the flow in the Ganga River System is bereft of manmade pollution; hence the river water quality should not be affected by human activities.

Anthropogenic pollutant ingress into the Ganga River System is from both point and non-point (i.e., distributed) sources. The liquid and solid waste disposed into the Ganga River System from Class I, Class II, Class III towns, villages and various industries in the NRGB are the point sources of pollution. In addition, accumulation of garbage and the widespread practice of open defection results in the general accumulation of filth on the NRGB landmass. This waste is entrained in the surface runoff during rainy season and becomes a source for non-point pollution in the NRGB. The agricultural sector is also a major source for non-point pollution in NRGB. Fertilizers and pesticides applied on agricultural fields are leached into irrigation return flows or storm runoffs.

The MND provides a plan to gradually minimize the ingress of pollutants into the Ganga river system. This will require prohibiting and restricting certain activities in the NRGB. The prohibited activities include; discharge of sewage (either treated or untreated) from Class I towns; discharge of industrial effluents (either treated or untreated) from any large, medium or cluster of small industries; direct injection of sewage and industrial effluents (either treated or untreated) into the subsurface; disposal of un-burnt and partially burnt corpses and animal carcasses in rivers; open defecation and dumping of municipal/ industrial solid wastes or sludge in any river or its active flood plain; and construction of new residential, commercial or industrial structures in river flood plains. The restricted activities include; discharge of sewage (either treated or untreated) from Class II and smaller towns and villages; disposal of sewage or industrial sludge except in secure landfills/ hazardous waste sites; discharge of industrial effluents (either treated or untreated) from small scale industry; disposal and/ or discharge of mining and construction debris in any river or its floodplains; river bed farming and agricultural activities in the active flood plain; ritual immersion of idols; and floral and other offerings in rivers, washing of clothes, vehicles, etc., in rivers, and usage of chemical fertilizers and agrochemicals in the farming sector.

Enforcement of the above admonishments will require major improvements in the solid and liquid waste management practices prevalent in domestic/ commercial, industrial and agriculture sectors in NRGB. This may be achieved by promoting certain activities in NRGB. The recommendations regarding activities to be promoted are grouped under the following categories: (A) Management of Solid and Liquid Wastes Generated from Domestic/ Commercial Sources; (B) River-frame Development, Floodplain Management and Rejuvenation of Water Bodies; (C) Management of Solid and Liquid Waste Generated from Industrial Sources; and (D) Management of Polluted Agricultural Runoff. Actions consistent with the above recommendations should be undertaken in the NRGB to achieve the objectives of MND. These actions should be undertaken in a de-centralized phase-wise manner through the implementation of numerous projects.

Effective co-ordination of these activities is envisaged through a high-level constitutional body tentatively named the 'National River Ganga Basin Management Commission' (NRGBMC). Until the NRGBM Bill is considered by the appropriate legislature bodies and NRGBMC is formed, the role of NRGBMC may be carried out by the National Mission for Clean Ganga (NMGC), an executive arm of the National Ganga River Basin Authority (NGRBA) presently attached to the Ministry of Water Resources, River Development and Ganga Rejuvenation.

Preparation of URMPs
(Urban River Management Plans) for Class I towns, and subsequently also for Class II and Class III towns is essential for Project Planning

Project planning should begin with preparation of detailed Urban River Management Plans (URMPs) for Class I towns, and subsequently also for Class II and Class III towns. The URMPs should be followed by preparation of DPRs, following which funds should be allocated for project implementation. Fund allocation should be prioritized for projects designed to prevent direct discharge of large quantities of liquid waste into the River System (Priority Level I), followed by projects designed to prevent direct discharge of large quantities of solid waste into the River System (Priority Level II), followed by projects concerning river-frame development and restoration of floodplain in urban areas along the Ganga River System (Priority Level III). All funds budgeted by the central/ state/ local governments for Ganga Rejuvenation over the next 15 years must be only used for above types of projects.

Projects related to MND may be conceived by the central, state, local governments, NGOs and other private organizations/ industries. Financing of these projects may be through funds budgeted by central/ state governments for Ganga Rejuvenation, local revenue, corporate and private donations and grants, low cost debt from multinational organizations, commercial debts from banks and private equity. Wherever possible, project implementation including operation and maintenance should be contracted to 'service providers', i.e., public/ private agencies with relevant expertise. Payments must be released to the 'service provider' only after monitoring by an independent third-party.

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 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.

GRBMP focuses on the basin's overall resource environment and the major factors affecting it, 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 "Nirmal Dhara" (MND) is to ensure that the flow in the Ganga River System is bereft of manmade pollution; hence the river water quality should not be affected by human activities.

3. IMPORTANCE OF NIRMAL DHARA FOR GANGA RIVER BASIN MANAGEMENT

Ganga river's water quality had been acclaimed in ancient times. Its life-giving and healing qualities are evident from the following description in Rajanirghanta (~300 AD) meaning *"The qualities of Ganga water are: Coolness, sweetness, transparency, high tonic property, wholesomeness, potability, ability to remove evils, ability to resuscitate from swoon caused by dehydration, digestive property and ability to retain wisdom"*

अस्या जल्स्य गुणा: शीतत्वम्,स्वादुत्वम, स्वछत्वम, अत्यन्तरुच्यत्वम्, पथ्तत्वम्, पावनत्वम्,
पापहारित्वम्, तृष्णामोहध्वंसत्वम्, दीपनत्वम, प्रज्ञाधारित्वंच, इति राजनिर्घण्ट:

The properties of Ganga river's waters of earlier times quoted above are remarkable, to say the least. But, at present, the river water quality is abysmal, posing a grave threat to life in the region.

The change in water quality may have been occurring over many centuries. Ancient scriptures had cautioned against misusing the Ganga river. For instance, the following edict in Sanskrit prohibited fourteen types of human actions: (1) defecation, (2) gargling, (3) shampooing (4) throwing of used religious offerings, (5) rubbing of filth, (6) flowing bodies (human or animal), (7) frolicking; (8) acceptance of donations; (9) obscenity; (10) considering other shrines to be superior, (11) praising other shrines, (12) discarding garments; (13) hurting anyone, and (14) making noise.

गंगां पुण्यजलां प्राप्य चतुर्दश विवर्जयेत् ।
शौचमाचमनं केशं निर्माल्यं मलघर्षणम् ।
गात्रसंवाहनमं क्रीड़ां प्रतिग्रहमथोरतिम् ।
अन्यतीर्थरतिचैव: अन्यतीर्थ प्रशंसनम् ।
वस्त्रत्यागमथाघातं सन्तारंच विशेषत: ॥

It is possible that such strictures got diluted over time. But, the environmental significance of many of these precautions is obvious to the modern mind. And, what is equally significant, they convey a sense of deep respect for National River Ganga.

The vision statement of GRBMP affirms the restoration of 'Nirmal' dhara (unpolluted flow) in River Ganga and her tributaries as one of the goals of GRBMP. Measures to be implemented to achieve this objective have been specified in the present document describing the Mission 'Nirmal' Dhara (MND).

The necessary condition for restoration of 'Nirmal Dhara' in River Ganga and her tributaries, i.e., the Ganga river system, is the prevention of the ingress of pollutants into the rivers. It was realized that pollutant ingress into the Ganga River system cannot be controlled unless certain solid and liquid waste management and other practices in the NGRB were modified. This realization was the origin of the basin-wide approach for the formulation of MND.

4. GANGA RIVER SYSTEM: SOURCES OF POLLUTANTS

Various types for waste generation in NRGB have been identified in Figure 4.1. Two broad types of wastes generated in the NGRB, whose improper disposal adversely impact water quality of the Ganga system are, 1) solid wastes and 2) liquid wastes.

Solid waste can be broadly classified as, 1) non-hazardous and 2) hazardous. Non-hazardous solid waste is generated mostly from domestic, commercial and agricultural sources. Industrial activity may result in the generation of both non-hazardous and hazardous solid waste.

Liquid waste is produced when pollutants are intentionally dissolved or suspended in water for transport away from their point of generation. Such point

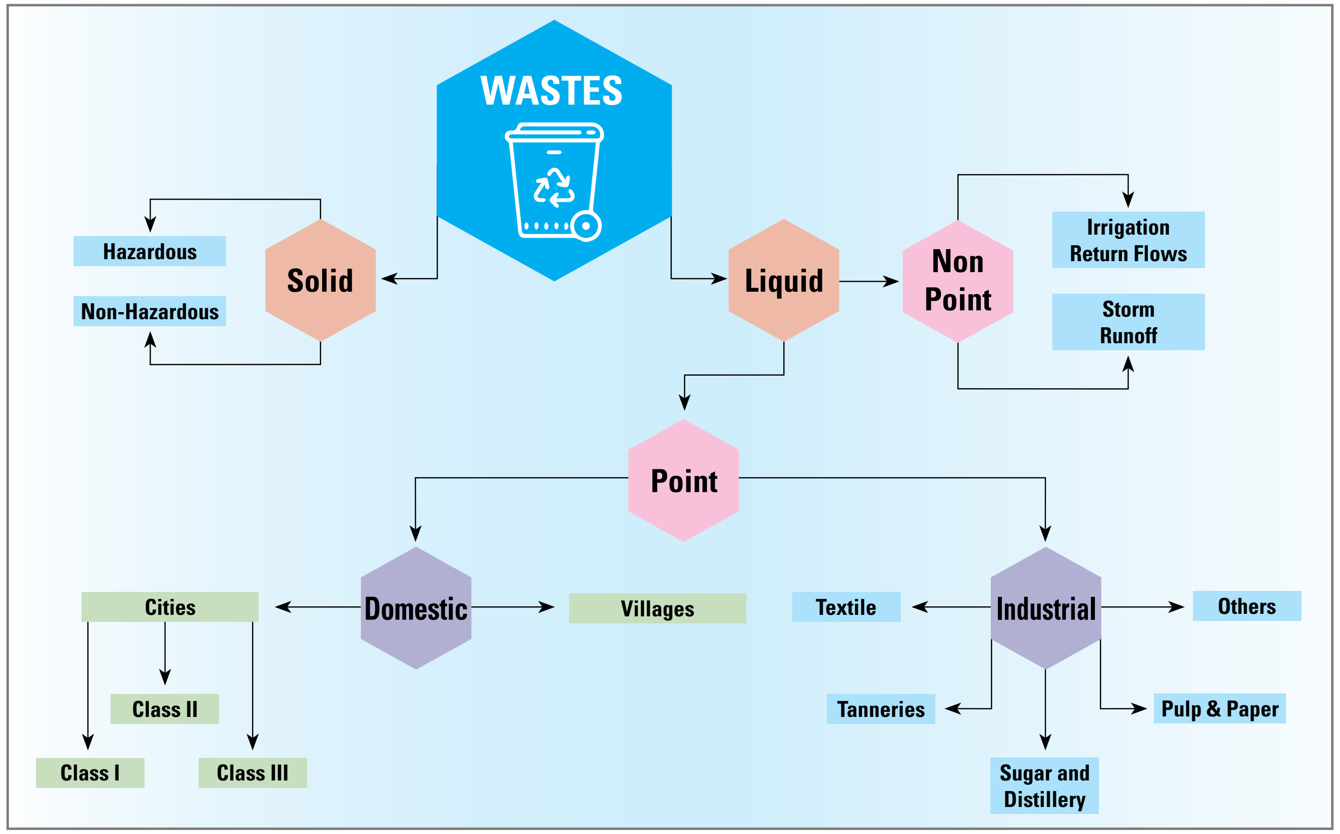


Figure 4.1: Various Types of Waste Generated in Ganga River Basin

sources of liquid waste generation are attributable to domestic, commercial and industrial activities. Thus all Class I, Class II, Class III towns and villages in the NRGB are point sources for liquid waste. Inaddition, the industries in NRGB including, sugar and distillery, pulp and paper, tannery, textiles and others are also major point sources of liquid waste.

Liquid waste is also generated from non-point (i.e., distributed) sources. The accumulation of garbage and the widespread practice of open defection results in the general accumulation of filth in the NRGB landmass. This is entrained in the surface runoff during rainy season and becomes a source for non-point pollution in the NRGB. The agricultural sector is also a major source for non-point pollution in NRGB. Fertilizers and pesticides applied on agricultural fields are leached into irrigation return flows or storm runoffs.

Pollutant ingress into the Ganga river system occurs in three ways, (i) by direct discharge of pollutants, (ii) discharge of polluted surface runoff into rivers, and (iii) seepage of polluted subsurface flows into rivers.

5. GANGA RIVER SYSTEM: POLLUTANT INGRESS

Pollutant ingress into the Ganga river system occurs in three ways, 1) by direct discharge of pollutants, 2) discharge of polluted surface runoff into rivers, and 3) seepage of polluted subsurface flows into rivers.

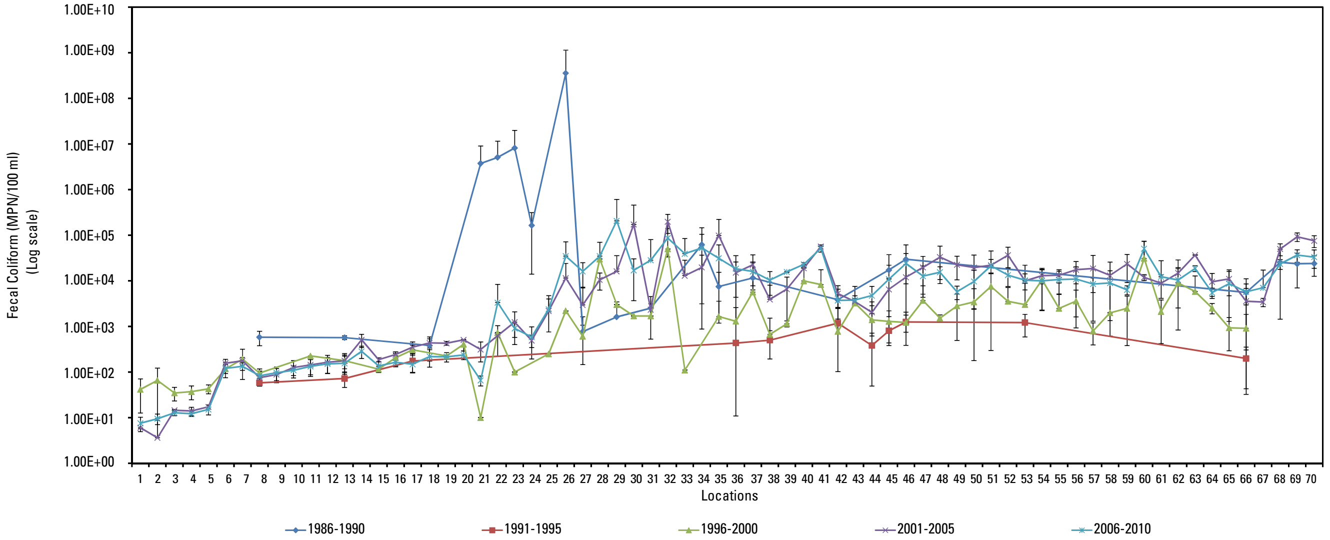
Direct discharge of pollutants into rivers occur due to, i) discharge of liquid wastes generated from point sources into rivers, ii) dumping of municipal and industrial solid waste, devotional offerings, animal carcasses, un-burned/partially burned human bodies, etc. into rivers, and iii) non-ritual bathing with the intention of cleaning body dirt, direct defecation, washing of clothes, washing of vehicles, washing/wallowing of animals, etc.

The origin of polluted non-point surface discharge into the Ganga river system are twofold, i) surface runoff containing leached fertilizers and pesticides applied on agricultural fields and ii) surface runoff containing entrained solid waste, i.e., garbage, industrial waste, human and animal feces, etc.

Some portion of the liquid waste generated from both point and non-point sources described above infiltrates into the subsurface and pollute the groundwater. Seepage of this polluted ground water also results in pollution of the Ganga river system.

6. GANGA RIVER SYSTEM: POLLUTION STATUS

Examination of Ganga water quality data indicates that at Dev Prayag (confluence of rivers Bhagirathi and Alaknanda) and further downstream, the fecal coliform numbers in Ganga River are on an average, 100 times more than the levels acceptable for bathing (Figure 6.1). Downstream of large cities like Kanpur, the fecal coliform numbers are 1000 times or more than acceptable levels. Fecal coliforms are bacteria normally found in human feces. Discharge of, i) untreated/ partially treated domestic sewage into the river, and ii) storm runoff contaminated with human feces is mainly responsible for the high fecal coliform numbers observed.



1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, PakkaGhat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	DashashawmedhGhat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (U jahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

Figure 6.1: Variation in 5-year average Fecal Coliform at Various Locations along the Ganga River

The organic loading, as indicated by the Biochemical Oxygen Demand (BOD) is also high in some places of the Ganga river system (Figure 6.2). High BOD levels may result in low dissolved oxygen (DO) concentrations in water, which is injurious to the aquatic life in the rivers. The source of such pollution is mainly the point discharges of untreated/ partially treated domestic sewage and industrial effluents into the rivers.

The nutrient, i.e., nitrogen and phosphorus loading are also high in some places in the middle and lower reaches of the Ganga river system. High nutrient loading leads eutrophication of the river, i.e., excessive growth of algae and aquatic plants, leading to the choking of the river. A glaring example of this can be seen at upstream of Okhla Barrage on river Yamuna in Delhi. The high nutrient loading is attributable to, i) point discharges of untreated/ partially treated sewage and industrial effluents and ii) non-point loading of fertilizer, fecal and solid waste residues through surface runoff and seepage of groundwater. A ballpark estimation of pollutant load contributed through sewage generation in Class I and Class II towns (assuming that all sewage gets collected) in various NRGB states and NRGB Sub Basins is presented in Thematic Reports prepared by Consortium of 7 IITs [IITC, 2014a-k].

The issues of inorganic salt loading into the Ganga river system is mainly due to discharge of industrial effluents. Such loading is particularly high near tannery clusters in the Kanpur region.

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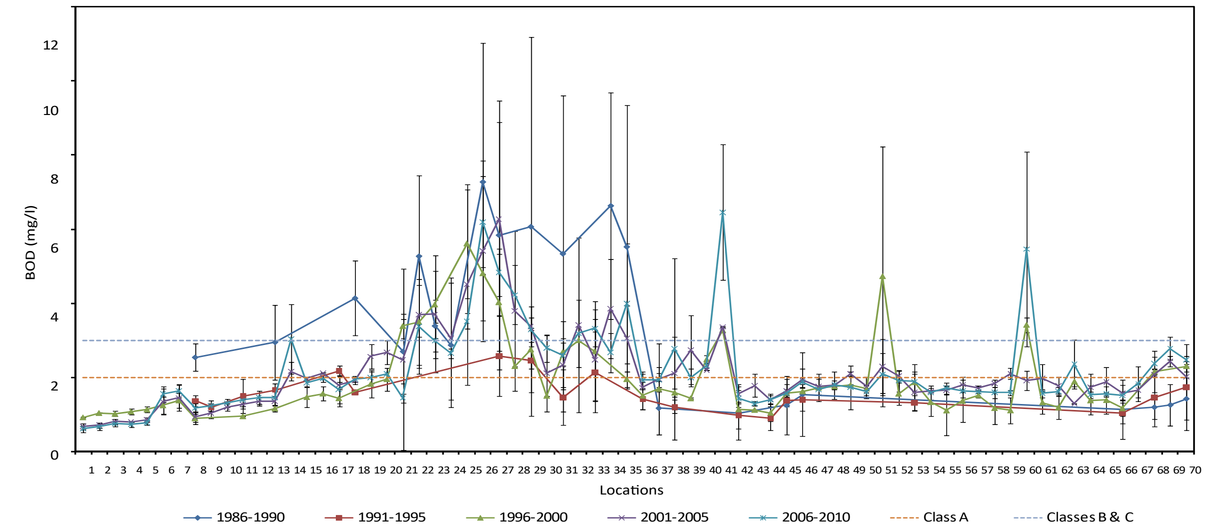

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, PakkaGhat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
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14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultangan/s	70	Uluberia (Middle)

Figure 6.2: Variation in 5-year Average BOD at Various Locations along the Ganga River

The data regarding loading of other pollutants i.e., pesticides and heavy metals into the Ganga river system is scanty [IITC, 2011b]. However, preliminary estimates indicate that concentration of pesticides and heavy metals in Ganga river system is low in most locations [IITC, 2011b].

Finally, it is estimated that approximately 70 percent of the volumetric pollution load on the Ganga river system is from domestic/commercial sources, i.e., from human urine/feces and solid waste. Major polluting industries along river Ganga are pulp and paper, sugar and distillery, tannery, textiles, etc. together with agricultural pollution contribute the remaining 30 percent pollution load to the river.

7. MISSION 'NIRMAL' DHARA: BROAD PLAN OF ACTION

The MND provides a plan to gradually minimize the ingress of pollutants into the Ganga river system. This is to be achieved using a simultaneous two-pronged approach, i) by prohibiting/ restricting certain activities in the NRGB, and ii) by promoting certain activities in NRGB through implementation of numerous projects.

To achieve the objectives of MND, certain activities must be prohibited in the NRGB as soon as possible. The list of prohibited activities in the NRGB include,

1) Discharge of sewage (either treated or untreated) from Class I towns, either directly or indirectly, into any river;
2) Discharge of industrial effluents (either treated or untreated) from any large, medium or cluster of small industries, either directly or indirectly, into any river;
3) Direct injection of sewage and industrial effluents (either treated or untreated) into the subsurface;
4) Disposal of un-burnt and partially burnt corpses and animal carcasses in any river or riverbank;
5) Open defecation and dumping of municipal/ industrial solid wastes or sludge in any river or its active flood plain;
6) Construction of new permanent structures in river flood plains for residential, commercial and industrial purposes, but excluding bridges and associated roads, jettys/ ghats and hydraulic structures for storage/ diversion/ control/ chanelisation of river waters.

Further, certain activities must be gradually restricted, i.e., permitted only with adequate safeguards or even prohibited in future. The list of restricted activities in NRGB include,

1) Discharge of sewage (either treated or untreated) from Class II town and smaller towns and villages, either directly or indirectly, into any river;
2) Disposal of sludge derived through treatment of sewage and industrial effluents except in secure landfills/ hazardous waste sites;
3) Discharge of industrial effluents (either treated or untreated) from small scale industry into any river;
4) Fisposal and/ or discharge of mining and construction debris in any river's flood plain, river bank or the river itself;
5) River bed farming and agricultural activities in the active flood plain of any river;
6) Ritual immersion of idols, and floral and other offerings in any river;
7) Wallowing of domestic animals, washing of clothes, vehicles, etc., in any river;
8) Widespread use of chemical fertilizers and pesticides in agriculture, horticulture, aquaculture, animal husbandry, forestry, etc. in NRGB.

8. MND: IMPLEMENTATION STRATEGY

Enforcement of the admonishments regarding prohibited and restricted activities stated above will require major improvements in the solid and liquid waste management practices prevalent in domestic/ commercial, industrial and agricultural sectors in NRGB. Simultaneously, river-frame development, restoration of natural drains ('nala')/ other surface water bodies and management of river flood plains need to be carried out in a coordinated manner. This can be achieved by promoting certain broad activities in NRGB. The specific activities to be promoted for implementation of MND have been grouped under four categories as follows.

8.1 Category A: Management of Solid and Liquid Waste Generated from Domestic/ Commercial Sources

Broad recommendations for management of wastes generated from domestic/ commercial sources from Class I, II and III cities and villages are the following,

1) All new colonies/ townships and large multi-storied complexes must adopt a zero-liquid discharge policy, wherein domestic sewage generated within the complex must be treated and recycled/reused within the complex itself.
2) Domestic sewage generated from all other sources should be collected and transported in closed conduits for treatment followed by reuse/ recycle.
3) In cases where reuse/ recycle is not possible, the treated sewage must be used for rejuvenation of surface water bodies and/ or for irrigation.
4) Toilets must be provided in villages and in slums in urban areas, such that open defecation is eliminated. The waste/ sewage generated from such toilets must be collected and treated in an acceptable manner.
5) Solid waste, sludge and septage generated in Class I, II, III towns and villages should be collected and either recycled or disposed in a scientifically acceptable manner.
6) Arrangements must be made for stoppage of practices like open defecation, disposal of un-burnt/ half-burned human remains and animal carcasses in river banks/ floodplains or into the rivers.
7) Adequate arrangements must be made for activities such as disposal and/or discharge of mining and construction debris in river flood plain, river bank or the river itself and ritual immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, etc., in river banks/ floodplains or in the rivers.

Enforcement of the admonishments regarding prohibited and restricted activities will require major improvements in the solid and liquid waste management practices. Simultaneously, river-frame development, restoration of natural drains / other surface water bodies and management of river flood plains need to be carried out in a coordinated manner.

8.2 Category B: River-frame Development, Floodplain Management and Rejuvenation of Water Bodies

Broad recommendations for river-frame development, floodplain management and rejuvenation of water bodies are the following,

1) River-frame in urban centers should be cleared of encroachments and developed to encourage pilgrimage, commercial/ recreational activities and tourism.
2) Ingress of domestic sewage into natural drains, canals, ponds, etc. in urban areas should be prevented and these water bodies must be restored for improvement of urban drainage and for promotion of recreational/ commercial activities.
3) Slum clusters and other encroachments should be removed from river flood plains at all places. Wherever possible, river flood plains may be used for the development of ecological parks, surface water recharge structures, etc.
4) Agricultural activity in the river floodplains and riverbeds must be properly managed.

8.3 Category C: Management of Solid and Liquid Waste Generated from Industrial Sources

Broad recommendations for management of wastes generated from industrial sources are the following,

1) All large industries in the NRGB, i.e., tannery, sugar and distillery, pulp and paper and textiles, etc. should adopt a zero liquid discharge (ZLD) policy with recycle/ reuse of treated effluent.
2) Combined Effluent Treatment Plants (CETPs) to be set up for industrial clusters/ estates based on ZLD principles.
3) Arrangements made for stoppage of the discharge of industrial effluent into municipal sewers.
4) Suitable infrastructure to be provided for conveyance of effluent from dispersed small-scale industries to CETPs or for efficient management of ETPs. A cluster of ETPs could be managed by a single Service Provider.

5) All solid waste generated from industries to be disposed as per scientifically accepted norms/ principles.

8.4 Category D: Management of Polluted Agricultural Runoff

Broad recommendations for management of polluted agricultural runoff are the following,

1) Introduction of organic farming for agricultural activities in the active flood plain and river bed.
2) Increased use of organic fertilizers and pesticides in agriculture, horticulture, aquaculture, animal husbandry, forestry, etc. in NRGB.

Actions consistent with the above recommendations should be undertaken in the NRGB to achieve the objectives of MND. These actions should be undertaken in a de-centralized phase-wise manner through the implementation of numerous projects.

9. COORDINATION: NATIONAL RIVER GANGA BASIN MANAGEMENT COMMISSION (NRGBMC)

Coordinating the activities concerning all missions of GRBMP (including MND) is a complex task that requires dedicated and specialized expertise. It is proposed that the central government enacts legislation in parliament to constitute a constitutional body tentatively named the 'National River Ganga Basin Management Commission' (NRGBMC). NRGBMC is envisaged as a non-executive body which shall act as the 'voice' of River Ganga and thus will be the custodian of NRGB and responsible for implementation of GRBMP (including MND). A draft "National River Ganga Basin Management Bill" has been prepared as a part of GRBMP.

NRGBMC shall ensure coordination between various ministries/ departments of the central, state and local governments as required for the efficient implementation of MND. Specifically, it shall have the responsibility for, i) overall monitoring of the implementation of various projects related to MND, ii) providing project management and technical advice to public/ private organizations entrusted with the responsibility of executing projects related to MND, and, iii) acting as an interface for facilitating the participation by non-governmental organizations (NGOs) and others in the implementation and monitoring of various projects related to MND. In addition it is envisaged that the NRGBMC shall have quasi-judicial powers for ensuring that the admonishments in the MND report regarding prohibited/ restricted activities in the NRGBB are enforced.

Projects related to MND may be conceived by the central, state, local governments, NGOs and other private organizations/ industries. The detailed project proposals (DPRs) vetted by NRGBMC for technical soundness and overall relevance to the objectives of MND will be termed "MND Projects" and will receive due consideration for funding under Ganga rejuvenation programmes (e.g. Namami Gange).

Until the NRGBM Bill is considered by the appropriate legislative bodies and NRGBMC is formed, the role of NRGBMC may be carried out by the National Mission for Clean Ganga (NMGC), an executive arm of the National Ganga River Basin Authority (NGRBA) presently attached to the Ministry of Water Resources, River Development and Ganga Rejuvenation.

10. PROJECT PLANNING: URBAN RIVER MANAGEMENT PLAN (URMP)

As a prelude to conception and implementation of MND projects, all Class I towns of the NRGB must compulsorily prepare Urban River Management Plans (URMP). The URMPs should have all relevant data regarding the water availability, sewage generation, solid-waste disposal, sanitation conditions, drainage conditions, etc. prevalent in the town. Further details on URMP are available elsewhere [IITC, 2010a]. Additionally, the URMPs should also provide a complete analysis regarding measures which need to be implemented in a town as per the recommendations of MND. These measures must be listed in the form of work packages, which can later be developed as detailed project reports (DPRs) for implementation as MND projects. Central and state funding should be made available to all Class I towns in the NRGB for reimbursement of the cost for preparing URMPs. URMPs should be prepared by professional organizations with the cooperation of urban local bodies (ULBs).

For a start, URMPs for some towns, selected on the basis of geographical, topographical, socio-cultural and industrial distinctiveness, should be prepared most urgently. Towns like Uttarkashi, Shrinagar, Rishikesh, Haridwar (all in Uttarakhand), Garhmukteshwar, Mathura, Vrindawan, Agra, Moradabad, Lucknow, Kanpur, Allahabad, Varanasi (all in Uttar Pradesh), Indore, Ujjain, Dewas (all part of most polluted Kshipra Sub-Basin of NRGB in Madhya Pradesh), Patna, Bhagalpur (both in Bihar), Kolkata and Delhi NCR, are most suitable for preparing the initial URMPs. It is also highly desirable that the Consortium of 7 IITs (IITC) actively engages with the concerned Central, State and Local agencies in selecting a panel of professional organizations for preparing URMPs and subsequently guides the process of URMP preparation for the abovementioned towns. This will ensure that the IITC vision on the implementation of MND will get transferred in a proper manner to the ground level. Using the above URMPs as templates, the process of preparing URMPs for all other towns in NRGB can be continued and completed as soon as possible.

11. PROJECT PLANNING: OTHER CASES

It is desirable that in addition to Class I towns, URMPs should gradually be prepared for all Class II and Class III towns of the NRGB and government funds must be available for this purpose. Further, all industries and industry clusters in NRGB should individually come up with comprehensive plans for management of industrial effluent and solid waste generated within their premises as per MND recommendations. Implementation of MND recommendations in rural areas will mainly be through projects concerning i) provisioning of toilets, ii) septage and solid waste management, iii) provisioning of low cost sewage conveyance systems, and iv) provisioning of natural biological systems for sewage treatment.

12. MND PROJECTS: DPR PREPARATION AND IMPLEMENTATION

Data available in URMPs and other sources should be used to prepare the DPRs for various projects. In order to receive due consideration under the Ganga rejuvenation program as 'MND projects', the DPRs need to be of high quality and vetted by NRGBMC for technical soundness and overall relevance to the objectives of MND. The skilled manpower required for preparation of high quality DPRs for 'MND projects' may not be readily available at all levels. Hence it is recommended that these responsibilities should be, wherever possible, contracted to 'service providers', i.e., reputed public or private sector entities with relevant expertise. It is proposed that Ganga rejuvenation funds may be set aside for preparation of such DPRs by expert agencies in deserving cases.

Project implementation will start after approval of DPRs by NGRBMC and arrangement of funds. Wherever possible, project implementation including operation/ maintenance should be contracted to 'service providers', i.e., public/ private agencies with relevant expertise. However, the primary responsibility for contract administration, and release of payments to the 'service providers' must remain with the project proponent. Payments must be released to the 'service provider' only after monitoring of the progress of the project implementation by an independent third-party. If required, adequate sensitization and training must be provided to the project proponents for adopting this role as project administrators.

Projects concerning recommendations listed in Category A should be conceived by local governments, or by authorities set up for administering new urban developments. Projects concerning recommendations listed in Category B should be mostly conceived by local or state governments. Projects concerning recommendations in category C should be conceived by individual industries/ industry clusters/industry associations. Projects concerning recommendations in Category D should be conceived by state governments.

13. IMPORTANT PROJECTS FROM MND PERSPECTIVE

It is important to prioritize projects on which the funds available for implementation of MND are utilized. Projects which are designed to prevent direct discharge of large quantities of liquid waste into the Ganga River System must be given the highest priority (Priority Level I) for implementation. Projects designed to prevent direct discharge of large quantities of solid waste into the Ganga River System are to be given the next level of priority (Priority Level II). Projects concerning river-frame development and restoration of floodplain in the urban areas along the Ganga River System must be next in the priority level (Priority Level III). Ideally, for the next 15 years, all available funds for Ganga rejuvenation must be spent on above types of projects.

13.1 Examples: Projects in Priority Level 1

Projects dealing with management of liquid waste from Class I and Class II towns and large/ medium industrial units fall in this category. The MND vision regarding this is as follows, 1) discharge of such wastes into natural drains in Class I and Class II cities must be stopped and the drains must be re-converted into storm water drains, 2) STPs must be renovated/ constructed to treat all the sewage generated in Class I and Class II towns to tertiary levels suitable for recycle/reuse, 3) provisions for use of treated sewage for rejuvenation of natural surface water bodies or for irrigation must be made, and 4) all large/ medium industrial units must adopt the ZLD concept, wherein the industrial effluent is treated and reused. Basis and justification for this is given elsewhere [IITC, 2010b; IITC, 2011a; IITC, 2011c; IITC, 2012; IITC, 2014m]. Typical projects in this class are as follows,

- **Restoration of natural drains in Class I and Class II towns:** Currently most natural drains ('nalas') carry untreated/ partially treated domestic sewage and industrial effluent into the Ganga River System from all Class I and Class II towns in NRGB. This situation must be changed such that these nalas are recovered to drain storm water with minimal or no urban flooding, and during the non-monsoon season remain dry or carry only tertiary treated sewage. Ideally, all such nalas should become habitat for freshwater organisms. It is recommended that projects must be conceived for restoration of such drains. This would involve preventing sewage discharge into such drains by constructing intercepting sewers parallel to the drains. The sewage collected in the intercepting sewers must be diverted to at multiple locations along the drain to existing STPs with spare capacity. Alternatively, decentralized STPs may be constructed in the vicinity of the drains or over the drains. All STPs must treat sewage up to tertiary levels. The treated water from such STPs must be recycled/ reused or used for other beneficial purposes. After diversion of sewage, the drains may be cleaned and restored for carrying storm drainage. There should be no discharge from such drains into rivers during dry season. Disposal of solid waste into or along the banks of such drains must be prevented. The restored drains and the area surrounding such drains may be cleared of encroachments and utilized for recreational/ commercial purposes.

- **Sewage treatment in Class I and Class II towns using ZLD system:** Projects for renovation of existing sewage treatment plants (STPs) in Class I and Class II towns of the NRGB for tertiary level treatment of sewage are welcome. All new treatment plants constructed at sewer outfalls or other places must be designed for tertiary level treatment of sewage. The treated sewage cannot be discharged, either directly or indirectly, into the river. The plan for utilization of the treated sewage must be clearly specified in the project.

> **Nalas must be recovered to drain storm water with minimal or no urban flooding, and during the non-monsoon season remain dry or carry only tertiary treated sewage. Ideally, all such nalas should become habitat for freshwater organisms.**

- **Reuse/ recycling of treated sewage in Class I and Class II towns:** Considering the goal that no discharge of treated sewage into rivers is allowed in Class I and Class II towns, projects must be conceived for reuse/ recycling of tertiary treated sewage in Class I and Class II towns. Such reuse may be either for commercial, industrial or horticultural purposes that generate revenue stream for partially or fully meeting the expenditure on sewage treatment. Makeup water for industrial/ commercial applications must invariably be tertiary treated sewage. To achieve this condition, the price of freshwater for such applications must be kept much higher than the cost of recycling industrial/ commercial effluents. The objective is to make sewage treatment sustainable without continuous long term support from Central/ State Government.

- **Use of treated sewage for restoration/ creation of surface water bodies:** In areas with limited opportunities of reuse of treated sewage projects for use of treated sewage for restoration/ creation of surface water bodies is encouraged. Direct injection (i.e. without surface storage and subsequent percolation through soils) of treated sewage/ industrial effluents into sub-surface/ ground – waters should invariably be not allowed, i.e., is prohibited.

- **Use of treated sewage for irrigation:** Projects facilitating release of treated sewage into canals (flowing away from rivers) for irrigation purposes are encouraged.

Note on Sewage Management:

All STPs and associated sewage pumping stations in the NGRB should be operated by 'service providers', i.e. public or private agencies with expertise in such activities. It is also desirable that STPs should be funded using innovative financing models such as design-build-finance-operate (DBFO) wherein the 'service provider' makes the initial capital investment in the STP (including VGF, if any) and is paid back in annuities, based on satisfactory operation of the created infrastructure. Further, our vision is that all sewage generated in Class I and Class II towns of NGRB will be treated to tertiary levels as above and reused for various beneficial purposes. It is also envisaged that a business model involving sale of treated sewage may be developed to partially or fully defray the cost of sewage treatment.

- **Sewage management in new/ existing colonies, housing societies using ZLD system:** Projects for onsite sewage management as per the ZLD system in existing/ new housing colonies/ apartment complexes and townships are encouraged. However, major share of funding for such projects must be borne by the project proponents. The projects must ensure that there is no discharge of treated sewage outside the premises. To achieve this, the price of freshwater must be kept much higher than the cost of recycling sewage.

- **Zero-liquid discharge (ZLD) systems for large/ medium industries, including TDS management:** Projects for implementation of ZLD systems in large/ medium industries and industrial clusters, (including CETPs) are encouraged. The treated effluent from such systems must be reused in the industry itself. The proposed systems must include, if necessary, a comprehensive plan for TDS management. Major share of funding for such projects must be borne by the project proponents. However, concessional loans, etc. may be made available for some projects in a case-by-case basis.

Note on Sewage Management in New/ Existing Colonies/ Townships:

We envisage an accelerated pace of urbanization in NGRB in the next few decades. This should not put additional load on sewage infrastructure in place. It is hence recommended that all large planned urban developments, i.e., townships, housing colonies, large multi-storied apartment complexes, etc. adopt a ZLD policy, wherein all sewage generated in such entities should be treated and reused within the complex itself. Similar policy should be extended to existing colonies also, wherever possible.

Note on Sewage Management:

All STPs and associated sewage pumping stations in the NGRB should be operated by 'service providers', i.e. public or private agencies with expertise in such activities. It is also desirable that STPs should be funded using innovative financing models such as design-build-finance-operate (DBFO) wherein the 'service provider' makes the initial capital investment in the STP (including VGF, if any) and is paid back in annuities, based on satisfactory operation of the created infrastructure. Further, our vision is that all sewage generated in Class I and Class II towns of NGRB will be treated to tertiary levels as above and reused for various beneficial purposes. It is also envisaged that a business model involving sale of treated sewage may be developed to partially or fully defray the cost of sewage treatment.

13.2 Examples: Projects in Priority Level II

Projects dealing with dumping of solid waste and other undesirable activities in river, riverbank and river floodplains in Class I and Class II towns and from large/ medium industrial units fall in this category. The MND envisages stoppage/ control of the following activities, 1) dumping of solid and industrial waste, 2) disposal of corpses and animal carcasses, 3) open defecation, 4) disposal of mining waste and construction debris, 5) immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, etc., and 6) movement of stray and domesticated animals, e.g., cows, pigs, dogs, etc. Typical projects in this class are as follows,

- **Prevention of disposal of corpses/ human remains and animal carcasses in river, riverbank or river floodplain:** Projects concerning improvements in cremation facilities, improved disposal of animal carcasses, etc. with an objective of eliminating such practices, will be given due consideration

- **Prevention of open defecation in river, riverbank or river floodplain in Class I and Class II towns:** Projects involving construction of public/ community toilets and associated public

Note on Effluent Management in Large/ Medium Industries in NGRB:

All large and medium industries/industrial clusters, etc. in the NRGB must adopt a ZLD policy. Industries must form SPVs for implementing this policy. The SPVs must appoint expert 'service providers' for effluent treatment. Effluent treatment plants may be set up by the 'service providers' using DBFO or other financing models. The treated effluent will be sold back to the industries at a contracted price, such that the 'service provider' is adequately compensated.

awareness campaign for prevention of open defection, with the objective of eliminating such practices, will be given due consideration.

- **Removal of stray (e.g., dogs) and domesticated animals (e.g., cows, buffaloes, pigs, etc.) from river, riverbank or river floodplain in Class I and Class II towns:** Projects involving the development of the infrastructure and systems for capture and relocation of stray animals and relocation of domestic animals will be given due consideration.

- **Prevention of disposal of municipal and industrial solid waste in river, riverbank or river floodplain in Class I and Class II towns:** Projects for construction of municipal and hazardous waste landfills or other facilities as an alternative to disposal of such wastes on river banks and floodplains shall be given due consideration.

- **Prevention of disposal of mining and construction debris in river, riverbank or river floodplain:** Projects concerning scientific disposal/ reuse of construction and mining debris as an alternative to disposal of such wastes on river banks and floodplains shall be given due consideration.

- **Control of activities such as immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles in Class I and Class II towns:** Projects concerning development and implementation of alternative arrangements for immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, etc. to be given due consideration.

13.3 Example: Projects in Priority Level III

Projects dealing with comprehensive river-frame restoration and development and river floodplain management in Class I and Class II towns will be given due consideration. MND envisages 1) comprehensive river frame development with due aesthetic considerations, and, 2) restoration of river floodplain in all Class I and Class II towns. Typical projects in this class are as follows,

- **River-frame restoration and development in Class I and Class II towns:** Projects concerning comprehensive river-frame restoration and development including removal of encroachments, developments of ghats, walkways, etc., development of pilgrimage and tourist spots, recreational and commercial activities will be considered.

- **River floodplain restoration in Class I and Class II towns :** Projects concerning removal of encroachment from river flood plain and development of projects such as ecological parks, water recharge structures, etc. will be considered.

14. OTHER MND PROJECTS

Implementation of projects in the priority levels IV-VII will reduce the relatively small direct pollution loads and also the diffused pollution load from surface runoff and sub-surface seepage to the Ganga River System. The impact of these projects vis-a-vis the MND objectives is somewhat limited. Hence, implementation of these types of projects has a lower priority vis-à-vis the goals of MND. Funds earmarked for MND should be released for these projects only when the funding requirements of projects in priority levels I-III have been largely addressed.

14.1 Examples: Projects in Priority Level IV

Projects dealing with management of liquid effluents from small industrial clusters and dispersed small industrial units, and solid waste from all industrial sources in NGRB fall in this category. The MND vision for such industrial units is, 1) liquid effluent generated must be discharged separately, i.e., not allowed to mix with domestic sewage, 2) the collected effluent must be treated in-house or in CETPs as per ZLD norms and recycled in the industries itself, 3) all hazardous and non-hazardous solid waste must be collected and reused/ disposed as per norms. Typical projects in this class are as follows,

- **Hazardous and non-hazardous industrial solid waste management:** Projects concerning collection, transport, disposal and recycle/ reuse of industrial solid waste will be given due consideration.

- **CETPs for small industrial clusters based on ZLD concept:** Projects concerning CETPs for clusters of small industries or ETP Clusters for small industries in industrial estates/ clusters will be given due consideration.

- **Effluent collection and treatment from dispersed small industries:** Projects concerning separation of industrial and domestic waste streams in mixed neighborhoods and collection and treatment of industrial effluent in such cases will be considered.

Projects concerning development and implementation of alternative arrangements for immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, etc. to be given due consideration.

14.2 Examples: Projects in Priority Level V

Implementation of projects of this type will lead to general improvement of sanitation and general cleanliness in Class I and Class II towns and hence are essential from the urban renewal/ development perspective. The MND vision for Class I and Class II towns is that, 1) all sewage generated must be collected and transported through closed conduits, 2) open defecation must be completely eliminated, and 3) proper systems for solid waste collection and management must be developed, and 4) systems for septage collection and management must be developed. Typical projects in this class are as follows,

- **Conventional sewer systems in urban areas in Class I and Class II towns:** Projects may be formulated for laying sewers in un-sewered areas, renovation of existing sewers, replacement of open drains with sewers, etc. In addition projects concerning construction of trunk sewers, pumping stations, etc. will also be given due consideration.

- **Sewage collection systems in congested urban areas in Class I and Class II towns:** Projects may be formulated for providing small-bore sewer systems in old congested areas/ unauthorized colonies/ urban villages, etc. where providing conventional sewer systems may not be possible. Provision of interceptor tanks and septage management must be an integral part of such proposals.

- **Septic tank effluent and septage management in Class I and Class II towns:** Projects may be formulated for providing small-bore sewers for conveyance of septic tank effluents and septage management, including evacuation, conveyance and treatment.

- **Provision of community/ public toilets in urban slums in Class I and Class II towns:** Projects may be formulated for providing community toilets where many households may not have toilets. Projects may also be formulated for providing public toilets for itinerant or homeless population. Such toilets must be either pour flush or mechanical flush type with complete provision of fecale sludge and/or sewage management.

- **Municipal solid waste collection and disposal in Class I and Class II towns:** Projects formulated for municipal solid waste collection and disposal, including recycling/ reuse and waste to energy projects and other innovative solutions will be given due consideration.

14.3 Projects in Priority Level VI

Implementation of projects of this type will lead to general improvement of sanitation and general cleanliness in Class III towns and rural areas and such projects are desirable for overall sanitation and cleanliness even in smaller human habitations. The MND vision for such cases is that, 1) all sewage generated must be collected and transported through closed conduits, 2) open defecation must be completely eliminated, and 3) proper systems for solid waste collection and management must be developed, and 4) systems for septage collection and management must be developed. Typical projects in this class are as follows,

Projects may be formulated for providing small-bore sewer systems in old congested areas/ unauthorized colonies/ urban villages, etc. where providing conventional sewer systems may not be possible. Provision of interceptor tanks and septage management must be an integral part of such proposals.

- **Provision of toilets in Class III towns/ rural areas**
  Projects may be formulated for providing toilets in households without toilets, or community toilets in areas where many households may not have toilets. Such toilets must provide a sustainable sanitation solution.

- **Sewage collection in Class III towns/ rural areas**
  Projects may be formulated for providing small-bore sewer systems in areas were sewage generation is not sufficient to support a conventional sewage network or in congested areas where laying conventional sewers is impossible. Provision of interceptor tanks and septage management must be an integral part of such proposals.

- **Sewage treatment in Class III towns/ rural areas:** Projects formulated for using natural biological systems/ pond systems for sewage treatment may be considered.

- **Solid waste and septage management in Class III towns/ rural areas:** Projects formulated for municipal solid waste collection and disposal, including recycling/reuse and waste to energy projects and other innovative solutions will be given due consideration.

14.4 Projects in Priority Level VII

Implementation of projects of this type will result in the control of pollution from agricultural sources, i.e., reduction in nutrient and pesticide loading to the Ganga River System. However, projects of this type should only be undertaken once pollution ingress into the Ganga River system from domestic/ commercial and industrial sources is largely controlled. Typical projects in this class are as follows,

- **Promotion of sustainable riverbank farming:** Projects promoting organic farming and other sustainable farming practices on dry riverbeds and flood plains will be given due consideration.

- **Promotion of use of bio-fertilizers and bio-pesticides in agriculture, horticulture, aquaculture, forestry, etc:** Projects designed to minimize nutrient and pesticide loading from agricultural activities to the rivers will be considered.

15. MND PROJECTS: FINANCIAL STRUCTURING, PROJECT MANAGEMENT AND SUSTAINABILITY

Funding patterns for MND projects can vary depending on the type of project and availability of funds from different sources. Funding may come from various sources; Ganga rejuvenation fund budgeted by the central government, funds available with other ministries/ departments of central/ state governments, local revenue, corporate and private donations and grants, low cost debt from multinational organizations/ banks, commercial debts from banks and private equity. Generally for all projects, the project proponents must be willing to bear at least some cost of the project using local resources.

Funds will not only be required for initial capital cost of the infrastructure but also for operation/ maintenance and renovation/ reinvestment in the created infrastructure. Many projects in related areas have failed in the past because no enforceable guarantee for operation/ maintenance and renovation/ reinvestment in the created infrastructure was forthcoming during sanctioning of the project. The present recommendation is that MND projects must be sanctioned only after enforceable commitments are obtained regarding funding availability for both construction and operation/ maintenance phases over at least 15 years from the project inception.

Category A Recommendations: For projects dealing with implementation of Category A recommendations concerning liquid and solid waste from domestic/ commercial sources, central funds available under Ganga rejuvenation program and low cost debts from multi-national organizations may form a substantial part of the project cost. However, additional funds from state and local governments and a revenue generation model from such projects may also be required. The present recommendation is that such projects must be implemented in the public-private partnership (PPP) mode by specialized 'service providers' who are skilled in designing, building, operating and maintaining the created infrastructure.

Various modes of financing such PPP ventures may be explored, including the design-build-finance-operate (DBFO) model, wherein the 'service provider' provides the initial investment (with or without viability-gap funding) and is assured of returns on the investment based on performance appraisal though the construction and operation/ maintenance phases of the project.

Category B Recommendations: For projects dealing with implementation of Category B recommendations concerning river-frame development and river floodplain management, the availability of central funds should be limited. Such projects should mostly depend on state and local funds or low cost loans from multi-national organizations. A strong revenue model is desired for river-frame development projects. River-frame development projects must be implemented in the public-private partnership (PPP) mode by specialized 'service providers' who are skilled in designing, building, operating and maintaining the created infrastructure. Investment of private equity in such projects is desirable.

Category C Recommendations: Projects dealing with Category C recommendations concerning liquid and solid waste management in the industrial sector should mostly be funded by industries themselves. However, central funds or low cost loans from multi-national organizations may be available for this purpose to small-scale industries/ industrial clusters on a case-by-case basis. Industrial clusters may form special-purpose-vehicles (SPVs) for implementation of such projects. Individual industries/ SPVs should employ specialized 'service providers' for designing, building, operating and maintaining the created infrastructure.

Category D Recommendations: Projects dealing with Category D recommendations concerning control of agricultural pollutants should mostly be funded by central and state governments

16. MND: COST OF IMPLEMENTATION

The total cost of providing sanitation facilities, 1) including toilets (if necessary), 2) sewage conveyance in closed conduits, 3) 'nala' restoration works, including the necessary sewage interception and diversion works for protection of natural water bodies, 4) sewage pumping, and 5) sewage treatment to tertiary levels in all urban and human areas of the NGRB have been calculated (see Table 1). Further details are available elsewhere [IITC,2013]. The overall cost for domestic/ commercial liquid waste management amounts to Rs. 7.75/person/day (present prices).

Similarly total cost of providing municipal solid waste management facilities, including, 1) cost of collection, 2) cost of transport, 3) cost of restoring existing dumpsites including those along rivers and in floodplains, and 4) cost of solid waste disposal in the NRGB have also been calculated (see Table 2). Further details are available elsewhere [IITC, 2014l]. The overall cost for municipal solid waste management thus amounts to Rs. 1.15/person/day (present prices).

The overall cost of other projects associated with MND, including, 1) reuse/ recycle of treated sewage, 2) use of treated sewage for construction/ rejuvenation of water bodies, 3) use of treated sewage for irrigation purposes, 4) river-frame management and restoration, 5) river floodplain management and restoration, 6) industrial liquid and solid waste management, and 7) abatement of agricultural pollution, could not be calculated due to wide site specific variations in the cost of implementation of such projects.

The cost of supply of treated sewage for various beneficial purposes should be between 10 – 50 percent of the cost of sewage treatment. It is envisaged that this cost may be fully or partially recovered from the users, once proper incentive and regulatory structure for this purpose is put into place. The cost of industrial waste management, including reuse/ recycle of treated sewage is to be largely borne by the industries themselves with minimal support from central/ state governments. Our preliminary studies show that the industries can absorb such costs and in long run this will help in sustained growth of industries through internalizing the environmental costs. Some indications on expenditures for achieving Zero Liquid Discharge (ZLD) for some of the industrial sectors (e.g. Tanneries in Kanpur and Pulp and Paper industries in NRGB) are given elsewhere [IITC, 2011c; IITC, 2014m]. The costs of river-frame and flood plain restoration and management projects are expected to vary widely from project to project. Some support from central government is required for such projects. However, substantial infusion of private equity is desirable in river frame restoration projects. The projects for the abatement of agricultural pollution are of a relatively low priority at the present time.

Table 1: Total Cost* of Providing Sanitation in NRGB

State	Population (millions)	CAPEX Rs. (crore)	CAPEX (annualized) Rs. (crore/yr)	OPEX Rs. (crore/yr)	TOTAL Rs. (crore/yr)
Uttar Pradesh	200.95	89278	21372	34908	56280
Himachal P	6.87	2966	710	1229	1939
Uttarakhand	10.16	4531	1085	1776	2861
Haryana	25.35	11843	2835	4442	7277
Delhi	19.25	8448	2022	2894	4916
Rajasthan	68.75	31508	7543	12263	19806
Bihar	104.48	45827	10971	18435	29406
West Bengal	92.67	41391	9909	15935	25844
Jharkhand	33.28	15220	3644	5846	9489
Chhattisgarh	25.66	11882	2844	4563	7408
Madhya P	73.64	33367	7988	12835	20823
Total	**661.06**	**296260**	**70922**	**115125**	**186047**

Note: * Total Cost covers cost for management of all liquid waste generated from domestic and commercial sources in both rural and urban areas. This includes cost of sewage conveyance in closed conduits, sewage pumping and sewage treatment in all types of human settlements including congested/ unauthorized colonies, slums and rural areas. It also includes the cost of septage management, conveyance and treatment of septic tank effluent and providing community/public toilets as required; *annualized over 15 year period assuming an interest rate of 10% p.a.

Table 2: Cost Estimates on Solid Waste Management in GRB

State	Population (millions)	CAPEX Rs. (crore)	CAPEX (annualized) Rs. (crore/yr)	OPEX Rs. (crore/yr)	TOTAL Rs. (crore/yr)
Uttar Pradesh	200.95	9978	2180	6281	8461
Himachal P	6.87	341	74	214	289
Uttarakhand	10.16	504	110	317	428
Haryana	25.35	1258	275	792	1067
Delhi	19.25	956	176	601	778
Rajasthan	68.75	3413	746	2148	2894
Bihar	104.48	5188	1133	3265	4399
West Bengal	92.67	4601	1005	2896	3902
Jharkhand	33.28	1652	359	1040	1399
Chhattisgarh	25.66	1274	278	802	1080
Madhya P	73.64	3657	799	2302	3101
Total	**661.06**	**32826**	**71340**	**20663**	**27802**

Note: Includes cost of collection, conveyance and treatment; *annualized using 12% interest over 5 years for equipment and machinery and 12% interest over 20 years period for infrastructure and construction work.

17. MND: IMMEDIATE ACTIONS

Ganga rejuvenation works should be phased in a manner such that visible improvements in the condition of some rivers of NRGB are visible within 4 years of the start of implementation of MND. The most polluted portion of the NRGB with associated streams/ rivers, towns and industrial sectors are shown in Figure 17.1. Thus the initial MND projects must be taken up in areas/ sectors which exhibit gross pollution.

It is thus proposed that MND projects must immediately be implemented for reducing domestic sewage ingress into Ganga River system in the following towns of NRGB,

- In Kshipra Sub-basin of NRGB as a pilot covering Indore, Ujjain and Dewas towns;
- **On Yamuna river:** Delhi, Faridabad, Vrindavan, Mathura and Agra;
- **On Ramganga river:** Moradabad;
- **On Gomati river:** Lucknow;
- **On Ganga river:** Haridwar, Garhmukhteshwar, Kanpur, Allahabad and Varanasi;

The steps in the implementation schedule include,

1. Preparation of URMPs for above towns. The required time-period for this activity is 18 months.
2. Preparation of DPRs by expert agencies for Priority Level I projects in these towns using data available in UPMPs and other sources. The required time period for this activity is 4 months.
3. Vetting of the DPRs by competent agencies and arrangement of funds. The required time period for this activity is 3 months.
4. Implementation of DPRs concerning i) 'Nala' restoration, ii) construction of STPs, and iii) reuse/ recycle and other beneficial uses of tertiary treated sewage. The required time period for construction phase is 24 – 36 months.

In addition, MND projects must be undertaken immediately for the reduction of gross pollution to the Ganga River system from industrial sources. The industries to be targeted for this purpose are the paper and pulp, sugar and distillery, tannery and pharmaceutical industries in Uttarkhand and Uttar Pradesh. Industrial effluent treatment for these industries should be based on ZLD concept (including salt management) and recycle of treated industrial effluent within the industry itself. All above industries (including CETPs associated with such industries) must be required to prepare comprehensive plan for management of industrial effluent and should be required to move towards installation of ZLD system within 24-36 months.

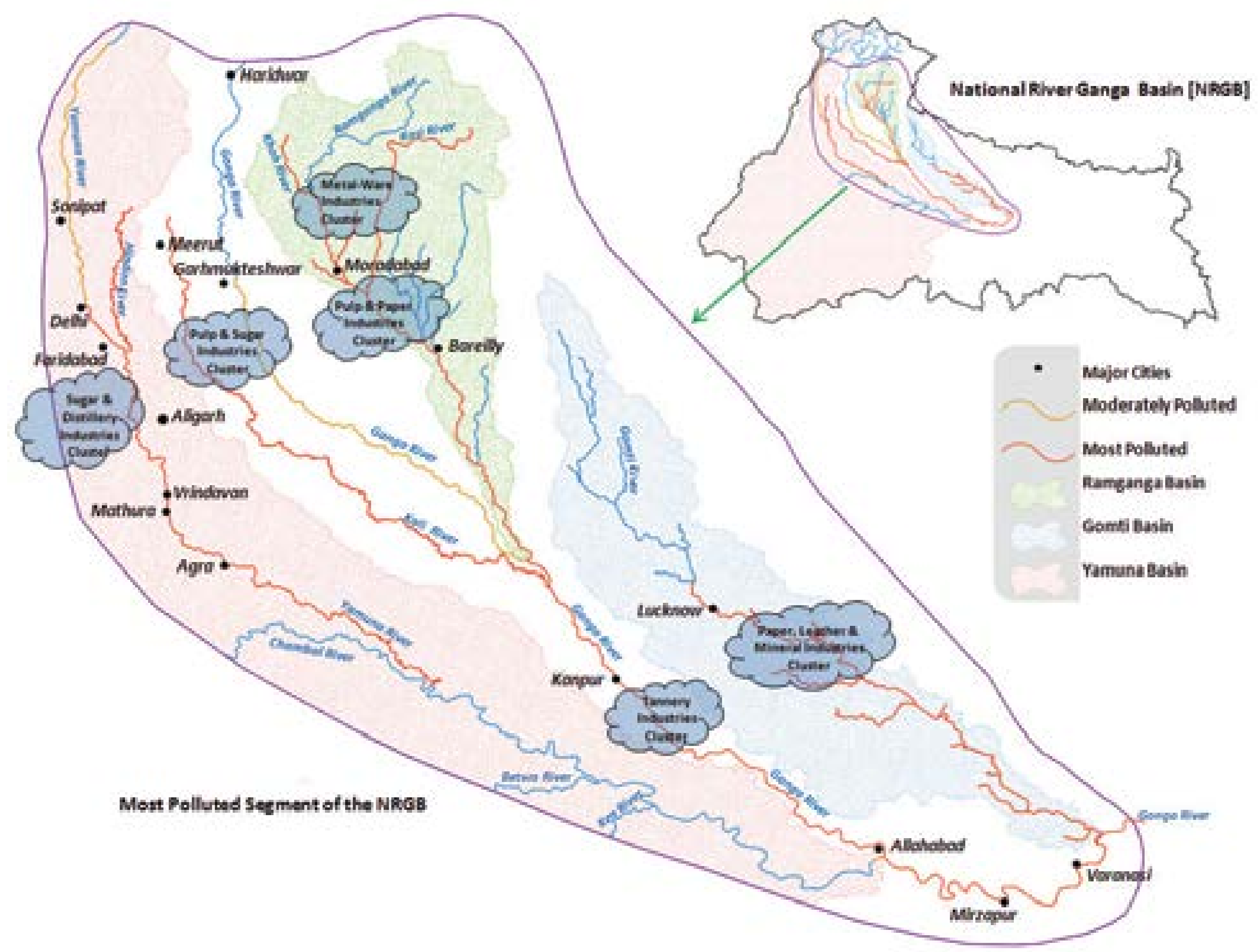


Figure 17.1: Most Polluted Stretches and their Pollution Sources in National River Ganga Basin

18. MND: BUDGET OUTLAY

In addition to the immediate actions above, other projects under Ganga Rejuvenation program should be undertaken as per the recommendations in this report in a phase-wise manner over the next 15 years. This shall constitute the Phase I of MND. The proposed Central Government budget outlay for Ganga Rejuvenation over next 15 years has been suggested with the assumption that all projects associated with recommendations in Priority Levels I-III will be funded within the next 15 years. The proposed budget outlay for specific 'project types' is given in the next few pages.

Project Type: Restoration of natural drains in Class I and Class II towns of NRGB [Priority Level I]

Activities: Natural drains ('Nalas') carry untreated/ partially treated domestic sewage and industrial effluent into the Ganga River System from all Class I and Class II towns in NRGB. It is recommended that projects must be conceived for restoration of such drains. This would involve preventing sewage discharge into such drains by constructing intercepting sewers parallel to the drains. The sewage collected in the intercepting sewers must be diverted to multiple locations along the drain to existing STPs with spare capacity. Alternatively, decentralized STPs may be constructed in the vicinity of the drains or over the drains. Treated sewage cannot be discharged back into the 'nalas'. After diversion of sewage, the 'nalas' may be cleaned and restored for carrying storm drainage. Thus, there should be no discharge from such drains into rivers during dry season. Disposal of solid waste into or around such drains must be prevented. The area surrounding such drains may be cleared of encroachments and utilized for recreational/commercial purposes.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for restoration of 'nalas' in Class I Towns: 247 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	1080	2160	2160	2160	2160	2160	1080	1080	1080	1080	1080	1080	1080	1080	1080	**21615**
OPEX	0	305	915	1525	2135	2745	3355	3660	3964	4269	4574	4879	5184	5489	5794	**48794**
Total	**1080**	**2465**	**3075**	**3685**	**4295**	**4905**	**4435**	**4740**	**5045**	**5350**	**5655**	**5960**	**6265**	**6570**	**6875**	**70409**

After 15 years, Rs. 6100 crore/yr (value as on date) will be required for operation/ maintenance (including renovation) of the created infrastructure

Values as on date (in Rs. Crore) for the CAPEX and OPEX for restoration of 'nalas' in Class II Towns: 139 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	97	194	194	194	194	194	97	97	97	97	97	97	97	97	97	**1940**
OPEX	0	30	91	152	213	274	335	365	395	426	456	487	517	548	578	**4867**
Total	**97**	**225**	**286**	**346**	**407**	**468**	**432**	**462**	**493**	**523**	**553**	**584**	**614**	**645**	**675**	**6810**

After 15 years, Rs. 608 crore/yr (value as on date) will be required for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the project costs (including CAPEX and OPEX over 15 years) will be available from the above budget allocated by central government under the Ganga Rejuvenation program

Project Type: Tertiary sewage treatment in Class I and Class II towns of NRGB [Priority Level I]

Activities: In addition to STPs associated with 'nala' restoration, projects for construction of new STPs and renovation of existing STPs at sewer outfalls and other locations in Class I and Class II towns of the NRGB are welcome. All STPs (including associated sewage pumping stations and other appurtenances) must be designed for tertiary level treatment of sewage. The treated sewage cannot be discharged, either directly or indirectly, into the river. The plan for utilization of the treated sewage must be clearly specified in the project proposal.

Budget Under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for tertiary sewage treatment in Class I Towns: 247 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	270	540	540	540	540	540	270	270	270	270	270	270	270	270	270	5404
OPEX	0	76	229	381	534	686	839	915	991	1067	1144	1220	1296	1372	1449	12198
Total	270	617	769	922	1074	1227	1109	1185	1261	1338	1414	1490	1566	1643	1719	17602

After 15 years, Rs. 1525 crore/yr (value as on date) will be required for operation/ maintenance (including renovation) of the created infrastructure

Values as on date (in Rs. Crore) for the CAPEX and OPEX for tertiary sewage treatment in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	24	49	49	49	49	49	24	24	24	24	24	24	24	24	24	486
OPEX	0	8	23	38	53	68	84	91	99	106	114	122	129	137	144	1217
Total	24	56	71	87	102	117	108	116	123	131	138	146	154	161	169	1702

After 15 years, Rs. 152 crore/yr (value as on date) will be required for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the project cost (including CAPEX and OPEX) over the first 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program

Project Type: Reuse/recycling of treated sewage in Class I and Class II towns [Priority Level I]

Activities: Considering that no discharge of treated sewage into rivers is allowed from any STP, projects must be conceived for reuse/recycling of tertiary treated sewage in Class I and Class II towns. Such reuse may be either for commercial, industrial or horticultural purposes such that the generated revenue stream can be used for partially or fully meeting the operating expenditure for reuse/ recycling schemes and sewage treatment. This would make sewage treatment sustainable without continuous long term support from Central Government.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX for reuse/recycle of treated sewage in Class I Towns: 247 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	100	500	500	500	1000	1000	1000	500	500	500	500	200	200	200	100	7300

*OPEX (including renovation cost) to be recovered from the revenue generated from the sale of treated sewage.

Values as on date (in Rs. Crore) for the CAPEX for reuse/recycle of treated sewage in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	10	50	50	50	100	100	100	50	50	50	50	20	20	20	10	730

*OPEX (including renovation cost) to be recovered from the revenue generated from the sale of treated sewage.

Source of Funds: 90% of the project cost (only CAPEX) will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the OPEX (including renovation cost) for at least 15 years is available from other sources.

Project Type: Use of treated sewage for restoration/ creation of surface water bodies [Priority Level I]

Activities: In areas with limited requirement of treated sewage for reuse, projects for use of this treated sewage for restoration/ creation of surface water bodies in the immediate vicinity is encouraged.

Budget under Ganga Rejuvenation Program:

Values as on data (in Rs. Crore) for the CAPEX for rejuvenation/ creation of surface water bodies in Class I Towns: 247 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	50	250	250	250	500	500	500	250	250	250	250	100	100	100	50	3650

*OPEX (including renovation cost) to be pledged by the state/ local government

Values as on date (in Rs. Crore) for the CAPEX for rejuvenation/ creation of surface water bodies in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	5	25	25	25	50	50	50	25	25	25	25	10	10	10	5	365

*OPEX (including renovation cost) to be pledged by the state/ local government

Source of Funds: 90% of the project cost (only CAPEX) will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the OPEX (including renovation cost) for at least 15 years is available.

Project Type: Use of treated sewage for irrigation [Priority Level I]

Activities: In areas with limited demand for reuse of treated sewage, projects facilitating release of treated sewage into canals (flowing away from river) for irrigation purposes are encouraged.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX for use of treated sewage for irrigation in Class I Towns: 247 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	30	150	150	150	300	300	300	150	150	150	150	60	60	60	30	2190

*OPEX (including renovation cost) to be pledged by the state/ local government

Values as on date (in Rs. Crore) for the CAPEX for use of treated sewage for irrigation in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	3	15	15	15	30	30	30	15	15	15	15	6	6	6	3	219

*OPEX (including renovation cost) to be pledged by state/ local government

Source of Funds: 90% of the project cost (only CAPEX) will be available from the above budget allocated under this head by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the OPEX (including renovation cost) for at least 15 years is available.

Project Type: Sewage management in housing colonies/ societies and large multi-stories complexes using ZLD system [Priority Level I]

Activities: Projects for onsite sewage management as per the ZLD system in existing/new housing colonies/ apartment complexes and townships are encouraged. However, major share of funding for such projects must be borne by the project proponents. The projects must ensure that there is no discharge of untreated/ treated sewage outside the premises.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX for installation of ZLD systems in colonies/housing complexes																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	3	15	15	15	30	30	30	15	15	15	15	6	6	6	3	**219**

*OPEX (including renovation cost) to be pledged by the state/ local government

Values as on date (in Rs. Crore) for the CAPEX for rejuvenation/creation of surface water bodies in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	5	25	25	25	50	50	50	25	25	25	25	10	10	10	5	**365**

*OPEX (including renovation cost) to be pledged by the project proponents

Source of Funds: In most cases, the entire project cost (including CAPEX and OPEX) to be borne by the project proponents themselves. However, some budget (as above) is available for funding of the CAPEX of demonstration projects for existing colonies/ housing projects etc., up to a maximum of 50% of the CAPEX. However, such funds will be sanctioned only when an enforceable guarantee for the OPEX (including renovation cost) for at least 15 years is available.

Project Type: Zero Liquid Discharge (ZLD) systems for large/ medium industries, including TDS [Priority Level I]

Activities: Projects for implementation of ZLD systems in large/ medium industries and industrial clusters (including in associated CETPs) is encouraged. The treated effluent from such systems must be reused in the industry itself. The proposed systems must include, if necessary, a comprehensive plan for TDS management. Major share of funding for such projects must be borne by the project proponents.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) of the CAPEX for zero-liquid discharge (ZLD) systems for large/ medium industries, including TDS management																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	30	150	150	150	300	300	300	150	150	150	150	60	60	60	30	**2190**

*OPEX (including renovation cost) to be pledged by project proponents

Source of Funds: 30% of the project cost (only CAPEX) may be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the remaining CAPEX and OPEX (including renovation cost) for at least 15 years is available.

Project Type: Prevention of disposal of corpses/ human remains and animal carcasses in river, riverbank or river floodplain. [Priority Level II]

Activities: Projects concerning improvements in cremation facilities, improved disposal of animal carcasses, etc. will be given due consideration

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for projects concerning prevention of disposal of corpses/ human remains and animal carcasses in river, riverbank or river floodplain. in Class I Towns: 247 towns in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	55	111	111	111	111	111	55	55	55	55	55	55	55	55	55	**1108**
OPEX	0	17	52	87	122	157	192	209	227	244	262	279	296	314	331	**2789**

After 15 years, Rs. 349 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: Prevention of open defecation in river, riverbank or river floodplain in Class I and Class II towns. [Priority Level II]

Activities: Projects involving construction and operation/ maintenance of public/ community toilets and associated public awareness campaign and other actions leading to the prevention of open defection will be given due consideration.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for projects concerning prevention of open defecation in river, riverbank or river floodplain in Class I and Class II towns. in Class I Towns: 247 towns in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	55	111	111	111	111	111	55	55	55	55	55	55	55	55	55	**1108**
OPEX	0	35	105	174	244	314	384	418	453	488	523	558	593	628	662	**5579**

After 15 years, Rs. 697 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: Removal of stray (e.g., dogs) and domesticated animals (cows, buffaloes, pigs, etc.) from river, riverbank or river floodplain in Class I and Class II towns [Priority Level II]

Activities: Projects involving the development of the infrastructure and systems for capture and relocation of stray animals and relocation of domestic animals will be given due consideration.

Budget under Ganga Rejuvenation Program:

Value as on date (in Rs. Crore) for the CAPEX and OPEX for projects concerning removal of stray (e.g., dogs) and domesticated animals (cows, buffaloes, pigs, etc.) from river, riverbank or river floodplain in Class I and Class II towns
in Class I Towns: 247 towns
in Class II Towns: 139 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	28	55	55	55	55	55	28	28	28	28	28	28	28	28	28	**554**
OPEX	0	17	52	87	122	157	192	209	227	244	262	279	296	314	331	**2789**

After 15 years, Rs. 349 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: Prevention of disposal of municipal and industrial solid waste in river, riverbank or river floodplain in Class I and Class II towns [Priority Level II]

Activities: Projects for construction of municipal and hazardous waste landfills or other facilities as an alternative to disposal of such wastes on river banks and floodplains shall be given due consideration.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for projects concerning prevention of disposal of municipal and industrial solid waste in river, riverbank or river floodplain in Class I and Class II towns
in Class I Towns: 247 towns
in Class II Towns: 139 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	55	111	111	111	111	111	55	55	55	55	55	55	55	55	55	**1108**
OPEX	0	52	157	262	366	471	575	628	680	732	785	837	889	941	994	**8368**

After 15 years, Rs. 1046 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: Prevention of disposal of mining and construction debris in river, riverbank or river floodplain [Priority Level II]

Activities: Projects concerning scientific disposal/ reuse of construction and mining debris as an alternative to disposal of such wastes on river banks and floodplains shall be given due consideration.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for projects concerning prevention of disposal of mining and construction debris in river, riverbank or river floodplain
in Class I Towns: 247 towns
in Class II Towns: 139 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	28	55	55	55	55	55	28	28	28	28	28	28	28	28	28	**554**
OPEX	0	17	52	87	122	157	192	209	227	244	262	279	296	314	331	**2789**

After 15 years, Rs. 349 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: Control of activities such as immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, non-ritual bathing, etc. in Class I and Class II towns [Priority Level II]

Activities: Projects concerning development and implementation of alternative arrangements for immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, non-ritual bathing, etc. to be given due consideration.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for Projects Concerning Control of activities such as immersion of idols, floral and other offerings, wallowing of domestic animals, washing of clothes, vehicles, non-ritual bathing, etc. in Class I and Class II towns
in Class I Towns: 247 towns
in Class II Towns: 139 towns

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	55	111	111	111	111	111	55	55	55	55	55	55	55	55	55	**1108**
OPEX	0	35	105	174	244	314	384	418	453	488	523	558	593	628	662	**5579**

After 15 years, Rs. 697 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation cost) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Project Type: River-frame restoration and development in Class I and Class II towns [Priority Level III]

Activities: Projects concerning comprehensive river-frame restoration and development including removal of encroachments, developments of ghats, walkways, etc., development of pilgrimage and tourist spots, recreational and commercial activities will be considered.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX for projects concerning river-frame restoration and development in Class I and Class II towns in Class I Towns: 247 towns in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	250	500	500	500	500	500	250	250	250	250	250	250	250	250	250	**5000**

*OPEX (including renovation cost) to be pledged by the project proponents

Source of Funds: 70% of the CAPEX will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX (including renovation costs) for at least 15 years is available.

Project Type: River floodplain restoration in Class I and Class II towns [Priority Level III]

Activities: Projects concerning removal of encroachment from river flood plain and development of projects such as ecological parks, water recharge structures, etc. on the floodplains will be considered.

Budget under Ganga Rejuvenation Program:

Values as on date (in Rs. Crore) for the CAPEX and OPEX for Projects concerning river floodplain restoration in Class I and Class II towns in Class I Towns: 247 towns in Class II Towns: 139 towns																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
CAPEX	250	500	500	500	500	500	250	250	250	250	250	250	250	250	250	**5000**
OPEX	0	50	150	250	350	450	550	600	650	700	750	800	850	900	950	**8000**

After 15 years, Rs. 1000 crore/yr (value as on date) must be budgeted for operation/ maintenance (including renovation) of the created infrastructure

Source of Funds: 90% of the CAPEX and 50% of the OPEX (including renovation costs) over 15 years will be available from the above budget allocated by central government under the Ganga Rejuvenation program. However, funds will be sanctioned only when an enforceable guarantee for the balance CAPEX and OPEX for at least 15 years is available.

Proposed Budget (value as on date) for the next 15 years under Ganga Rejuvenation Program

	Values as on date (in Rs. Crore) of the CAPEX and OPEX for Projects in Priority Levels I – III in NRGB in Class I Towns: 247 towns in Class II Towns: 139 towns																
	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
	Allocation for URMP Preparation and Vetting																
URMP Preparation		95	190	190	190	190	190	95	95	95	95	95	95	95	95	95	1900
URMP Vetting		5	10	10	10	10	10	5	5	5	5	5	5	5	5	5	100
	Allocation for DPR Preparation and Vetting																
DPR Prep. Support		76	380	380	380	380	380	304	190	190	190	190	190	190	190	190	3800
DPR Vetting		4	20	20	20	20	20	16	10	10	10	10	10	10	10	10	200
	Allocation for 'MND Projects'																
Priority Level	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
I	CAPEX	1702	4098	4098	4098	5253	5253	3781	2626	2626	2626	2626	1933	1933	1933	1702	46288
I	OPEX	0	419	1258	2096	2935	3773	4613	5031	5449	5868	6288	6708	7126	7546	7965	67075
II	CAPEX	277	554	554	554	554	554	227	227	227	227	227	227	227	227	227	5090
II	OPEX	0	174	523	872	1220	1569	1918	2092	2266	2441	2615	2789	2964	3138	3312	27894
III	CAPEX	500	1000	1000	1000	1000	1000	500	500	500	500	500	500	500	500	500	10000
III	OPEX	0	50	150	250	350	450	550	600	650	700	750	800	850	900	950	8000
TOTAL		2659	6895	8183	9470	11912	13199	12009	11376	12018	12662	13306	13257	13900	14544	14956	170,346

19. FINANCING MND PROJECTS

The financing of every single aspect of the rejuvenation of River Ganga is a gigantic task requiring large amounts of capital running into lakhs of crores of rupees. The Government as a source of finance, although significant, cannot be depended upon as the only source. Efforts must be made to tap into global capital pool so as to ensure timely delivery of capital. Delay in financing not only results in opportunity cost but can also lead to redundant efforts since the physical conditions of the projects might have changed.

Financing of projects mustn't also be set in a monolithic framework. The diverse nature of the problems within NRGB requires multitudes of financing structures to be established. The structures are better devised and implemented if assessed through their needs and categorized as follows.

19.1 Projects that can Utilize a PPP Structure

Projects that have a clear revenue generation model are best funded through a PPP structure. It is recommended that a large portion of total projects are funded through this mechanism as it puts the onus of successful delivery onto the investor/ financier. This will result in better design of projects from both technological as well as economic standpoint. The Government's role in the PPP structure is to ensure creation of a robust risk management model to enable increased capital flow into the underlying projects. Projects that fall under this category include:

- Industrial effluent treatment
- Sewage treatment where there is a clear revenue model
- Solid waste management
- Public toilets where a user-fee is possible

19.2 Projects that can only be Funded through Government Financing Mechanism

There are projects in which there is no clear revenue model and must only be financed through the Government sources. Although the Government will finance these projects, it must also adopt a Total Lifecycle Cost (TLC) approach so that all elements including capital expenditure (Capex), operational expenditure (Opex), repairs and maintenance are factored into the financial planning of the asset. This approach will ensure that the assets are well managed and deliver the desired results. Projects that fall under this category include:

- Restoration of natural drains (nalas)
- Constructing and managing a sewerage network
- Sewage treatment plants (where there is no clear revenue model)
- Public toilets where no user fee is possible
- Encroachment removal from river floodplain
- Maintenance/ construction of surface water bodies/ water recharge structures

19.3 Projects that can be Delivered through an Annuity Model

These are typically brown-field projects or those that require a long term operations and maintenance of assets. Projects that fall under this category include:

- Retrofitting existing and poorly operating STPs/ ETPs
- Operations & maintenance of STPs/ ETPs

19.4 Projects that can be Funded through Sale or Leasing of Assets

The land owned by Government at various locations along the river belt can be sold or given out on a long-term lease model to private/ third-party developers. The sale of proceeds can be utilized to finance a number of projects. Projects that fall under this category include:

- River-frame development
- Restoration of ghats
- River floodplain restoration
- Cremation facilities

19.5 Projects that can be Funded through a Licensing Mechanism

In cases where PPP models are not applicable but where there is a clear revenue stream associated, a licensing mechanism can generate substantial resources for the Government to finance projects. Examples include licensing fee generated through vendors, hawkers, kiosks, tourism operators and other service providers that operate on the banks of the rivers. Projects that fall under this category include

- Keeping riverside clean
- Prevention of disposal of corpses/ human remains

19.6 Enabling the PPP Framework

In order to develop and deliver an effective PPP framework, the most crucial element that all stakeholders

Financing of projects mustn't be set in a monolithic framework. The diverse nature of the problems within NRGB requires multitudes of financing structures to be established.

need to address is the risk within the system. All parties involved in the project are responsible for identifying and mitigating these risks. It is the Government's primary responsibility to develop a market framework that attracts private sector investment into the project.

Financing wastewater treatment projects using a PPP construct, be it sewage or industrial effluents, is only possible if payments to the 'service provider' is guaranteed through enforceable contracts. There must be clear and well enforced guidelines by the Government that prevents discharge of sewage or industrial effluent (either treated or untreated) to the rivers. In case of industries, the polluter must deploy a zero liquid discharge framework. In case of municipal wastewater, the Urban Local Body (ULB) must first try to sell treated sewage before using for other purposes. If anyone is discharging untreated wastewater then there must be a heavy penalty which will act as a deterrent.

19.7 Local Area Water Markets

In order to establish a revenue model for treated wastewater, the ULBs must establish the local area water market framework. This process will identify the producers of wastewater and bulk buyers. Each ULB can do this exercise in a relatively short span of time which will help it identify the market stakeholders as well as create an effective market.

19.8 Addressing Industrial Effluent Treatment

For industrial units without proper Effluent Treatment Plant (ETP), factoring the CAPEX and OPEX of the ETP into the economic model of the business may come as an unwelcome surprise. Some industries will find the cost increase rather difficult to absorb whilst others will simply not be able to spare or raise adequate capital to fund the establishment of the ETP.

The BOOT (Build-Own-Operate-Transfer) framework can help such businesses that find financing the ETP a challenge. A third party developer will assume the responsibility to design, finance and operate such an ETP. It will recover its investment and the return on capital by entering into a long term agreement with the industry needing such an ETP. An effluent treatment or a water purchase agreement will have to be signed between the two parties clearly listing the base tariff and escalation parameters. However bankability of such projects will remain a challenge for entities that have relatively poor credit rating. The following steps can be employed to make such projects more bankable:

Financing wastewater treatment projects using a PPP construct, be it sewage or industrial effluents, is only possible if payments to the 'service provider' is guaranteed through enforceable contracts.

1. Open Book Planning: Engineering, Procurement and Construction (EPC) costs depend on quantity and characteristics of effluents. A realistic assessment of these costs is essential or the financing of the project will remain a challenge. Neither party should try to conceal or hide any facts or truths from one another. The industry owner must be open and forthcoming about their actual effluent discharge volumes and characteristics. If the fundamental objective is to treat 100% of the effluent coming out of the plant with subsequent capacity expansion, then the developer has to take these into account when scoping the capacity and other parameters of the plant that have a direct impact on the cost of setting one up and operating it.

Similarly the developer must also be fully transparent on its true Engineering, Procurement and Construction (EPC) costs. The developer will also charge a premium and build that into the tariff agreement to recover its cost and the return on capital investment. It is prudent that the developer does an open book accounting and cost of capital modeling with upfront ROI targets agreed by the industry owner.

Mutual trust and collaborations are the keywords underpinning this relationship.

2. Having Skin in the Project: The project developer is taking a significant risk by setting up such a project which is not a standalone business. If things go sour it isn't that the developer can simply dismantle the plant and take it away elsewhere. It is important for the industry owner to co-invest with the project developer in the setting up of the ETP. Although it is fairly evident that the main driver behind such a project relationship is of industry owner's lack of capital, even a small contribution to the tune of 20% of developer's capital investment will go a long way in demonstrating confidence.

3. Waterfall Revenue Arrangement and Pooling: Just because the ETP is at the very end of the process chain doesn't mean that it is at the very end of the chain when receiving its income through the agreed tariff. It is important that the ETP is considered as one of the most important elements of an industrial process and that the tariff for the plant should be set aside as soon as the revenues of the industrial unit owner are received.

4. Resource Allocation: Well structured EPC and O&M contracts that provide for a buffer in case of any payment defaults will help improve the credit rating of the project. The parties should keep aside 6-12 months of O&M tariff through use of resource allocation instruments such as Letters of Credit (L/C) or an escrow account.

5. Default Backstops through Counterparty Guarantee: In the event the industry owner defaults, winds the business down or is unable to make the payments, there should be recourse to other assets within the group. This is one of the most important points that will improve the bankability of the projects. In case the off-taker is a Government agency, the backstop arrangement can be provided through a sovereign or sub-sovereign guarantee.

6. Project Insurance: Putting in place a robust insurance policy that is globally recognized will give a lot of comfort to lenders and investors of the project. There are a number of specialist brokers who can source such a policy.

7. Credit Rating: Once a number of aforementioned credit enhancement mechanisms are put in place, the project developers should get the project rated through a credible ratings agency. This will greatly enhance the bankability as project lenders can quantify the level of risk and ascertain a premium as per the rating.

Not having a credit rating, no matter how good the project is, can adversely affect its bankability.

8. Take-out Financing through Bond Issuance: Commercial lenders are mostly unable to lend for longer tenures. Therefore if a project has a commercial rating, its developers should consider issuing a bond so that the fixed income investors can then take the banks out at the end of the tenure.

9. Global Green Capital: There is ample capital available for good quality environmental projects. The project developers should look at global sources to mobilize such capital through dedicated green- infra-funds, development finance institutions and other quasi Governmental agencies. These agencies will take a more positive view to financing the projects than normal commercial institutions and their risk appetite level will also be much larger.

10. Better Procurement through Export Credit Assistance Schemes: Many developed nation economies are facing a slower growth and the Governments are putting measures and schemes to boost exports through providing various financial instruments to either the exporter or the project. These come in various forms such as export guarantee, equipment financing or straight non-recourse concessionary project lending. Procuring equipment strategically from such markets will also increase the probability of financing the projects.

19.9 Government Created Financial Frameworks

The Government may also take proactive measures and create a slew of instruments that will enable greater flow of investments into addressing the restoration and rejuvenation of river Ganga.

1. Ganga Bonds: Issuing long term bonds in Indian or international capital markets can generate significant capital base for the Government. These long term bonds can finance most of the sewage treatment plants and sewerage network that needs to be built in the NRGB.

2. **Technology Upgrade Fund:** A specialist fund targeted at MSME industry segment that find it challenging to access to best technologies and global best practices.

3. **Shadow Tariffs:** If industry is unable to pay for the entire O&M tariff for the efficient operation of the industrial effluent treatment plant, then a shadow tariff mechanism paid through a specialist fund can help bring the requisite revenues to the plant owner/ operator.

4. **Long-term Low Cost Loans:** Government can provide long term low cost loans to entities willing to set up effluent treatment facilities. Lowering the cost of capital will reflect in lower tariffs that will lower the burden on industry or other users paying for treatment of water.

5. **Foreign Currency Hedging:** Many industry units will be able to borrow through external commercial borrowing route. If Government helps in absorbing the hedging costs or fixing the foreign currency conversion rates, then it will allow industry owners to tap into a larger pool of capital which will also lower the cost of finance.

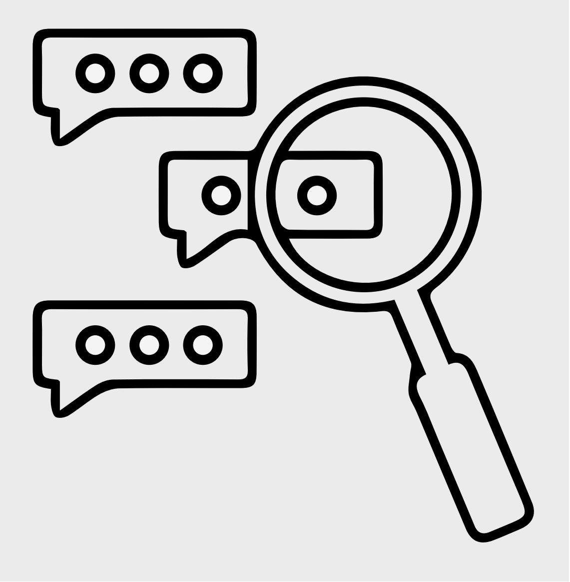
6. **Credit Rating:** Government should make it mandatory for all parties to credit-rate their projects and achieve a minimum credit rating if they are to avail of the Government sponsored facilities. This will bring significant fiscal discipline and improve the quality of underlying credit thereby attracting both domestic and international lenders/ investors.

7. **Take-Out Financing:** One of the most crucial instruments, take-out-financing is long term capital that comes in after the commercial lenders finish their tenures. This is crucial to be put in place right at the beginning so that it gives comfort to the lenders and investors.

8. **Water Quality Trading:** This instrument can effect major transformation in the water sector. It is based on the same principles of carbon trading but is applied at a very local level. The trading happens between two parties that are discharging different quantities of effluents. The one below the pre-defined threshold level sells credits to the one that is above the threshold level. The thresholds can be applied both on quality and quantities. This creates a local market which can be monitored by a Government agency.

9. **Credit Risk Pooling:** A government sponsored credit pool can allow either municipalities and/ or industrial effluent treatment plant managers to pool their risk into a single vehicle. This diversifies risk for the insurer and thereby reduces the cost of capital.

20. MND PROJECTS: MONITORING AND FEEDBACK



The overall objective of Mission “Nirmal Dhara” (MND) is to ensure that the flow in the Ganga River System is bereft of manmade pollution, such that water quality of the Ganga River System is not substantially affected by human activities in NRGB. Ingress of all anthropogenic pollutants into the Ganga River System must ultimately be eliminated to achieve this goal.

However, the more limited objective of MND over the next 15 years is to implement numerous projects in the industrial and domestic/ commercial (Class I and II towns) sectors designed to, A) prevent direct discharge of large quantities of liquid waste into the Ganga River System, B) prevent direct discharge of large quantities of solid waste into the Ganga River System, and C) promote river-frame development and restoration of floodplain in Class I and II towns along the Ganga River System.

The amount of funding available for MND projects over the next 15 years is obviously a big determinant for the ultimate success of MND. In case of Class I and II towns in NGRB, major share of funding required for ‘MND projects’ must be available from Ganga Rejuvenation funds earmarked by the central government. In case of industries, majority of the required funding must come from industries itself.

DPRs for relevant projects will be presented by project proponents for vetting and approval to NGRBMC. High quality DPRs consistent with the objectives of MND will be approved as ‘MND Projects’ and hence will be eligible for partial funding from the Ganga rejuvenation budget. A DPR will only be given the final ‘green signal’ for implementation when an enforceable guarantee for funding (CAPEX, OPEX and renovation/ re-investment cost) is finalized for at least 15 years from the time of project commencement.

All 'MND projects' will have an in-built mechanism for announced/ unannounced independent third-party inspections coordinated by NGRBMC. NGOs and other civil society organizations (CSOs) may be involved in this effort. The payments to the contractor/ 'service provider' should be closely linked to the results of such inspections.

The overall success of MND over next 15 years will ultimately depend on the success of towns and large/ medium scale industries and industrial clusters in NGRB in implementing 'MND projects'. It is recommended that NGRBMC should come up with suitable metrics related to project outcomes to assess the success of MND at the level of individual towns, industries and even states as a whole. The scores obtained against these metrics can be published each year such that comparisons can be made across towns, industries and even states regarding the effectiveness of MND implementation.

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GANGA RIVER BASIN MANAGEMENT PLAN
(GRBMP)

MISSION 3: ECOLOGICAL RESTORATION

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
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NIT-K
DU
NIH Roorkee
ISI Kolkata
Allahabad University
WWF India

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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.	**MoWR, RD&GR**	:	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

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.

Ecological restoration of National River Ganga is urgently needed since river biodiversity is being rapidly lost.

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.

It is not only soil and water that are mutually interactive, living organisms also interact with them and help shape the basin's environment.

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 3.1 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 stated, an ecosystem is a community of living organisms (plants, animals and microbes) in conjunction and interacting with nonliving components of their environment [Wikipedia, 2013]. 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

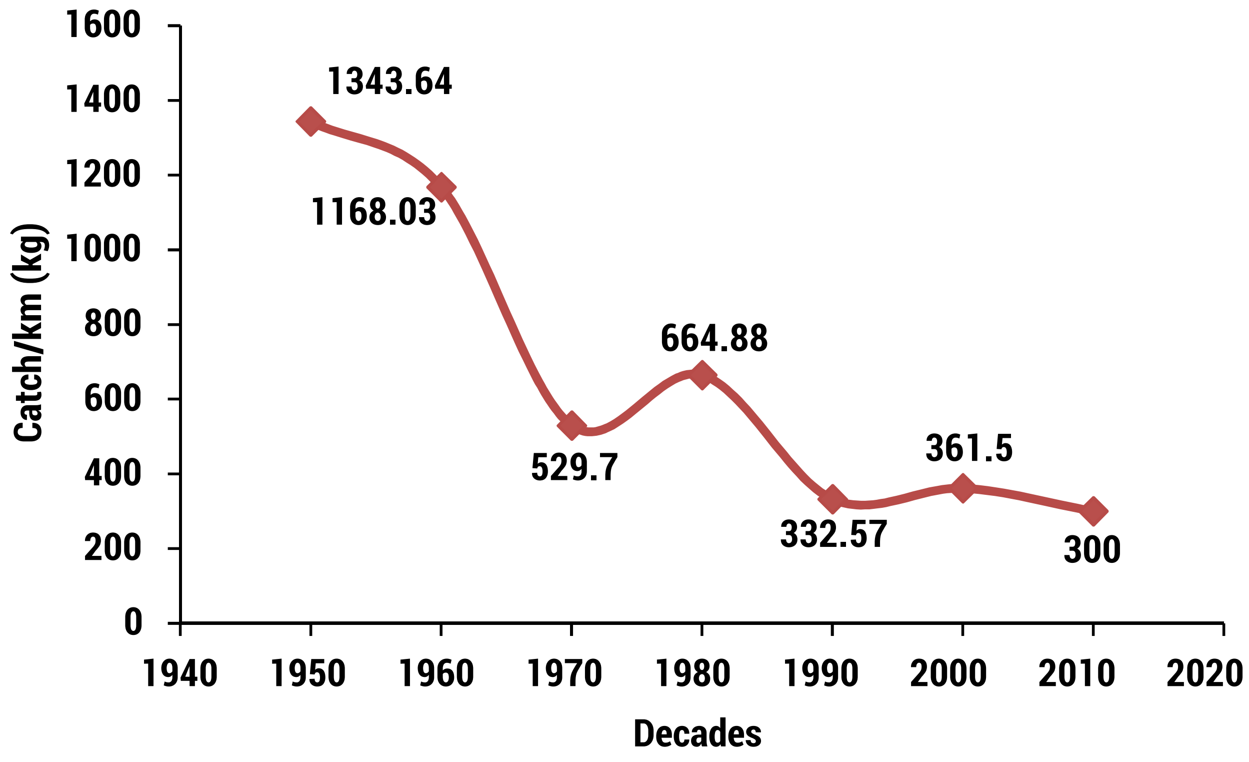

Figure 3.1: Decline of Fish Catch per km at Allahabad between 1950 to 2010 [IITC, 2014]

species biodiversity plays an important role in ecosystem functioning.

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, 2012]. 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.

The properties of Ganga river's waters of earlier times quoted above are remarkable, to say the least. But, at present, the river water quality is abysmal, posing a grave threat to life in the region.

The change in water quality may have been occurring over many centuries. Ancient scriptures had cautioned against misusing the Ganga river. For instance, the following edict in Sanskrit prohibited fourteen types of human actions: (1) defecation, (2) gargling, (3) shampooing (4) throwing of used religious offerings, (5) rubbing of filth, (6) flowing bodies (human or animal), (7) frolicking; (8) acceptance of donations; (9) obscenity; (10) considering other shrines to be superior, (11) praising other shrines, (12) discarding garments; (13) hurting anyone, and (14) making noise.

It is possible that such strictures got diluted over time. But, the environmental significance of many of these precautions is obvious to the modern mind. And, what is equally significant, they convey a sense of deep respect for National River Ganga.

The vision statement of GRBMP affirms the restoration of 'Nirmal' dhara (unpolluted flow) in River Ganga and her tributaries as one of the goals of GRBMP. Measures to be implemented to achieve this objective have been specified in the present document describing the Mission 'Nirmal' Dhara (MND).

The necessary condition for restoration of 'Nirmal Dhara' in River Ganga and her tributaries, i.e., the Ganga river system, is the prevention of the ingress of pollutants into the rivers. It was realized that pollutant ingress into the Ganga River system cannot be controlled unless certain solid and liquid waste management and other practices in the NGRB were modified. This realization was the origin of the basin-wide approach for the formulation of MND.

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 4.1. 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.

The biodiversity of River Ganga is unique, as it synthesizes three major eco-regions of India situated along different climatic gradients.

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.

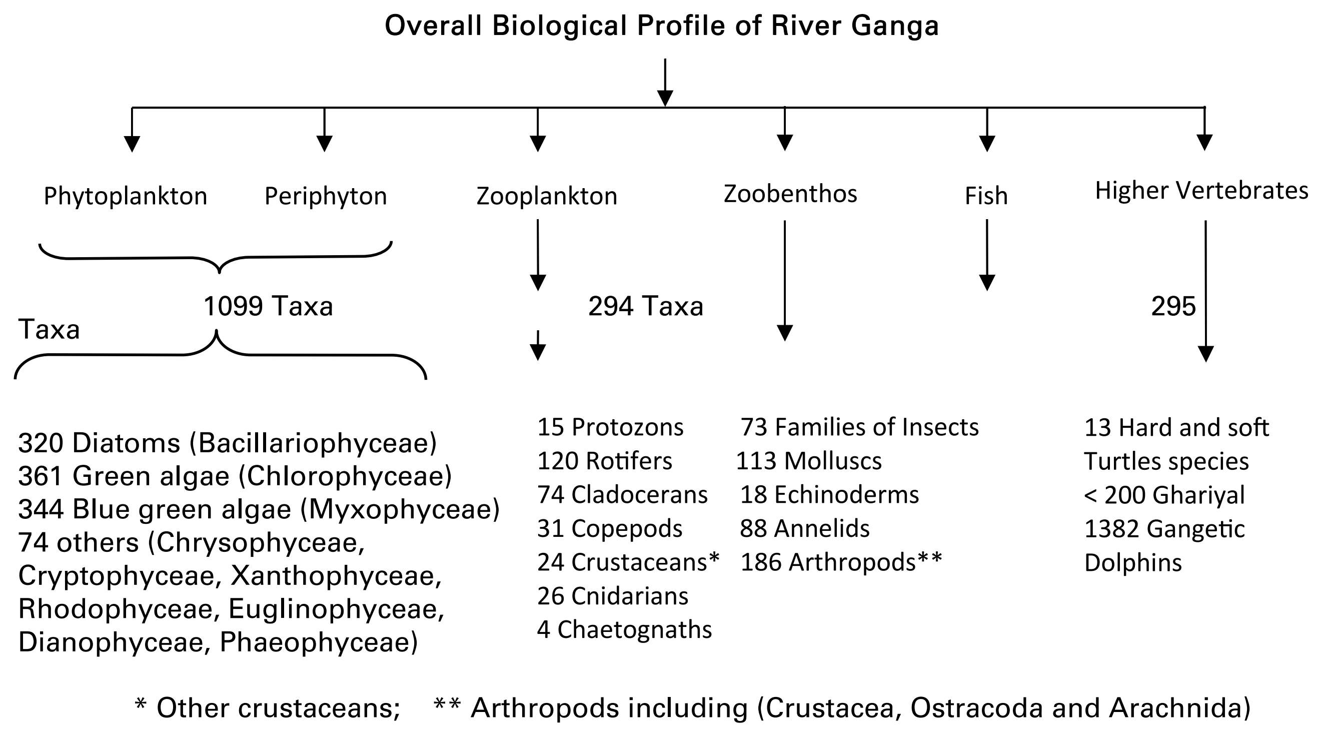

Figure 4.1: Biodiversity of River Ganga at a Glance [IITC, 2014]

On the basis of available data, the present ecological scenario for four stretches of the main Ganga river are presented in Table 4.1, 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 4.1: Indicative Biological Profile of Different Stretches of River Ganga [IITC, 2014]

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 5.1 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 5.2. 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.

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

Table 5.2: 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

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 [Rajvanshi, 2012]. However, the study may have had some shortcomings [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.

It is necessary to ensure longitudinal connectivity – along with adequate water and sediment flows – throughout the Ganga river network.

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.

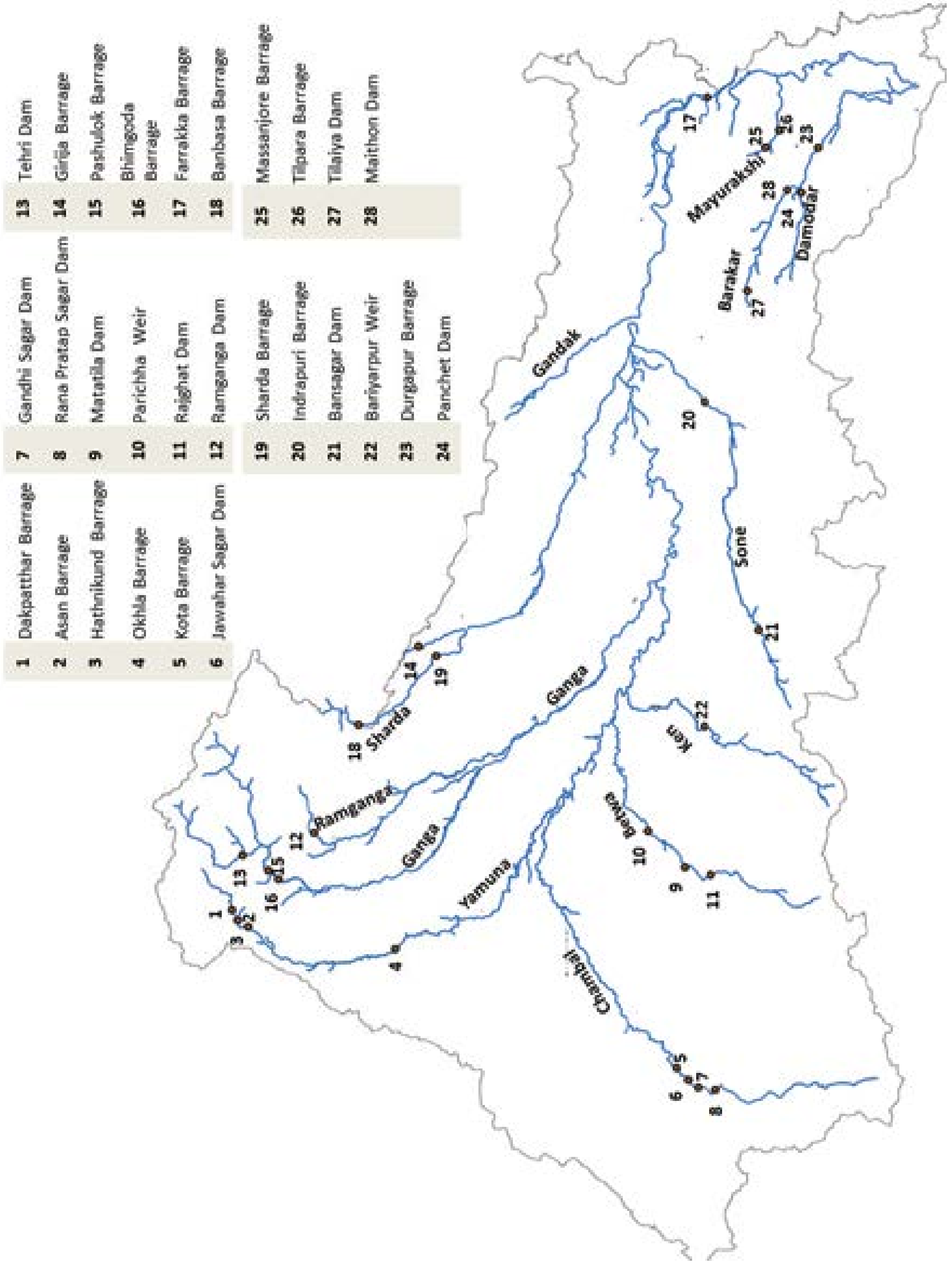

Figure 3: Major Structural Obstructions on River Ganga and Her Tributaries within India [MoWR, 2014]

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 . 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 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 by way of increased runoff rates 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 . 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.

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 also. 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

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.

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 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 et al., 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 definite 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 as the round goby and other exotic goby fishes to river disturbances. 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 river bank 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

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

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 the damming of river 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 supply to the river ecosystem is through 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.

It is highly desirable to conduct comprehensive research to understand the ecological dynamics of National River Ganga.

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 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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GANGA RIVER BASIN MANAGEMENT PLAN
(GRBMP)

MISSION 4: SUSTAINABLE AGRICULTURE

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

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ABBREVIATIONS AND ACRONYMS

1.	**FAO**	Food and Agricultural Organisation
2.	**GRBMP**	Ganga River Basin Management Plan
3.	**IFDC**	International Fertilizer Development Center
4.	**IITC**	IIT Consortium
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.	**MoWR, RD&GR**	Ministry of Water Resources, River Development & Ganga Rejuvenation
10.	**NGRBA**	National Ganga River Basin Authority
11.	**NMCG**	National Mission for Clean Ganga
12.	**NPK**	Nitrogen, Phosphorous, Potassium
13.	**NRGB**	National River Ganga Basin
14.	**NRGBMC**	National River Ganga Basin Management Commission
15.	**SOM**	Soil Organic Matter
16.	**SRI**	System of Rice Intensification
17.	**UNEP**	United Nations Environment Programme

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 aspects were factored in to assess the basin's resource dynamics. Modern agricultural practices have been major causes of soil degradation and fertility loss, pollution of water bodies and natural resource depletion in NRGB. Hence transition to sustainable agriculture is urgently needed to maintain NRGB's ecosystem services. Though arable land is a limiting constraint in NRGB, NRGB's agricultural growth almost quadrupled in forty years since the 1960s by adopting high-yield crops with high fertilizer and water inputs. But extensive use of water, chemical fertilizers and pesticides, soil tillage, and mono-cropping have increased soil erosion and degradation, depleted soil nutrients and biodiversity, dwindled the basin's waters, and polluted its ecosystems. The main agricultural reforms recommended in NRGB are therefore identified as follows: (1) Adoption of Conservation Agriculture (involving no tillage, crop diversification, and permanent organic soil cover) to enhance long-term soil fertility and agricultural output, especially in degrading lands. (2) Adoption of Organic Farming where economically feasible or essential. (3) Improved water and nutrient management techniques in rice cultivation. (4) Promoting other specific resource conservation technologies wherever possible. (5) Resource use optimization by extensive soil testing for balanced management of nutrients and soil amendments. (6) Promoting regional (landscape-scale) resource conservation measures to mollify agroecosystem impacts. (7) Infusing experimentation, adaptability and flexibility in NRGB's agricultural practices. (8) Devising appropriate policy measures to achieve the above goals within the existing socio-cultural, economic and institutional framework.

Modern agricultural practices have been major causes of soil degradation and fertility loss, pollution of water bodies and natural resource depletion in NRGB.

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.

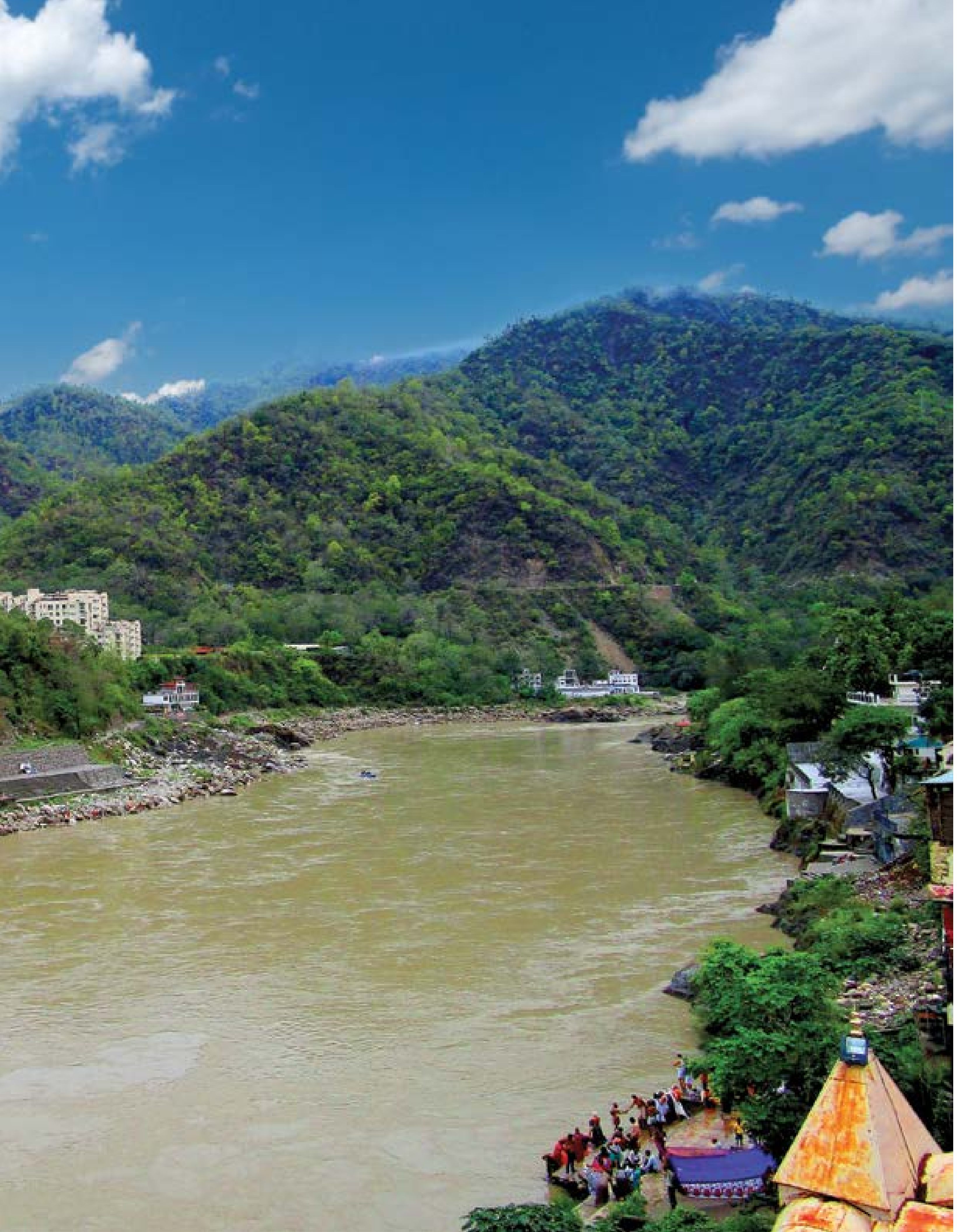
The Ganga river basin is the largest river basin of India that covers a diverse landscape, reflecting the cultural and geographical diversity of the India. It is also a fertile and relatively water-rich alluvial basin that hosts about 43% of India's population [MoWR, 2014]. It is fitting, therefore, 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.

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.

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 environment, the biotic resources depend on the constituent ecosystems of the basin – 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 in recent times [Pahl-Wostl, 2006]. Nonetheless, GRBMP attempts to incorporate the interactive 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 "Sustainable Agriculture" is to ensure that agriculture remains environmentally sustainable in NRGB, i.e. agricultural productivity can remain sufficiently high and enduring without fouling or depleting the natural resources of the basin.

3. WHY SUSTAINABLE AGRICULTURE IS IMPORTANT FOR GANGA RIVER BASIN MANAGEMENT

Soil and water are the main physical resources of a river basin that support all life in the basin. Over the last several millennia, human civilization has been increasingly using these resources in agriculture to sustain and expand human communities. Thus, if shifting cultivation needed 2–10 ha of land to feed a person and early floodplain-based agricultural societies used 0.5–1.5 ha, modern agriculture needs only about 0.25 ha to feed each person, with the world's most intensively farmed regions using just 0.1–0.2 ha to support a person [Montgomery, 2007]. India is among such "most intensively farmed" regions in the world. The total area under cropland in India was nearly 190 million ha in 2000 [MOA, undated], indicating a per capita cropland of only about 0.18 ha. If one considers only the sown area, the area would be even less – about 0.14 ha per capita. More significantly, India accounts for only about 2.4% of the world's geographical area and 4% of the world's water resources, but supports about 17% of the world's human population [MOA, undated; MoWR, 2008]. Thus, with respect to world averages, India's per capita water availability is only about 23% and per capita land availability is just 14%. In NRGB (which occupies about 26% of India's land area, hosts about 43% of her population, and has about 28% of her water resources, vide GRBMP – Main Plan Document) the corresponding figures are more telling – only about 16% for water and 8-9% for land. Thus, in terms of global averages, not only is water a meagre resource, but land – and hence

soil – is an even more critical resource. This double constraint underlies the overwhelming difficulty in sustaining agricultural productivity in NRGB.

Sustainable agriculture integrates environmental viability, economic profitability and social equity [IITC, 2014]. But, among these three aspects, environmental sustainability is the most important, since the latter two goals are contingent upon it. Now, as noted by Montgomery [2007], "conventional agriculture has dramatically increased soil erosion around the world. … With global agricultural soil erosion outpacing soil production by a wide margin, modern conventional agriculture is literally mining soil to produce food. ... (Moreover) soil productivity involves nutrient budgets, not just soil loss. Ecologically productive soils, those with more soil microorganisms and organic matter, can support greater plant growth." Thus, apart from soil erosion, regular tillage and the extensive use of chemical fertilizers and pesticides have affected soil fertility by debilitating soil's nutrient cycles and leading to progressive soil degradation. In water-constrained areas, increased crop water use has also led to water crises in many parts of the region. While these issues are global, the extreme land and water constraints of NRGB's agriculture have speeded up the degradation of its agricultural lands, with eroded soils and nutrients running into the Ganga river network and seriously affecting the rivers and other ecosystems. Thus, there is an urgent need to devise and promote appropriate sustainable agricultural practices to protect the basin and its agricultural lands from any further damage.

4. STATUS OF NRGB'S AGRO-ECOSYSTEMS

An agroecosystem is an interactive group of biotic and abiotic components, only some of which are under human control. Agroecosystems are intentionally disturbed ecosystems that, through human influences, are forced into states different than the natural systems from which they are derived [Elliot and Cole, 1989]. The change in the state of an agroecosystem is essentially due to change in the state of its soils. The effect of modern agricultural on soils has been negative in many ways, with alarming soil erosion and land degradation in many parts of the world. Globally, the rate of soil erosion from conventional agricultural lands is estimated to average 1.54 (±0.32) mm/year whereas the rate of soil formation is only about 0.075 (±0.05) mm/year [Parikh & James, 2012]. Additionally, deterioration of soil properties has led to many types of soil degradation.

In India, a large area of about 120.40 million ha (out of India's total geographical area of 328.73 million ha) is reportedly affected by land degradation, with annual soil loss of about 5.3 billion tonnes through erosion [MOA, undated]. In economic terms India's soil degradation ranged from 11 to 26 percent of her Gross Domestic Product during the 1980s and 1990s [IITC, 2014]. The general picture is probably the same for NRGB, given its intensively cultivated farmlands. In addition to general soil degradation in terms of edaphic parameters is the depletion of soil nutrients and biota, information on which is limited. Such depletions have necessitated increased inputs of chemical fertilizers and pesticides to compensate for the loss of soil fertility and pest resistance, whose consequences on NRGB's agroecosystems are obvious. As noted in the IITC [2014] "the high input-intensive farm practices followed by farmers in the basin have caused depletion in the groundwater table, deterioration in the quality of soil and water… ." The direct adverse effects of these "high input" and "intensive" farm practices are on the agricultural land itself – loss of valuable topsoil, depletion of nutrients, decimation of soil biota, and degeneration of soil structure. These effects, in turn, affect the entire ecozone. Agriculture is the main source of livelihood of about half of the population of NRGB and the majority of its rural population [IITC, 2014]. Considering the trend, pattern, influence, ascendancy, problems, and prospects etc., the significant agricultural areas of NRGB were assessed to comprise the states of Uttarakhand, Uttar Pradesh, Bihar and West Bengal, vide FIgure 4.1 [IITC, 2011]. There has been significant agricultural growth in the above regions of NRGB over the last 4–5 decades. But, on the whole, the growth has been limited by land constraints rather than of water or other natural resources. Most of the arable land has already been brought under cultivation, while the land demand for non-agricultural uses has increased. In contrast, irrigation water supplies have been increasing rapidly through groundwater usage.

The Borlaug seed-fertilizer technology ushered into India in the 1960s raised crop outputs rapidly in India (including the NRGB). The average value of crop output in the delineated NRGB area grew almost four-fold from Rs. 1.97 billion during 1962-65 to Rs. 5.24 billion during 2003-06 (at 1990-93 prices), vide Figure 4.2 [IITC, 2011]. The growth was enabled by crop yields more than doubling from Rs. 4,300 to Rs.9,900 per hectare of gross cropped area from 1962-65 to 2003-06 (at 1990-93 prices), vide Figure 4.3 [IITC, 2011]. The Green Revolution's impact on agricultural yields were evidently limited in the first couple of decades, but accelerated since the 1980s. The gross cropped area during the four decades from the mid 1960s grew by about 20% from 502 to 599 thousand hectares per district (vide Figure 4.4), but the gross irrigated area more than tripled from about 134 to 411 thousand hectares per district (vide Figure 4.5), while average fertilizer consumption grew many-fold from 1,700 to 76,300 tonnes per district (vide Figure 4.6) [IITC, 2011], with consistently increasing trends of fertilizer usage in different regions of NRGB (see Figure 4.7) [IITC, 2014]. Thus, it is obvious that the remarkable agricultural growth in NRGB was sustained by rapidly increasing agricultural inputs rather than significant increase in cropping area.

Figure 4.1: Geographical Delineation of Significant Agricultural Area of NRGB [IITC, 2011]

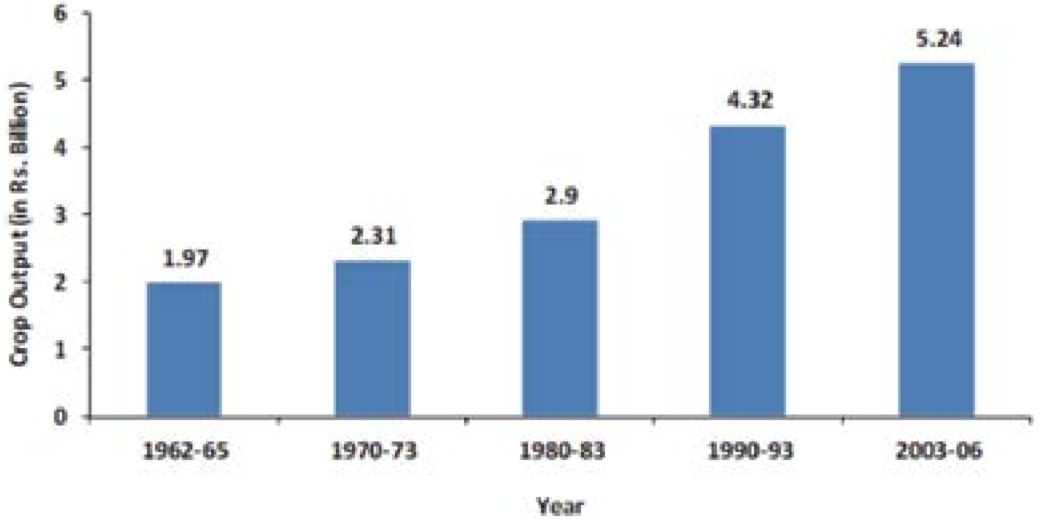


Figure 4.2: Average Crop Output Value per District in NRGB between 1962-65 to 2003-06 [IITC, 2011]

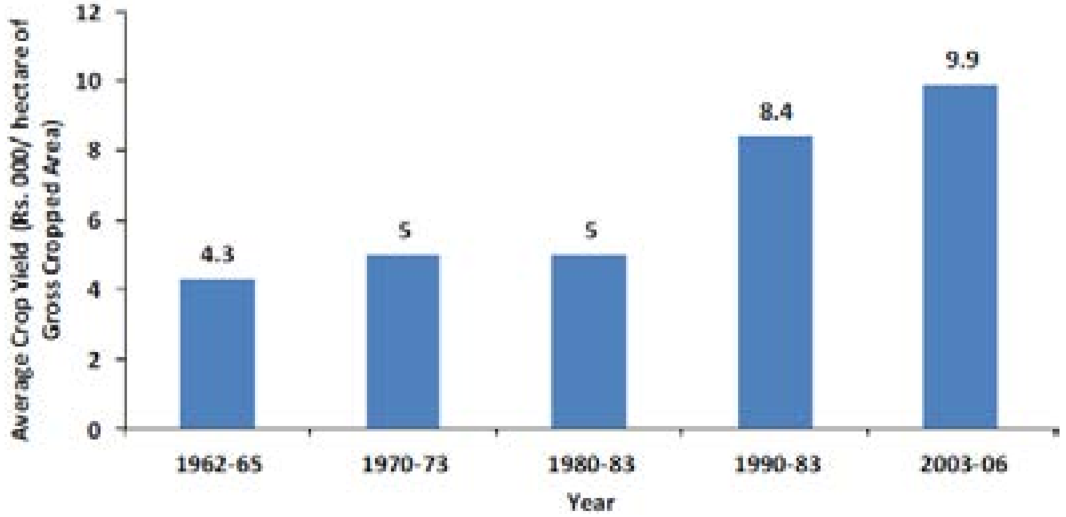


Figure 4.3: Average Crop Yield (Rs.1000/ hectare of Gross Cropped Area) per district in NRGB, 1962-65 to 2003-06 [IITC, 2011

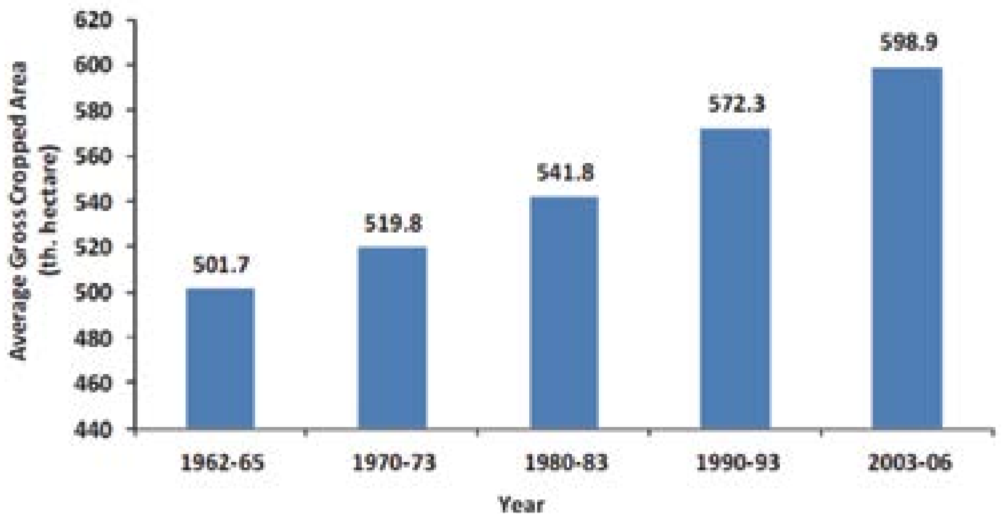


Figure 4.4: Average Gross Cropped Area (thousand hectares) per District in NRGB between 1962-65 to 2003-06 [IITC, 2011]

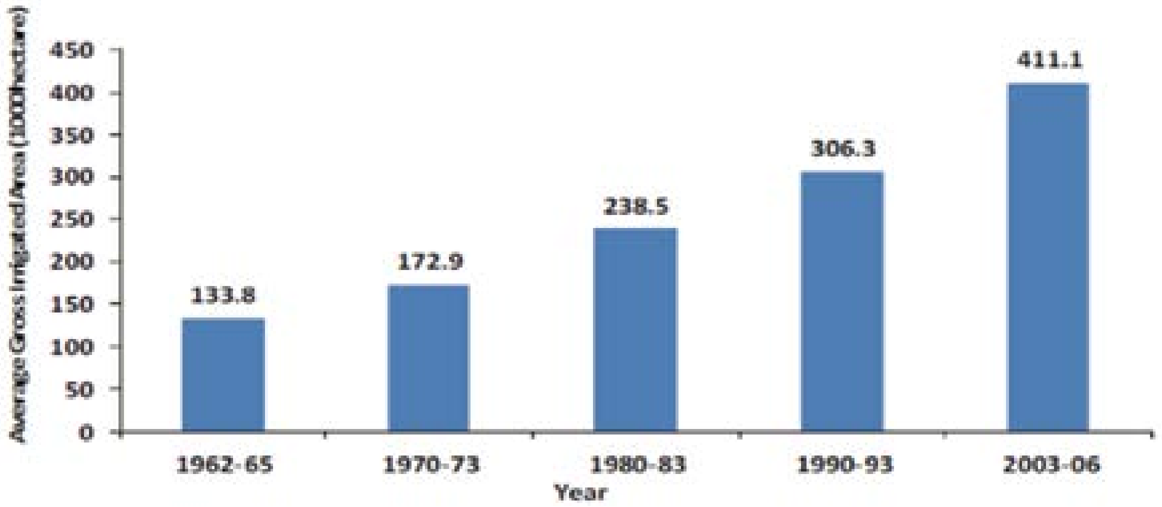


Figure 4.5: Average Gross Irr igated Area (1000 hectares) per District in NRGB between 1962-65 to 2003-06 [IITC, 2011]

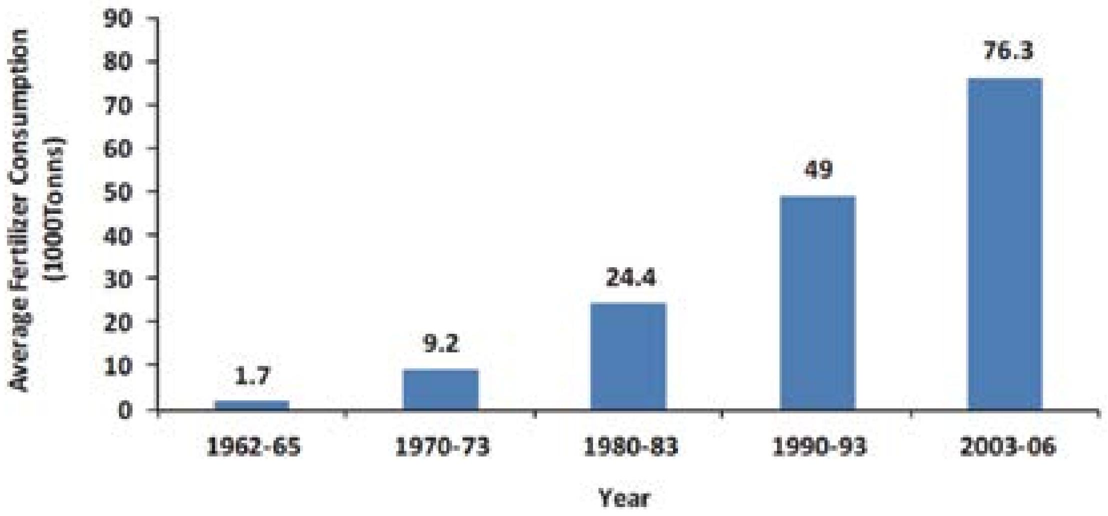


Figure 4.6: Average Fertilizer Consumption (1000 tonnes) per District in NRGB between 1962-65 to 2003-06 [IITC, 2011]

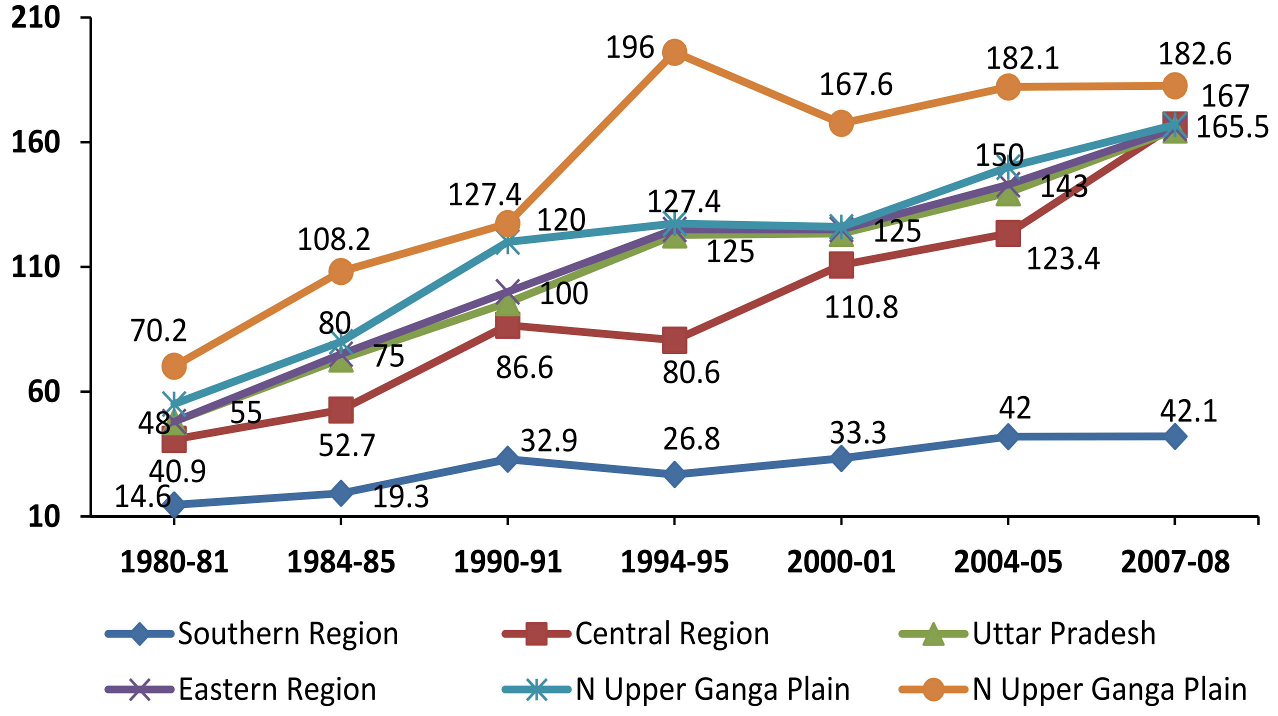


Figure 4.7: Region-wise Trends in use of Chemical Fertilizers per Hectare [IITC, 2014]

The above data indicate the extent of growth of agricultural inputs and outputs in NRGB. It may be also noted here that rice, wheat and sugarcane constitute the bulk of agricultural crops in the basin. Out of these, rice and sugarcane are high water-consuming crops, whose growth depended not only on mineral fertilizer inputs, but also on escalating groundwater irrigation (e.g. groundwater irrigation covered about 80% of the gross irrigated area in the Middle Ganga Basin in 2007-08, vide IITC, 2014). A second point of note is that fertilizer usage is far from balanced, with Nitrogen fertilizers comprising about 75% of the total fertilizer usage [IITC, 2014]. Farm mechanization also grew rapidly over the decades. The consequence of the composite agricultural developments in NRGB's agroecosystems can easily be surmised to have increased soil erosion and reduced soil fertility, besides dispatching eroded soils and much of the nutrients beyond the croplands and adversely affecting the basin's ecosystems (including the Ganga river network).

5. AGRO-ECOSYSTEM CONCERNS IN NRGB

As evident from the preceding section, current agricultural practices in NRGB have had diverse negative impacts on the region's ecosystems that make it nearly impossible to maintain agriculture growth (and perhaps even the present agricultural output) in the long run. Urgent reforms are needed to prevent (or at least minimize) soil erosion and maintain soil fertility (soil structure, nutrient base and biodiversity), besides also protecting the region's various other natural resources (including water, nutrients, biodiversity and forests) from agriculture's adverse effects. These goals together comprise the parameters defining the need for sustainable agriculture in NRGB. They are in fact universally acknowledged in today's world. As summed up by Brodt et al. [2011], "a sustainable agriculture approach seeks to utilize natural resources in such a way that they can regenerate their productive capacity, and also minimize harmful impacts on ecosystems beyond a field's edge." The main concerns about NRGB's evolving agroecosystems are outlined below in further detail.

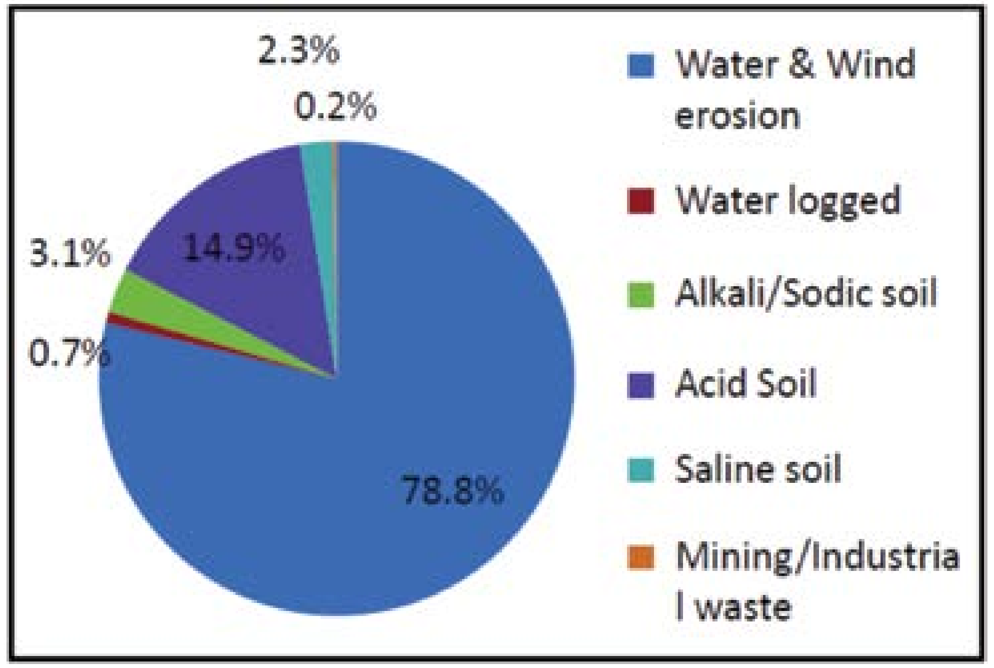


Figure 5.1: Share of Different Types of Land Degradation in India [MOA, undated]

5.1 Soil Erosion

Among the major types of land degradation in India, soil erosion is reported to be the most important, causing nearly 4/5th of the degradation, vide Figure 5.1 [MOA, undated]. Much of this erosion is from agricultural lands, with agricultural soil erosion being largely related to soil tillage (besides topography, soil texture, soil composition, etc.). Minimizing soil tillage is, therefore, a key step in erosion control.

5.2 Soil Nutrients

Plant nutrient requirements include many chemical elements needed by plants in varying quantities. There are at least 17 essential elements required for plant growth as listed in Table 5.1. The lack of any of these essential nutrients can result in a severe limitation of crop yield. Of the 17 or more essential elements, the non-mineral elements C, H and O are obtained from air and water, but the mineral elements must be available in the soil as water-soluble compounds suitable for plant uptake. Among the 14 mineral elements, N, P and K are primary macronutrients that are needed in the greatest quantities. Secondary macronutrients (Ca, Mg and S) needed in smaller quantities, are typically sufficiently present in soil, and hence are seldom limiting for crop growth. The remaining 8 elements – Fe, Mn, Zn, Cu, B, Mo, Cl and Ni – are micronutrients (or trace nutrients), that are needed in very small amounts, and can be toxic to plants if in excess. Besides these 17 elements, Silicon (Si) and sodium (Na) are also essential elements, but due to their ubiquitous presence in soils they are never in short supply [Epstein, 1994; Parikh and James, 2012]. In addition to the above micronutrients, cobalt (Co) is also an essential micro-element required by nitrogen-fixing plants [Graham, 2008].

Much of this erosion is from agricultural lands, with agricultural soil erosion being largely related to soil tillage (besides topography, soil texture, soil composition, etc.).

It should be noted here that the above 17 or 18 elements are the ones known to be essential for plants in general, but there are likely to be more essential elements that are still unknown or those that are required by specific plant species. The possible additions include at least 8 more elements known to be essential for animals (including humans), viz. selenium (Se), iodine (I), chromium (Cr), tin (Sn), fluorine (F), lithium (Li), silicon (Si), arsenic (As) and vanadium (V) [Graham, 2008]. Since these additional microelements are sourced by humans and animals mainly through plants (directly or indirectly through the food chain) and since billions of people worldwide are estimated to have been already affected by their deficiency – especially of Se and I [Graham, 2008], the availability of these elements in soil should also be considered essential for human and ecosystem health.

Table 5.1: Essential Plant Nutrient Elements and their Primary form Utilized by Plants [Parikh et al., 2012]

Essential plant element		Symbol	Primary form
Non-Mineral Elements:			
	Carbon	C	CO_2 (g)
	Hydrogen	H	H2O (l), H^+
	Oxygen	O	H_2O (l), O_2(g)
Mineral Elements:			
Primary Macronutrients	Nitrogen	N	NH_4^+, $NO\neg_3^-$
	Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
	Potassium	K	K^+
Secondary Macronutrients	Calcium	Ca	Ca_2^+
	Magnesium	Mg	Mg_2^+
	Sulfur	S	SO_4^{2-}
Micronutrients	Iron	Fe	Fe^{3+}, Fe^{2+}
	Manganese	Mn	Mn^{2+}
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Boron	B	$B(OH)_3$
	Molybdenum	Mo	MoO_4^{2-}
	Chlorine	Cl	Cl^-
	Nickel	Ni	Ni^{2+}

The mere presence of nutrient elements in soil does not assure their adequate supply to plants. Some nutrients, such as N and P, are often present in the soil in large amounts but are made available to plants only very slowly. Others, such as K, are readily available for plant uptake. An important parameter of nutrient availability in soil is its relative mobility, which is high for N, S and B but low for P and most micronutrients. In general, as nutrient mobility increases, its location in the soil becomes less important for plant uptake, but the potential for nutrient loss increases. Thus, the potential for N loss from the soil is generally high, and little available N accumulates in the soil. Conversely, P availability near plant roots is critical for its uptake, and the loss of P from soils usually requires erosion of the soil itself. However, recent evidence indicates that significant amounts of soluble P can also be lost in runoff from fields when the soil becomes saturated with excessive soil test phosphorus levels [PSU, 2013].

In recent times, the two major fertilizer inputs N and P have been a cause for soil degradation and environmental pollution in many parts of the world. On the one hand, overuse of N fertilizers can lead to acidification of croplands[1], which has already happened significantly in China [Guo et al., 2010]. On the other hand, N and P fertilizers tend to damage neighbouring ecosystems. For instance, many forests have been severely affected by the excessive use of N fertilizers in modern agriculture [Nosengo, 2003]. As noted by Goulding et al. [2008], *"N is a particular problem. Its importance as a growth- and yield-determining nutrient has led to large and rapid increases in application rates, but with often very poor efficiencies. … (And) the view that P is strongly held in soils and so applying more than enough P is 'money in the bank' has resulted in the build-up of excessive P levels in some soils, resulting in enhanced leaching… (and) loss by erosion."* Globally, only 30–50% of applied nitrogen fertilizer and about 45% of phosphorus fertilizer is taken up by crops. A significant amount of the applied N (and a smaller portion of the applied P) is lost from agricultural fields. These nutrient losses as well as gaseous nitrogen oxides (NOX) emitted from fertilized soils harm off-site ecosystems, water quality and aquatic ecosystems, and increase atmospheric ozone to damaging levels [Tilman et al., 2002]. The increasing amounts of reactive nitrogen in the environment due to N fertilizers have in fact become a global issue [UNEP-WHRC, 2007; Bodirsky et al., 2014].

It is also worth noting that, while N fertilizers are manufactured from petroleum, P and K fertilizers are produced from ores, whose reserves have been steadily declining worldwide. P fertilizers, in particular, are a matter of concern due to globally limited P reserves [Elser and Bennett, 2011; Vacari, 2009]. P ores are available at only a few places on earth, and 85% of the known reserves are concentrated in just 3 countries, with the bulk of the reserves being in Morocco and its disputed territory of Western Sahara [Elser and Bennett, 2011], vide Figure 5.2. For India, which is almost entirely dependent on imports for P fertilizers, the limited and skewed global P reserves are a matter of special concern, and this is an additional reason for restrained and efficient use of P fertilizers.

In terms of the primary macronutrients (N, P and K), India's overall soil fertility status is probably satisfactory, but there are significant variations across different states (including in NRGB) [Pathak, 2010]. And there are likely to be even more significant variations between different parts of each state. Hence, a uniform recommendation of fertilizer application of 120:60:30 NPK kg/ha dose (in 4:2:1 ratio) for wheat/ rice crop [vide IITC, 2014] could be damaging for some of NRGB's agroecosystems.

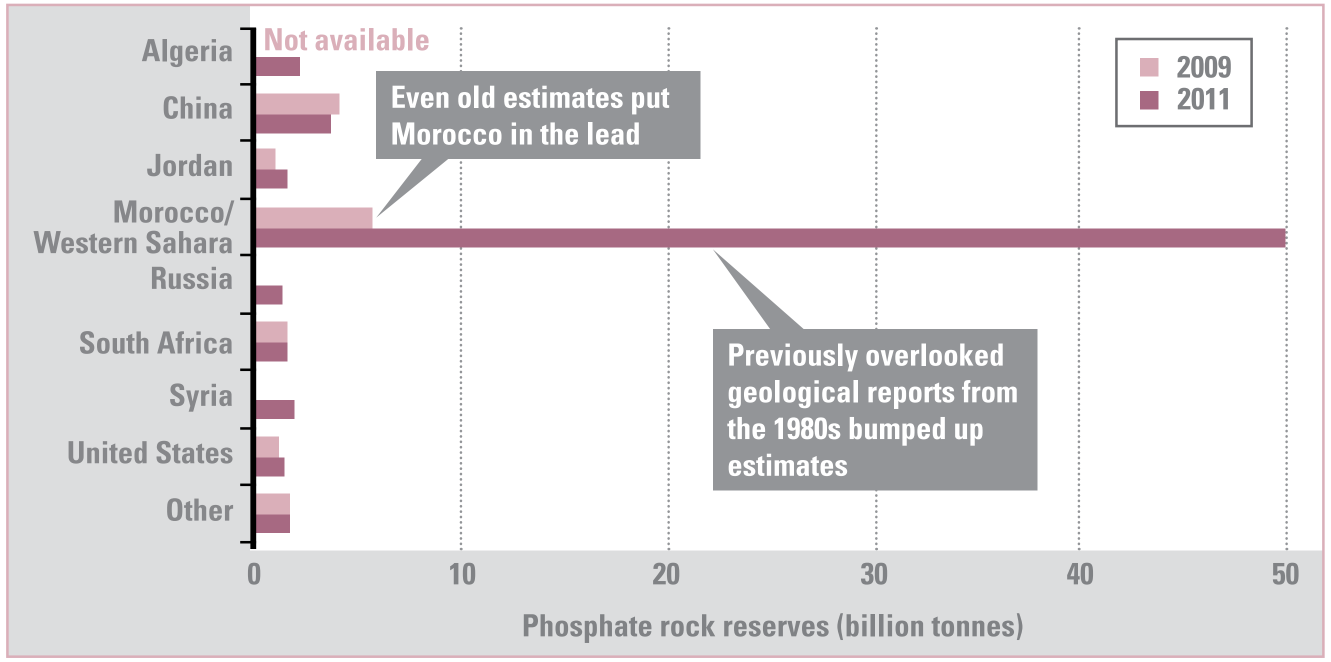


Figure 5.2: Global Phosphate Reserves: 2009 and 2011 estimates [Elser & Bennett, 2011] (Note: India's phosphate reserves being negligible, phosphate fertilizers are almost entirely import-dependent in India.)

A further cause for concern is the growing deficiencies of micronutrients in Indian soils, especially since the onset of Green Revolution. The increasing deficiencies are largely due to excessive mining of soil micronutrients by agricultural crops, whose output increases aided by NPK fertilizer inputs are not complemented with corresponding micronutrient inputs. Figure 5.3 depicts the extent of deficiencies of some micronutrients in India [Singh, 2004]. Among the micronutrients shown, zinc is the most common deficiency in India's and NRGB's soils. But there are deficiencies of other micronutrients (like boron and sulphur) also in NRGB's soils, plus possibly even those of macronutrients like calcium as evident from cattle produce [Singh, 2009]. Where micronutrients are not actually deficient in soil, their availability may still be limited by soil acidity or

A significant amount of the applied N is lost from agricultural fields. This nutrient loss as well as gaseous nitrogen oxides (NOX) emitted from fertilized soils harm off-site ecosystems, water quality and aquatic ecosystems, and increase atmospheric ozone to damaging levels.

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[1] **Note:** As seen from Figure 8, nearly 15% of the 21% non-eroded degraded land in India is acidic; hence possible acidification of more agricultural lands due to N fertilizers is of concern in India.

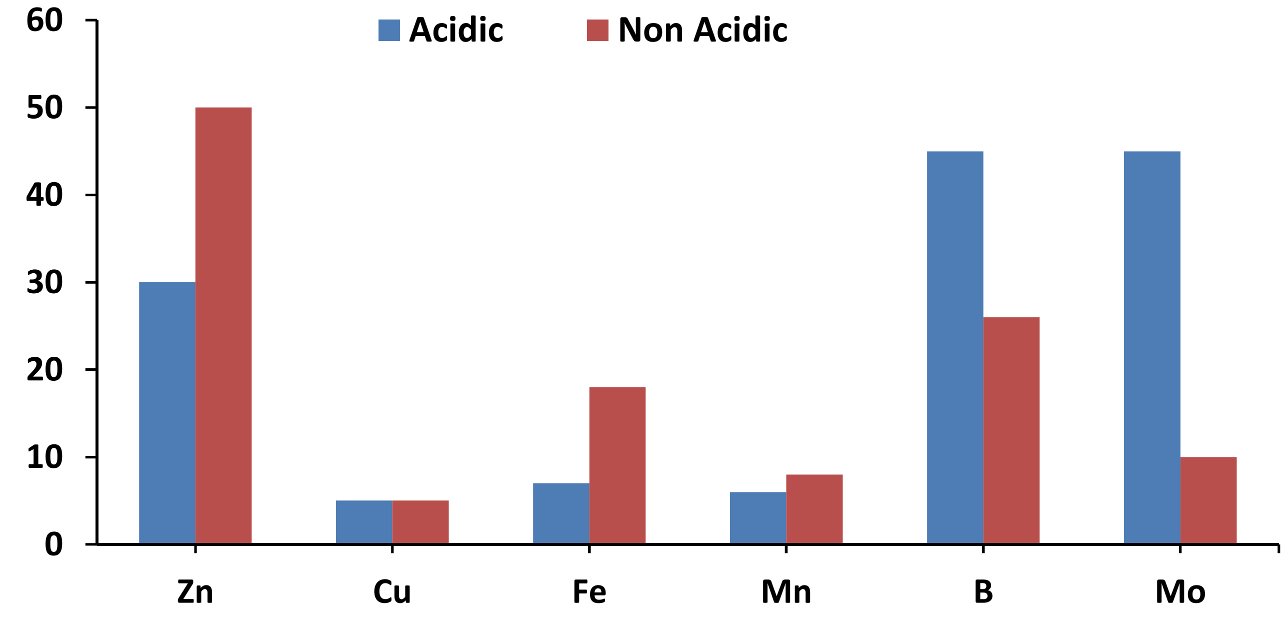

Figure 5.3: Micronutrient Deficiencies in Indian Soils [Singh, 2004]

alkalinity [FAO, 2000]. Comprehensive measures to ensure balanced nutrient fertility in NRGB's soils are, therefore, essential.

5.3 Soil Biodiversity

Soil biodiversity plays a key role in soil fertility, vide Figure 5.4 (although the figure depicts the role of soil biota in nutrient movements of C and N only). As noted by Scholes and Scholes [2013], *"the key to understanding the behaviour of life-supporting elements in soils lies not in the absolute amounts present, but in the fluxes between their various forms, modulated by biology. … The variety of ways in which soil constituents can be processed and transformed by a diverse soil microbial community provides an energy-efficient, nonleaky, self-regulating system that can adapt to changing environments."* But not only soil micro-organisms, invertebrates (such as earthworms and macro-arthropods) present in the soil are extremely useful for robust soil structure and nutrient recycling – by building large and stable organo-mineral structures, and by breaking up large organic litter. Soils rich in organic matter contain many thousands (or even millions) of species of micro-flora such as bacteria (including actinomycetes), fungi and algae plus micro-fauna such as protozoa and nematodes. The microbes decompose the active component of soil organic matter (or SOM) composed of fresh plant or animal material, thereby releasing nutrients for plant uptake [Giller et al., 1997; Hoorman & Islam, 2010]. Without adequate microbial activity, the nutrients would remain inaccessible to plants. For a typical case of soils containing 1% SOM, the macronutrients in the topsoil have been valued at about US $ 680, vide Table 2. The table illustrates the economic importance of soil biodiversity for maintaining soil fertility.

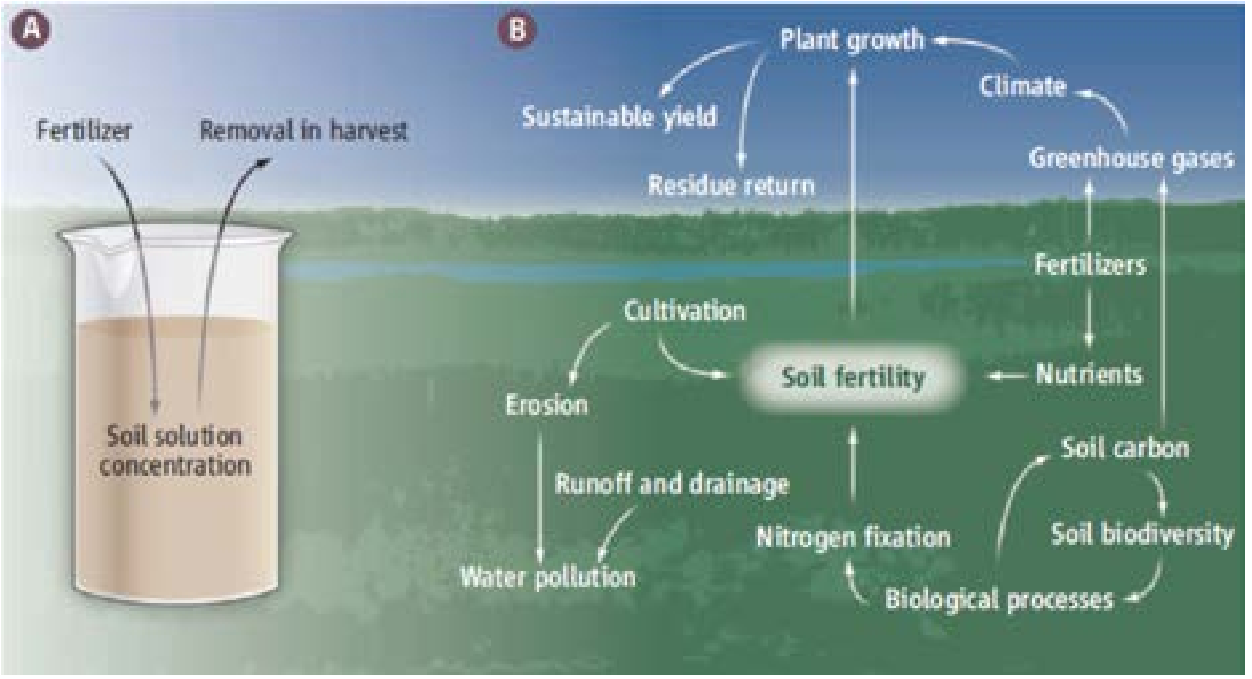

Figure 5.4: Soil Fertility Management Models – (A) Conventional Simplistic Model. (B) Realistic Model based on Soil Biodiversity [Scholes and Scholes, 2013]

Table 5.2: Typical Nutrient Value of Soil Organic Matter [Hoorman & Islam., 2010]

Assumptions: 2,000,000 pounds soil in top 6 inches	
Nutrients	1% organic matter = 20,000 # 50%
Carbon, C:N ratio = 10:1	
Nitrogen	1000 # * $0.50/#N = $500
Phosphorus	100# * $0.70/#P = $70
Potassium	100# * $0.40/#K = $40
Sulfur	100# * $0.50/#S = $50
Carbon	10,000# or 5 ton * $4/Ton = $20
Value of 1% SOM Nutrients/Acre	= $680
Relative Ratio of Nutrients	100 Carbon/ 10 Nitrogen/ 1 Phosphorus/ 1 Sulfur

A brief overview of soil microbial activity is presented here based on Giller et al. [1997] and Hoorman & Islam [2010]. Protozoa and nematodes (soil micro-fauna) consume microflora and release N as ammonia, which becomes available to other microorganisms or is absorbed by plant roots. Between bacteria and fungi, bacteria are generally quick to digest labile organics (fresh plant and animal residues), while fungi are slower but more efficient decomposers. Notable among fungi are the mycorrhizal fungi that live on the surface of or within plant roots (usually in symbiotic association) that aid the transport of mineral nutrients and water to plants. But fungi are not as hardy as bacteria in surviving starvation conditions, and their population tends to decline with tillage. In general, organic residues with a low carbon to nitrogen ratio (C:N < 20) are easily decomposed and nutrients are quickly released (4 to 8 weeks), while organic residues with high C:N ratio (> 20) decompose slowly, with microbes using up soil nitrogen in the process. This broad picture of soil microbial activity takes various complex forms in different conditions. Even in similar and nearby areas, the soil biodiversity can be vastly different depending on plant communities and human interventions. For instance, American prairie soils abound in a sturdy variety of bacteria (Verrucomicrobia) that are specialized for low-nutrient conditions, but these bacteria do not exist in fertilized agricultural soils of the region [Scholes & Scholes, 2013]. The key biological functions in tropical agricultural soils, the principal groups of organisms responsible for them, and the agricultural management practices that impact them the most were succinctly summarized by Giller et al. [1997] as reproduced in Table 5.3.

It is evident from the above discussions, that building up soil organic matter to restore soil biodiversity is the key to achieving lasting food and environmental security [Scholes & Scholes, 2013]. This fundamental principle underlies agricultural sustainability in NRGB.

Building up soil organic matter to restore soil biodiversity is the key to achieving lasting food and environmental security. This fundamental principle underlies agricultural sustainability in NRGB.

Table 5.3: Key Biological Functions, the Groups of Soil Biota Principally Responsible for these, and Management Practices Most Likely to Affect them [Giller et al., 1997]

Biological function	Biological/ functional group	Management practices
Residue comminution/ decomposition	Residue-borne microorganisms, meso/ macrofauna	Burning, soil tillage, pesticide applications.
Carbon sequestration	Microbial biomass (especially fungi), macrofauna building compact structures	Burning, shortening of fallow in slash-and-burn, soil tillage
Nitrogen fixation	Free and symbiotic nitrogen-fixers	Reduction in crop diversity, fertilization
Organic matter/nutrient redistribution	Roots, Mycorrhizas, soil macrofauna	Reduction in crop diversity, soil tillage, fertilization
Nutrient Cycling, Mineralization/ immobilization	Soil microorganisms, soil microfauna	Soil tillage, irrigation, fertilization, pesticide applications, burning
Bioturbation	Roots, soil macrofauna	Soil tillage, irrigation, pesticide applications
Soil aggregation	Roots, fungal hyphae, soil macrofauna, soil mesofauna	Soil tillage, burning, reduction in crop diversity, irrigation
Population control	Predators/grazers, parasites, pathogens	Fertilization, pesticide application, reduction in crop diversity, soil tillage.

5.4 Water Usage

High water usage in agriculture in NRGB is a matter of concern because, on the one hand it tends to deplete limited water resources; on the other hand, it enhances soil erosion, loss of soil nutrients and wastewater generation through leaching and runoff. These issues are well-known and have been discussed under Missions Aviral Dhara and Nirmal Dhara of GRBMP. But a few points deserve mention regarding groundwater irrigation. Large-scale groundwater usage for irrigation has been occurring in India (and elsewhere in the world) only in the last 5-6 decades. The enhanced groundwater extraction rates have caused land subsidence in some places, and is also considered a potential cause for earthquakes (vide Mission Report on Geological Safeguarding). Secondly groundwater irrigation can sometimes be a cause for mineral toxicity in plants and animals. For instance, high arsenic levels in groundwater have been widely reported in many parts of West Bengal and contiguous regions, which entail a distinct possibility of arsenic entering the food chain in NRGB if groundwater irrigation continues unabated. Likewise, toxic fluoride levels in groundwater exist in many areas. The spurt in groundwater irrigation in NRGB over the past few decades therefore needs to be monitored, and deep groundwater usage certainly needs to be restrained.

6. MEASURES TO IMPLEMENT SUSTAINABLE AGRICULTURE IN NRGB

The preceding discussions underscore the basic requirements to be fulfilled to achieve agricultural sustainability in NRGB, viz., conservation of soil resources (primary soil particles, nutrients and biodiversity) and water resources of the region. Fulfilling these goals require minimization of tillage and of agricultural inputs (mainly chemical fertilizers and pesticides), which, together with economic water use, can protect neighbouring ecosystems from the ill-effects of present agricultural practices. Based on the issues covered and recommendations of in GRBMP Thematic Reports [IITC, 2011; IITC, 2014] and other sources [e.g. FAO, 2014; MOA, 2010; MOA, undated; Planning Commission, 2007; Tilman et al., 2002; Wilkins, 2008; Winterbottom et al., 2013], the desired changes in agricultural practices that can economically meet the sustainable agriculture goals in NRGB are outlined below.

6.1 Conservation Agriculture

Conservation agriculture, aimed at preventing soil erosion and maintaining soil fertility, is defined by FAO as combining three working principles, namely: (i) minimum mechanical soil disturbance ("no till" or "minimum tillage"), (ii) permanent organic soil cover, and (iii) crop diversification. All the three components of conservation agriculture – crop diversification (crop rotation, intercropping), organic soil cover (cover crops and mulching) and "no till" or "zero tillage" farming – are essentially part of traditional agriculture [Derpsch, 2004; Roland, 2012]; but these were actively revived in the mid-twentieth century, especially in North and South America, before gaining worldwide ascendancy. By the year 2000, about 45–60% of cropland areas of Paraguay, Brazil and Argentina and about 17% of croplands in USA had converted to no-tillage [Derpsch, 2004]. However, no-tillage farming has been slow to pick up in Asia and Europe, vide Table 6.1, and in India it was limited to only about 5 million ha in 2007-08 [Huggins & Reganold, 2008; Friedrich et al., 2012; UNEP, 2013]. In brief, "no till" farming implies no soil erosion caused by tillage. Together with the other two principles of conservation agriculture, it ensures high soil fertility and, hence, reduced agriculture inputs and higher agricultural productivity. Conservation agriculture is, therefore, an economically advantageous reform needed in NRGB (especially in degrading soils), and no-till farming has been recommended by the Indian government [MOA, undated]. However, the adoption of conservation agriculture has inherent difficulties that need to be addressed.

Table 6.1: Global Extent of No Tillage Cultivation in 2007-08 [UNEP, 2013]

Country	Climate Zone	Base Year	Area under no-tillage in 2007/08	Best estimate cumulative avoided greenhouse gas emissions by replacing till-with no-till cultivation (between indicated base year and 2007/08)
Unit			*(million hectares)*	*(MtCO$_2$e)*
Notes	*(a)*	*(b)*	*(c)*	*(d)*
Australia (e)	warm-dry	1976	17	95.2
Argentina	warm-moist	1993	19.7	109.4
Bolivia	warm-moist	1996	0.7	3.1
Brazil	warm-moist	1992	25.5	145.7
Canada	cool-moist	1985	13.5	82.3
China(f)	cool-dry	2000	2	1.6
Kazakhstan	cool-dry	2006	1.2	0.2
New Zealand	cool-moist	1993	0.16	0.7
Uruguay	warm-moist	1999	0.66	2.0
USA	cool-moist	1974	26.5	241.3

Notes:

(a) Considering the lack of information on where no-till cultivation is being practiced, we assume one climate zone throughout the country, considering, where possible, the regional distribution of no-till agriculture.

(b) The base year is the estimated year in which the area of no-till cultivation began significantly expanding from a small baseline value in the country. The base year was estimated by linearly extending adoption rates from Derpsch et al. (2010), unless otherwise stated.

(c) From Derpsch et al. (2010) unless otherwise stated.

(d) Mitigation here refers mostly to avoided carbon dioxide emissions, with a small amount of avoided nitrous oxide emissions. Mitigation estimates on a per hectare basis are from Smith et al. (2008). There were multiplied by the area covered by no-till cultivation to obtain a value for total avoided emissions were summed for each year from 2007/08 back to the base year (in column 3). To compute the area covered by no-till cultivation in each year, it was assumed that the area covered decreased linearly from 2007/08 back to the base year (in column 3). In countries with long histories of no-till agriculture this probably led to an underestimate of the mitigation that was achieved. However, if the use of no-till cultivation began very slowly, then it is also possible that cumulative avoided emissions were overestimated.

(e) The 2007/08 estimate is derived from Derpsch et al. (2010) whereas the base year was established from Llewellyn and D'Emden (2010).

(f) The area stated for China is derived from Liu and Qingdong (2007) and Ministry of Agriculture (2009).

Financial support/ incentives

and timely technical help/ advice are essential for speedy and successful transition to conservation agriculture in NRGB.

No-till farming and conservation agriculture have been reviewed extensively in literature [e.g. Huggins & Reganold, 2008; Hobbes, 2008; Hoorman et al., 2009; UNEP, 2013], and based on these reviews and FAO [2014], it needs to be emphasized that transition from conventional farming to no-till may take several years during which agricultural output could be considerably reduced. Thus adequate support (including supply of increased N fertilizers and suitable herbicides) may be needed by farmers to tide over the transition period. Secondly, selection of cover crops and crop rotations should be suited to the specific agro-zone, for which farmers may need advice. Thirdly, specialized (and expensive) seeding equipment are needed in no-till farming. Fourthly, the availability of crop residues for fuel and fodder may be significantly reduced due to the green cover needed on croplands. Finally, the adoption of no-till for wetland rice and root crops (like potatoes) is problematic. Nonetheless, as observed by Huggins & Reganold [2008], "ultimately all farmers should integrate conservation tillage, and no-till if feasible, on their farms." Overall, financial support/ incentives and timely technical help/ advice are essential for speedy and successful transition to conservation agriculture in NRGB.

6.2. Organic Farming

Like no-till farming, organic farming is also a relatively recent agricultural revival of earlier practices, having gained ascendancy towards the end of the twentieth century. However, unlike conservation agriculture which focuses on natural resource conservation, organic farming grew out of human health concerns due to extensive chemical inputs in modern agriculture, and hence its main focus is on human health. Thus, several agroecosystem problems (like soil erosion, nutrient balance, soil biodiversity, and effects on nearby ecosystems) may not be adequately met by organic farming. Moreover, the agricultural productivity of organic farming can be significantly lower (and hence costlier) by about 13–34% than that of conventional agriculture [Seufert et al., 2012]. Connor [2008] pointed out the limited spread of organic farming in world agriculture (only 0.3%) and showed that the additional land needed in organic farming to generate organic fertilizers and grow legume crops implies significantly reduced productivity of organic agriculture as compared to conventional agriculture. In an earlier critique of organic farming, Trewavas [2001] had pointed out some other shortcomings of organic farming including the harmfulness of certain bio-pesticides for human and animal health, extensive labour inputs needed for weed and pest control, and inefficient nutrient utilization. Despite these drawbacks, however, organic farming can result in significant improvement of agroecosystem health, protect surrounding ecosystems from damaging spillovers of chemical nutrients and pesticides, and reduce irrigation water requirement. Hence, organic farming methods should be promoted wherever feasible (e.g. for horticulture and high-value crops) with adequate support for the transition period of a few years.

6.3. Water and Nutrient Management Techniques in Rice Cultivation

Two key methods for improved resource conservation for paddy cultivation are: (a) Alternate Wetting and Drying irrigation cycles (including the System of Rice Intensification or SRI), which can result in up to 40% water saving, and (b) Urea Deep Placement to drastically improve efficiency of N uptake and thereby reduce N fertilizer use [Adhya et al., 2014; Thyiagarajan & Gujja, 2013; UNEP, 2013]. While SRI has been adopted in parts of

India since 2000, its spread in the NRGB – along with Urea Deep Placement – needs to be hastened since rice is a major crop grown in NRGB.

6.4. Additional Resource Conservation Techniques

Several resource conservation technologies need to be promoted in NRGB keeping their cost-effectiveness in view. These include Laser Land Leveling, Raised Bed Planting, and Micro-Irrigation Systems (sprinkler and drip irrigation), besides Urea Deep Placement (or Fertilizer Deep Placement, vide IFDC, 2013) technology mentioned in the previous section.

6.5. Resource Optimization Measures

As discussed in Section 5.2, NRGB's soils have been found to have varying degrees of nutrient deficiencies (such as of calcium, zinc, boron, sulphur, etc.) in different places. But soil nutrient balance is essential for optimizing agricultural productivity. In case of selective nutrient deficiencies, the output is limited by the deficient elements, while other soil nutrients being in relative excess may be wasted. Thus extensive soil testing is necessary in NRGB's agriculture, along with the availability of needed nutrients (through organic or chemical fertilizers of sufficiently high purity) and other soil amendments (especially for acidic, alkaline and saline soils). Improved seed quality (with bio-fortification where needed) and fertilizer quality can also improve nutrient uptakes and reduce resource wastage.

6.6. Regional (Landscape-scale) Resource Conservation Measures

While the above measures are implementable at the level of small farms, large farms and communities of farms spread over large areas should be coordinated for controlling region-scale agroecosystem impacts. This measure also includes other agricultural activities than crops – such as fisheries and animal husbandry. The main approach is to promote mixed farming systems combining various types of plants (such as agro-forestry, crop-horticulture) as well as crops, freshwater fisheries and livestock (with grazing pasture lands interspersed between croplands). Rejuvenation or creation of water bodies and harvesting of rainfall and irrigation runoffs are also needed to enhance local irrigation water availability and reduced dependence on groundwater. Curbs on cultivation of non-essential water-guzzling crops (such as sugarcane) are also desirable, particularly in water-constrained regions. Finally, adequate buffer regions of natural vegetation (trees, shrubs and grasslands) between farmlands and rivers, lakes, etc. are often useful in minimizing polluted runoff from agricultural fields directly reaching nearby water bodies.

Rejuvenation or creation of water bodies and harvesting of rainfall and irrigation runoffs are also needed to enhance local irrigation water availability and reduced dependence on groundwater.

6.7. Scoping Future Advancements

Globally, the shift from intensive mechanized agriculture to ecologically sustainable agriculture started some decades ago but gained momentum only in recent times as tradeoffs between agricultural outputs and other ecosystem services and between quantity and quality of agricultural outputs raised new concerns. This new impetus has propelled radically new thinking and experimentation covering the whole gamut of agricultural techniques from land and water management to crop breeding and biotechnological applications. The attempt must, therefore, be to keep ground-level options open to experiment with, adopt and adapt radically new technologies and practices developed within NRGB and outside. An example of such radically new quests is the attempt to develop perennial deep-rooted crops in place of seasonal shallow-rooted ones [Glover et al., 2007]. As observed by Tilman et al. [2002], "sustainable agriculture … will require increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics, and major changes in some livestock production practices. Advances in the fundamental understanding of agroecology, biogeochemistry and biotechnology that are linked directly to breeding programmes can contribute greatly to sustainability." The agricultural future of NRGB will depend considerably on openness and adaptability to promising developments worldwide on agroecosystem management as also on re-evaluation of traditional practices.

6.8. Policy Issues

The means to speedily achieve the above reforms in NRGB depend upon a variety of social, institutional and economic factors relating to the large number of small and fragmented landholdings in the basin, the extent of poverty and limited educational levels prevalent in the farming community, social fissures, institutional constraints, etc. Various measures have been suggested [IITC, 2014; MOA, 2010; MOA, undated; Planning Commission, 2007] to help the transition to sustainable agriculture overcome these constraints through financial support (credits, incentives, disincentives, subsidies, etc.), knowledge support (knowledge dissemination, training, demonstration, etc.), extension services in implementing new technologies, allocation of water rights and credits, improved availability of farm equipment and agricultural inputs, improved market access, organizing individual farmers through farmers' collectives and contract farming, etc. These and other appropriate policy measures need to be finalized depending on basin-wide assessment of the implementation bottlenecks in NRGB.

7. SUMMARY OF RECOMMENDED ACTIONS

The main recommendations for speedy transition to sustainable agriculture in NRGB are summarized below:

i) Promotion of conservation agriculture practices, aimed at preventing soil erosion and maintaining soil fertility, by means of "no till" or "minimum tillage" of soils, permanent organic soil cover, and crop diversification, especially in degrading agricultural lands.

ii) Promotion of organic farming where feasible to reduce damage to soil health and human health by chemical inputs.

iii) Adoption of resource conservation practices in rice cultivation including System of Rice Intensification and Urea Deep Placement techniques.

iv) Promotion of resource conservation technologies like Laser Land Levelling, Micro-irrigation Systems, Raised Bed Planting, Urea Deep Placement, Bio-fortified seeds, etc.

v) Extensive soil testing facilities with easy availability of micronutrients and soil amendments.

vi) Regional (landscape) level resource management through agro-forestry, crop-livestock-fishery-grassland combinations, water harvesting, and buffering of water courses and water bodies by forests and natural vegetation.

vii) Building adaptability and flexibility in agricultural practices of NRGB through assimilation of new sciences, knowledge exchanges with the outer world, field-level experimentation, and regeneration of traditional knowledge systems.

viii) Selection of appropriate policy measures to implement the above goals, keeping in view the existing social, cultural, economic and institutional strengths and constraints.

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GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 5: GEOLOGICAL SAFEGUARDING

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

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ABBREVIATIONS AND ACRONYMS

1.	**GRBMP**	: Ganga River Basin Management Plan
2.	**IITC**	: IIT Consortium
3.	**MoEF**	: Ministry of Environment and Forests
4.	**MoEFCC**	: Ministry of Environment, Forests & Climate Change
5.	**MoWR**	: Ministry of Water Resources
6.	**MoWR, RD&GR**	: Ministry of Water Resources, River Development & Ganga Rejuvenation
7.	**NGRBA**	: National Ganga River Basin Authority
8.	**NMCG**	: National Mission for Clean Ganga
9.	**NRGB**	: National River Ganga Basin

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 aspects were factored in to assess the basin's resource dynamics. Geologically, river networks tend to achieve equilibrium between tectonic uplift and erosional phenomena in river basins, but both factors have come under significant anthropogenic influence in modern times. Hence geological safeguarding and geomorphological upkeep of the basin are of key importance. The identified geological vulnerabilities of NRGB include disruptive underground activities such as excavations, explosions, tunneling, mining, fracking, and over-withdrawal of ground-water from confined and semi-confined aquifers, as well as over-ground activities such as the operation of large reservoirs. Anthropogenic geomorphological damages are identified as being primarily due to harmful land-uses that enhance erosional stresses. The recommended actions include control/ restriction of geologically hazardous activities and geo-morphologically damaging land-use practices, drainage improvement and stabilization of disturbed areas, mapping of river migration zones, and continuous geological monitoring of the NRGB and her dynamic rivers.

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 both soil and water have 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 environment, the biotic resources depend on the constituent ecosystems of the basin – 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 in recent times [Pahl-Wostl, 2007]. Nonetheless, GRBMP attempts to incorporate the interactive 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 "Geological Safeguarding" is to formulate suitable means to protect the geological foundation of the river basin and safeguard its geomorphological integrity from anthropogenic damages.

3. WHY GEOLOGICAL SAFEGUARDING IS IMPORTANT FOR GANGA RIVER BASIN MANAGEMENT

Geologically, river networks are the backbone of most terrestrial landscapes. Dynamic aspects of these networks include channels that shift laterally or expand upstream, ridges that migrate across the earth's surface, and river capture events whereby flow from one branch of the network is rerouted in a new direction. These processes have direct implications for mass transport and the geographic connectivity within and between ecosystems. Ultimately, this dynamic system strives to establish equilibrium between tectonic uplift and river erosion, but transient conditions in river basins are often in response to tectonic perturbation or erosional phenomena [Willett, 2014].

In modern times, both tectonic perturbation and erosional phenomena have increasingly come under anthropogenic influence. On the one hand, modern human activities can stimulate tectonic perturbations and threaten the geological formations supporting river basins in new ways. To cite, "Human-induced earthquakes have become important … (since) these events may be responsible for widespread damage and an overall increase in seismicity. It has long been known that impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and injection of fluids into underground formations are capable of inducing earthquakes" [Ellsworth, 2013]. On the other hand, modern human activities are also increasingly influencing natural geomorphological processes in the basin. Present-day human actions are a known cause for various geomorphological disturbances involving soil erosion, landslides, flood frequencies and intensities, river instabilities, water-logging, and silting of water bodies. Ensuring suitable practices for geomorphological upkeep and geological safety of the basin are therefore of key importance for the safety of NRGB.

4. PROBLEMS AND THEIR REMEDIATION

Modern human activities threaten earth's crustal formations in new ways as noted by Ellsworth [2013]. The problem becomes significant for river basins when the geological structure supporting them becomes vulnerable to such effects. In particular, underground activities such as excavations, explosions, tunneling, mining and fraccing (or fracking or hydraulic fracturing of rocks) are potential threats to the geological base of river basins. Likewise, over-withdrawal of ground-water from confined and semi-confined aquifers may create unbearable overburden pressures, thereby causing (partial) collapse of the aquifer matrix, land subsidence, and enhanced seismicity in a region (see Box 4.1).

Box 4.1

"Earthquake initiation, propagation and arrest are influenced by fault frictional properties and preseismic stress. … the distribution of shallow slip during the Mw 5.1 **earthquake in Lorca**, southeast Spain, that occurred on 11 May 2011 could be controlled by crustal unloading stresses at the upper frictional transition of the seismogenic layer, induced by **groundwater extraction.**"

Gonzales et al. [2012]

Another potential threat is due to large reservoirs. Operation of such reservoirs – involving their filling up during high flows and emptying during lean periods – produces significant variations in soil water pressures, which build up additional cyclical stress patterns. In fact, the mere creation of large reservoirs is suspected to be a potential cause for geological disturbances in a region (see Box 4.2).

Many of the geomorphological features of river basins are more vulnerable than the underlying geologic strata to both natural and manmade stresses. While naturally occurring phenomena such as storms, cloudbursts, seismicity, landslides and avalanches may not be controllable, various land-use practices that can be geomorphologically disturbing do need to be checked. Such practices include land-uses that significantly affect the physical functioning of catchments such as denudation/ deforestation and construction activities on hill slopes and in floodplains, agricultural tillage causing soil erosion, sand mining from river beds, and river bank modifications for local flood control and other purposes.

Since disruptions in existing geological features of a basin due to natural earth processes may get compounded by anthropogenic threat factors indicated above, the combined damage potential may increase significantly. Thus geological monitoring of critical earth processes in sensitive areas is essential. For example, Himalayan tributaries of the Middle Ganga segment – such as the Kosi and Gandak rivers – are known to be highly dynamic, i.e. with significant tendency to shift their courses. The highly meandering stretches of Ganga river downstream of Varanasi [IITC, 2011] may also indicate such tendencies. With regular monitoring of these rivers, timely controls can be imposed on destabilizing anthropogenic activities along with precautions against impending fluvial changes. It is also important to realize that river dynamics is a natural behavior of the river and, hence, it is important to accurately map the extent of migration and reaches prone to migration. This extent must be included in the 'space' defined for the river – comprising the active floodplain and river valley [IITC, 2010], and the concept of floodplain zoning must be pursued in order to improve river health.

Box 4.2

"… stresses from water piled behind the new **Zipingpu Dam may have triggered** the failure of the nearby fault, a failure that went on to rupture almost 300 kilometers of fault and kill some 80,000 people in last May's devastating **earthquake in China's Sichuan Province (in 2008).**"

Kerr and Stone [2009]

Underground activities such as excavations, explosions, tunneling, mining and fraccing (or fracking or hydraulic fracturing of rocks) are potential threats to the geological base of river basins.

5. SUMMARY OF RECOMMENDATIONS

Assessment and adoption of the following measures are essential for good geologic housekeeping of NRGB:

1. Geological safety measures to maintain the integrity of the basin including restrictions on deep groundwater withdrawals, underground excavations, explosions, tunnelling, mining and fracking, and operation of large reservoirs.
2. Region-specific restrictions on geo-morphologically harmful land-use practices including controls on denudation, deforestation and construction activities on hill slopes and in floodplains, excessive agricultural tillage, sand and gravel mining from river beds, and river bank modifications.
3. Drainage improvement and land reclamation in low-lying areas should be taken up as also improved drainage and stabilization measures in disturbed areas such as hillslopes subjected to road-cutting, degraded lands, and haphazardly built-up urban areas.
4. Mapping of river migration zones and continuous geological monitoring of the basin to forecast impending geological and geomorphological events.

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GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 6: BASIN PROTECTION AGAINST DISASTERS

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

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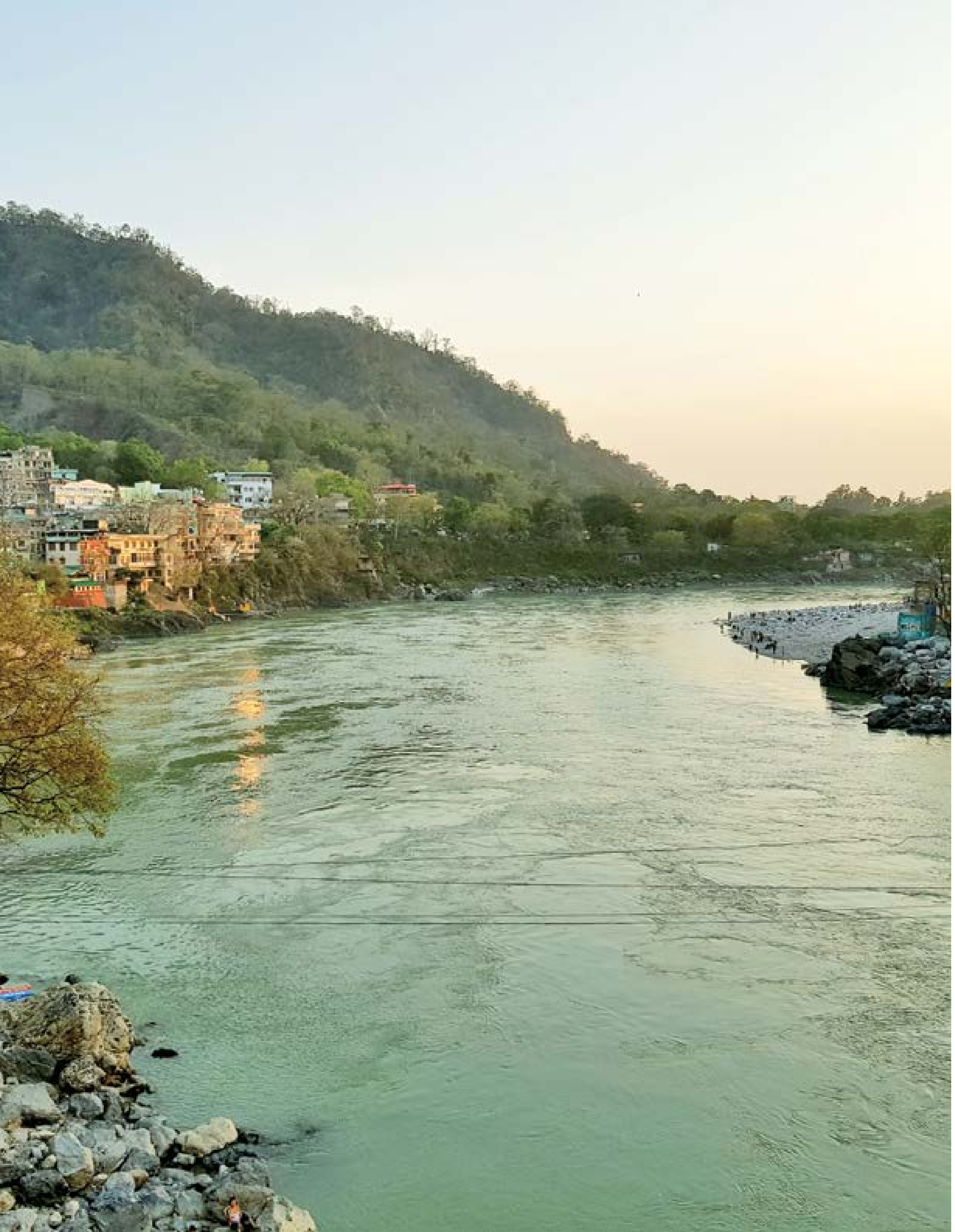
ABBREVIATIONS AND ACRONYMS

1. **IITC** : IIT Consortium
2. **FSI** : Forest Survey of India
3. **GRBMP** : Ganga River Basin Management Plan
4. **MoEF** : Ministry of Environment and Forests
5. **MoEFCC** : Ministry of Environment, Forests & Climate Change
6. **MoWR** : Ministry of Water Resources
7. **MoWR, RD&GR**: Ministry of Water Resources, River Development & Ganga Rejuvenation
8. **NGRBA** : National Ganga River Basin Authority
9. **NMCG** : National Mission for Clean Ganga
10. **NRGB** : National River Ganga Basin
11. **NRGBMC** : National River Ganga Basin Management Commission



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 aspects were factored in to assess the basin's resource dynamics. NRGB is prone to catastrophic natural disasters that can significantly harm the basin's ecosystems, and such disasters have been highly accentuated by modern anthropogenic activities. Hence special measures are needed to protect the basin against natural disasters. The major disasters of concern are *Extreme Floods, Extreme Droughts, Forest Fires, Tropical Cyclones, Landslides, and Epidemics and Biological Invasions.* The main recommendations are: (1) Routine hydro-meteorological and biological events perceived as disasters are often beneficial for the basin, and they need not be countered. (2) To withstand catastrophic disasters, ecosystems need strengthening by preserving wetlands, promoting mixed indigenous forests and vegetation resistant to specific disasters, and curbing land-use disturbances and encroachments by humans. (3) Extreme Floods are characteristic of sediment-charged Himalayan rivers of NRGB, to combat which floodplain regulations and vegetative measures are preferable to embankments/ levees, but upstream dams (with longitudinal connectivity and environmental flows) can also prove beneficial if the sediment trapped behind dams can be transferred to the downstream floodplains. (4) The ecology of Forest Fires and of Epidemics and Biological Invasions in NRGB's ecosystems need to be studied extensively and, until then, active interventions should be limited to checking harmful anthropogenic activities. (5) Landslides in Upper Ganga Basin are aggravated by deforestation, road and building constructions, and unsafe debris disposal, which need to be strongly checked. (6) Early rejuvenation of disaster-struck ecosystems should be aided by re-introducing indigenous species resistant to the specific disaster types and re-creating an enabling physical environment.

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, 2014a]; 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 "Basin Protection Against Disasters" is to devise suitable means to protect and fortify the National River Ganga Basin against natural disasters in order to reduce the damage to the basin (with its component ecosystems) and to enable its early recovery after such disasters.

3. WHY BASIN PROTECTION AGAINST DISASTERS IS IMPORTANT FOR GANGA RIVER BASIN

Conventional disaster management aims to protect human life and property from immediate losses caused by disasters and rehabilitate humans after the disaster has passed, while the consequences of disasters on the basin itself (on which humans depend in various ways) is often ignored. But natural disasters can significantly affect the basin's ecosystems over both the short and long terms. Thus, both from the perspective of basin health – or the health of its ecosystems – and the impact on human settlements in terms of the multifarious ecosystem services provided by the basin, strengthening the basin to face natural disasters and building its resilience to recover from the disasters are extremely important. In fact, even for conventional disaster management, modern recommendations emphasize ecosystem-based disaster resistance and resilience-building strategies [see, for example, Royal Society, 2014]. It is imperative, therefore, that the diverse effects of disasters on NRGB's environment are grasped in the broader perspective to fortify the basin and take protective measures against grievous impacts from disasters.

Disasters are broadly categorized as natural or manmade. Manmade disasters can be entirely unpredictable in nature. Hence their only antidote seems to be not to cause them. On the other hand natural disasters (such as floods, droughts, heat waves, earthquakes, tsunamis and cyclones) occur due to natural processes beyond human control. Unlike manmade disasters, most natural disasters tend to follow certain patterns of occurrence. It is, therefore, possible to anticipate the occurrences and/or damage potentials of such disasters, and strengthen the basin against their impacts on the basin. The heightened need for such measures arises in modern times because anthropogenic factors have tended to accentuate the frequencies and/or magnitudes of disaster impacts to such an extent that natural disasters may no longer be entirely natural [Kothari and Patel, 2006; UNICEF et al., 2013; Nel et al., 2014]. The resilience of a basin's ecosystems to survive and overcome the impacts of disasters gets severely tested in such cases, threatening the healthy functioning of the ecosystems. Manmade exacerbation of natural hazards thus adds urgency to protect NRGB from potentially debilitating effects of natural disasters.

4. MAJOR DISASTERS OF CONCERN FOR NRGB

Natural disasters that impact humans are also potential disasters or hazards for ecosystems since human beings themselves are evolutionary components of the ecosystems. There may also be some natural catastrophes that affect the functioning of ecosystems but have few immediate impacts on human communities; conventionally, such events may not even be considered as disasters, but they too are important for the basin. Natural disasters are generally classified according to the type of natural processes that cause them, such as hydrological, meteorological, geological, biological, cosmic, etc. In India, the commonly recognized natural disasters of human concern are [MHA, 2011; Wikipedia, 2013]:

- ***Hydrological:*** Floods, Flash Floods.
- ***Meteorological:*** Droughts, Extreme Temperature events (Heat Waves and Cold Waves), Snowstorms, Storms and Cyclones, Hailstorms, Forest Fires and Wildfires.
- ***Geological:*** Earthquakes, Landslides and Mudflows, Tsunamis, Snowstorms, Avalanches.
- ***Biological:*** Epidemics, Pest Attacks.

The above disasters are also among the major disasters in the Asia-Pacific region, vide Table 4.1 [ESCAP & UNISDR, 2010]. The ESCAP & UNISDR report [2010] also shows that during the period 1980–2009 India ranked only second to China in the number of disasters among various countries of the region. And within India itself, some of the most disaster-prone areas lie within the NRGB. However, at least one more event should be considered an important natural disaster for the basin's ecosystems – that of Alien Species Invasions.

There are some natural catastrophes that affect the functioning of ecosystems but have few immediate impacts on human communities; conventionally, such events may not even be considered as disasters, but they too are important for the basin.

Table 4.1: Top 10 Disaster Types in Asia – Pacific region [ESCAP & UNISDR, 2010]

Rank		Events	Deaths (thousands)	People affected (millions)	Damage ($ millions)
1	Floods	1,317	128.95	2,676.16	301,590
2	Storms	1,127	384.20	664.03	165,770
3	Earthquakes	444	570.80	109.71	264,530
4	Mass movements – wet	264	14.28	1.36	2,130
5	Extreme temperatures	119	17.51	85.90	18,080
6	Droughts	108	5.33	1,296.27	53,330
7	Wildfires	96	1.06	3.31	16,210
8	Volcanic eruptions	71	17.51	2.36	710
9	Mass movements – dry	20	1.53	0.02	10
10	Insect Infestations	8	0.0	0.00	190

Note: Damage and loss reported in $ millions at 2005 constant prices

Considering the potential damage or vulnerability of the basin, some of the above disasters are only sporadic or affect very small areas in NRGB; hence protecting NRGB against them may be unwarranted. On the other hand, frequently occurring disasters – especially hydro-meteorological ones – tend to be a desirable component of healthy ecosystem functioning. Hence – unless very extreme in magnitude – they are by no means "disasters" for the basin. Such events include especially hydro-meteorological disasters that help in eliminating weak links in ecosystems and enhance the resilience and biodiversity of the basin. Thus, out of about twenty eight natural and manmade disasters considered important for human beings in India by the National Disaster Management Authority [MHA, undated], only seven may be deemed significant for the integrity and performance of NRGB viz.: Extreme Floods, Extreme Droughts, Forest Fires, Tropical Cyclones, Earthquakes, Landslides, and Epidemics and Biological Invasions. Among these seven, methods to protect ecosystems against earthquakes are virtually unknown. Hence earthquakes are excluded from the present mission. (Anthropogenic factors that may trigger earthquakes have been already discussed in Mission Geological Safeguarding.) The other six disaster types of main concern are discussed below.

4.1 Extreme Floods

India is the second most flood-prone country in the world [ESCAP & UNISDR, 2010], which is attributed principally to intense monsoon rainfall, high soil erosion rates and river siltation [MHA, 2011]. However, among the three factors mentioned, soil erosion and river siltation are highly dependent on land-use and other human activities in the basin. Thus, even while floods are the most common type of 'natural disaster' in India – causing huge losses to life and property, the anthropogenic factors that accentuate flooding make the damages much worse. On the other hand, the benefits accruing from large floods in "shaping landscapes and removing debris from rivers" [Vidal, 2014] and in boosting soil fertility and productivity by depositing valuable mineral nutrients, fine silt and loam in floodplains [Dixit et al., 2008] are often overlooked in conventional flood management. Practicing Indian agriculturists, however, seem to be well aware of the long-term fertility value of river silts (*see Box 4.1*). The beneficial effects of river floods in regenerating soil fertility and boosting productivity are in fact well-known, and they have been the backbone of major agricultural civilizations throughout history. In the modern world, there is considerable effort to restore floodplains from their modified modern land uses to earlier fertile states. For instance, the goal of restoring (and creating new) floodplain meadows in the United Kingdom is explained thus: "Floodplain meadows were highly prized farming land, as their natural fertility was maintained by regular winter flooding with little need for extra nutrients. … These habitats are a rich source of biodiversity, a sustainable form of agriculture, and support populations of pollinating insects such as bees and hoverflies. … Once common across the floodplains of England and Wales, these meadows have been drained and modified …" [UK Environment Agency, 2013].

Box 4.1

For Maharashtra farmers, drought has its uses!

The severe drought in Maharashtra is proving to be a blessing in disguise for farmers in the State. Dried-up rivers, lakes and ponds are giving the farmers access to nutrient rich silt, which usually settle at the bottom of these water bodies. ... Farmers have to dig up the silt and cart it away to their farm. However, the process of transporting the silt is expensive. Banks, sensing a business opportunity, have decided to offer loans of up to Rs 1 lakh for every 2.5 acre of farmland. …

Progressive farmer and founder member of Organic Farmers' Association of India, Jayant Barve, said that silt can enhance the farm yield by a factor of ten. However, in the first year of application, it does not replace the chemical fertilisers. From the second year onwards, the benefits can be reaped. The valuable manure can be used for any kind of crop, he said.

Hindu Businessline [Wadke, 2013]

Within India, much of the Ganga basin is flood-prone, especially along the Himalayan range (*vide Figure 4.1*). MHA [2011] identifies the main causes of floods in India as "heavy rainfall, inadequate capacity of rivers to carry the high flood discharge, (and) inadequate drainage to carry away the rainwater quickly to streams/ rivers." While these reasons refer to natural processes that affect the magnitudes and frequencies of floods, the extent to which these very processes are affected by human activities are overlooked. Besides, there are other (natural/ manmade) factors too that can modify floods – such as soil porosity, the depth of groundwater table, and the presence or absence of wetlands, forests and built-up areas in floodplains. In any case, since moderate floods are beneficial for river basins in many ways, periodic flooding is desirable for rejuvenating the basin except when they are extreme floods. Extremely high flood magnitudes tend to inundate greater areas and for longer durations, thus damaging the basin's ecosystems beyond their immediate rejuvenation capacities. For instance, excessively long periods of inundation in forests tend to destroy plant roots [Foster, Knight & Franklin, 1998] thereby disrupting forest ecology unless the plant species are adapted to such inundations. Now, since floods occur due to rivers overflowing their banks, hence ensuring that anthropogenic activities do not increase water and silt inflows to rivers or decrease the carrying capacities of rivers forms the first line of defence against extreme floods. Secondly, keeping drainage lines open in floodplains and providing flood cushions through wetlands and forests can ameliorate the impacts of extreme floods. In many ways, modern anthropogenic activities – even those explicitly aimed at flood control – result in doing quite the opposite. To illustrate this point, the case of the Kosi river – one of the most flood-prone rivers in the world – is discussed below.

4.1.1 Example of Kosi River Floods

The Kosi river and her floods [Chen et al., 2013; Kale, 2008; Wikipedia, 2014b] may be briefly recounted here. River Kosi (or Saptakoshi in Nepal) is about 720 km long and drains about 61,000 km^2 area in China, Nepal and Bihar. The river carries enormous silt loads. Her upper

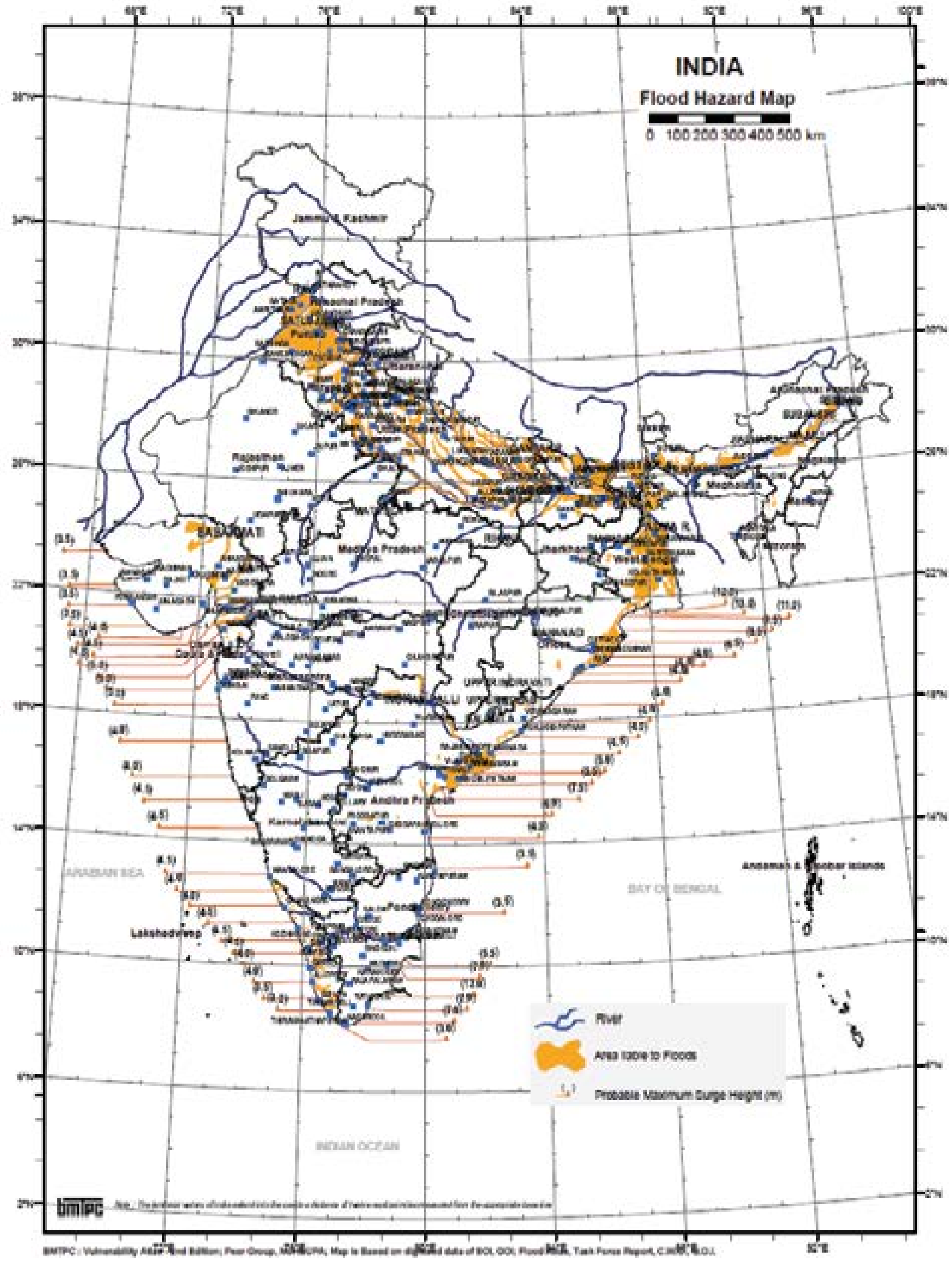


Figure 4.1: Flood Hazard Map of India [MHA, 2011]

catchment produces a silt yield of about 19 m^3/ha/year, one of the highest in the world. Consequently, as the river enters the plains in Bihar and slows down, the silt tends to deposit in the river and spill over onto her floodplains. Thus, over geological timescales, River Kosi has built up an immense alluvial fan ("megafan") of about 15,000 km^2 area. The high sediment loads and the alluvial fan are considered major factors underlying the frequent Kosi floods. Moreover, the relatively flat and erodible Kosi fan enables the formation of numerous interlacing channels, with frequent migrations and avulsions of the channels. Between 1760 and 1960, River Kosi is believed to have shifted slightly eastward, the shifting being random and oscillatory in nature. Naturally, the Kosi alluvial fan is extremely fertile, and hence densely populated. And it is perhaps because of this high population density that the Kosi river floods – even when they are not extreme events – are considered as major disasters, for they cause enormous damage to human life and property.

The greatest recorded Kosi flood in August 1954 had a discharge of more than 24,000 m^3/s [Kale, 2008; Wikipedia, 2014b]. Subsequent engineering measures, such as embankments and river training works, have however failed to control the floods, and major floods (though of lesser flood volumes) have struck the Kosi basin again in recent years. In analyzing the Kosi floods, Valdiya [2011] identified two major anthropogenic reasons causing them: (1) Innumerable constructions in the floodways (floodway being the land area inundated at least one-foot deep by a 100-year flood) of the Kosi river obstruct flood flows, which aggravates the natural flood hazard of the basin due to high denudation rates in the Nepal Himalayas and progressive geological subsidence of the region. (2) The construction of levees/ embankments to contain the Kosi river have caused sediment accretion in the river channel, thereby resulting in river bed levels to rise above the floodplains (vide Figure 4.2); thus when floodwaters overtop or breach the embankments, they inundate the floodplains from a higher elevation, causing enormous flood damages. To remedy this situation, Valdiya recommended that: (1) river floodways be precisely delineated and floodway regulations be strictly implemented; and (2) if river floods are to be controlled by embankments, the embankments should be built away from the channel on the higher edge of floodways.

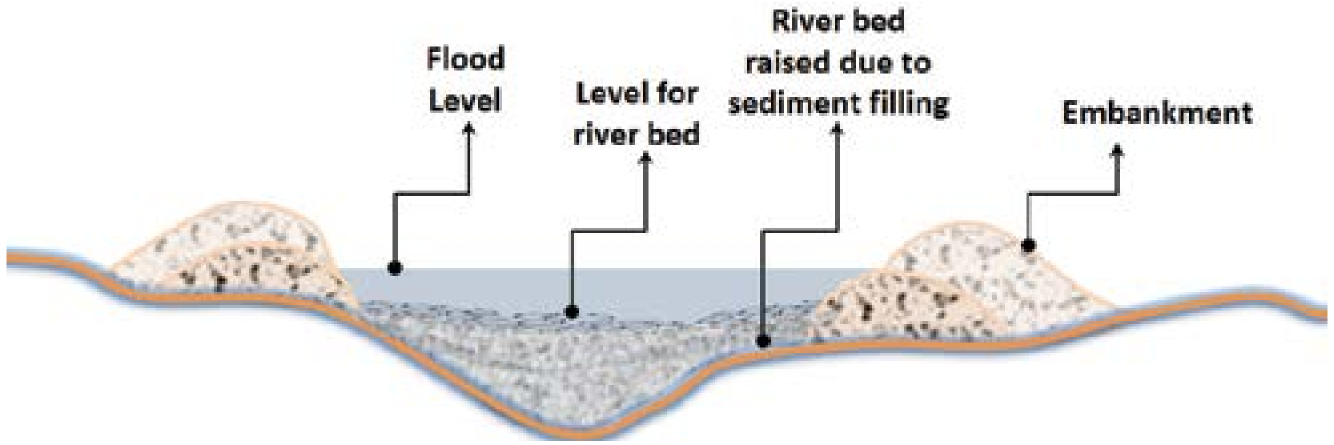


Figure 4.2: Cross-sectional Profile of Kosi river [adapted from Valdiya, 2011]

4.1.2 Example of Yellow River Flood Control Measures

The second of the two factors identified by Valdiya – manmade embankments – is, in fact, an ancient practice and one that has failed to contain floods for at least 2000 years in one of the most flood-damaging rivers of the world – the Yellow river of China. Like River Kosi the Yellow river is also a highly sediment-charged river, and bears much similarity to the Kosi river's dynamism; hence its millennia-old flood control measures deserve a closer look. As noted by Kidder & Liu [2014], "The Yellow River flows through the easily eroded Loess Plateau of central China and as a consequence the river entrains remarkable quantities of sediment; once it enters the alluvial plain… the carrying capacity of the river is exceeded by its sediment load leading to rapid aggradation…. The river's bed and banks are prone to erosion with changing flood conditions… (and) avulsions are common as the channel aggrades and the slope differential between the channel bed and the surrounding flood-basin increases." The Yellow river, with its hyper-concentrated sediment loads – exceeding even 900 kg/m^3 [Shu & Finlayson, 2011] – is thus no less dynamic than the Kosi river, just as the basins of the two rivers are prodigally fertile and densely populated.

The primary method adopted to contain the Yellow river's dynamism and flooding for nearly three millennia has been the construction of increasingly higher levees. But the levees did not prevent floods. In fact, "during a period of 2550 years … the Yellow River broke through its levees 1593 times with 26 major changes in course" [Shu & Finlayson, 2011] and caused several devastating floods. Almost certainly, the flood damages were enhanced because of the levees, since the increasingly higher levees converted the aggrading Yellow river into a perched river raised well above its floodplains (vide Figure 4.3). As summarized by Kidder & Liu [2014] "The effect was to – at least for a time – reduce flood frequency but at the cost of artificially increasing flood amplitude. These processes also shifted the risk profile of any given flood. High frequency floods are damaging but not necessarily catastrophic. Low-frequency high-amplitude floods are inherently catastrophic." The mighty Yellow river, perched above the floodplains, today poses a grave challenge since the levees cannot be dismantled overnight without excavating a long stretch of the perched Yellow river channel. To minimize flood damages in the present-day Yellow river, Shu & Finlayson [2011] therefore recommended that, before a breach in the levees becomes inevitable (due to high flood waves) the levees should be deliberately breached at pre-determined points to minimize the flood shocks.

In modern times, levee building as a flood control measure for the Yellow river has been supplemented with large flood-control dams on the middle reaches of the river and its tributaries, and through the establishment of off-river flood retention basins adjoining the lower Yellow River. However, these efforts too are perceived to be of limited and short-term success, the primary reason being that large quantities of sediments deposited in the reservoirs limit their ability to dampen the floods [Shu & Finlayson, 2011].

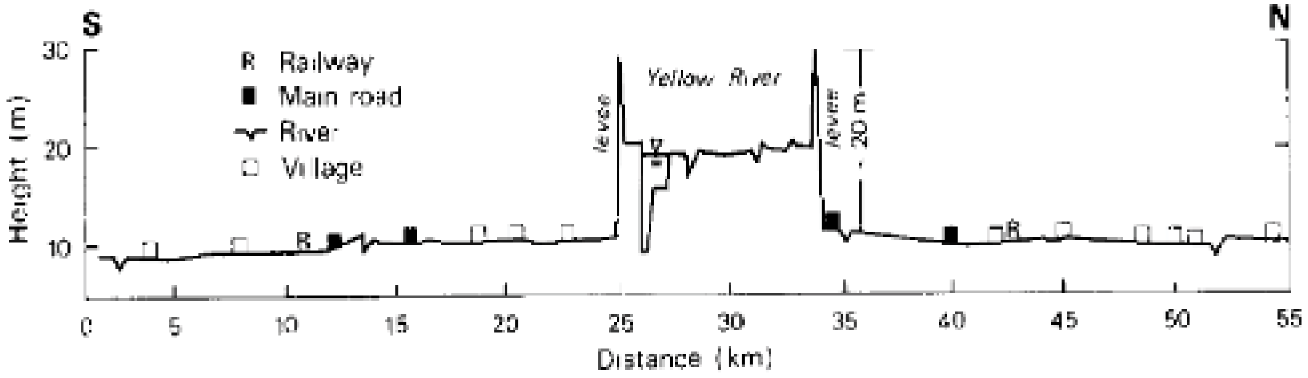


Figure 4.3: Cross-sectional Profile of Yellow river [Shu & Finlayson, 2011]

4.1.3 Measures Needed to Combat Extreme Floods in NRGB

The lesson from the millennia-old flood control measures on the Yellow river is clear: levees or embankments cannot control river floods on a long-term basis for sediment-laden rivers (which most Himalayan rivers are); on the contrary, levees may cause much greater damage in these rivers' floodplains due to levee-induced aggradation of the river bed. Hence, levees or embankments should be abolished as far as possible, with existing levees being gradually reduced in height by allowing the river channel to degrade over time.

The second engineering strategy of absorbing flood peaks in dammed reservoirs upstream of flood-prone regions can be more effective in the medium term, but the useful life of the reservoir may be severely dented by high reservoir siltation rates. Moreover, the trapping of river sediments in the reservoir should not affect the long-term fertility of the downstream river and its floodplains; hence river connectivity and environmental flows must be maintained at the dam (as detailed in Mission Aviral Dhara). Thus, for instance, if the proposed Saptakosi River High Dam in Nepal [CEA, 2014; Saurav, 2012; Shrestha et al., 2010] is to be erected, then its useful life and its effect on basin fertility should be carefully assessed, and there should be provision for release of environmental flows with sediments into the downstream river reach to prevent river degradation. However, flood control in the Kosi basin is probably a secondary objective of the Saptakosi Dam.

A really long-term engineering solution to prevent catastrophic flood events in the basin could lie in replicating the natural transfer of excess river sediments to floodplains – but sediments without disastrous flood waters. This would be possible if sediments trapped in upstream reservoirs can be periodically removed and dispatched to the downstream floodplains[1]. Until such a solution can be actualized, innovative dam operation (such as flushing the river and floodways with pre-determined floods just before the monsoon flood season) seems to be the main engineering help.

In conclusion, it bears repeating that to combat extreme floods checks are certainly needed on anthropogenic activities causing soil erosion in upland catchment areas and on unregulated constructions and encroachments in a river's floodway. In addition, floodplain wetlands and forests must be preserved and bolstered to dampen large flood waves, reduce inundation periods and curb water-logging.

4.2 Extreme Droughts

Droughts in India, averaging about once in every four years, have been attributed primarily to rainfall deficiency or prolonged dry spells [MHA, 2011]. However, droughts need not always be due to low rainfall. The MHA document itself declares that, while around 68 percent of the country is prone to drought in varying degrees, nearly 1/3rd of the drought-prone regions of India get relatively high rainfall of more than 1125 mm (annually). What really causes droughts in terrestrial ecosystems is the paucity of water at or near the land surface (i.e. as surface waters, soil moisture, and near-surface humidity). This is dependent not only on atmospheric precipitation, but also on the ability of a region to store water and to retain water flowing in from neighbouring regions. Thus water retention in surface water bodies, soils and aquifers plays a key role in preventing droughts, besides the ability of a region to capture surface and subsurface runoff and to attract rainfall.

It may be emphasized here that droughts must be viewed in terms of the inherent balance of specific ecosystems. Meteorologically, droughts depend on climatic history, but what constitutes drought in a relatively wet or humid region, could

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[1] An alternative possibility is the periodic removal of excess sediments deposited on the river bed and transferring them to nearby floodplains, but as noted in Mission Ecological Restoration frequent disturbance of the river bed is ecologically undesirable.

well be a normal condition in an arid zone or in a region facing frequent dry years. For natural ecosystems – such as water bodies, wetlands, forests and grasslands – meteorological droughts are debilitating only when they are rare and extreme events to which the ecosystem is not adapted.

Apart from unusually long dry spells, other climatic factors that induce droughts include high temperatures, wind, sunlight and lack of atmospheric moisture. Thus hot summer months are typically ideal for the occurrence of droughts rather than cold winter months, even when the latter constitute dry spells. In NRGB, the winter months actually get some rainfall in the north and in areas close to the Himalayan range, but the summer months before monsoon are typically dry in the basin except in forested regions. Thus, droughts must be combated with improved water retention in the basin through vegetative and structural means – by increasing water retention in surface water bodies (including wetlands), in groundwater, and in soils (especially by forests and ground vegetation, by minimizing agricultural tillage, and by avoidance of soil compaction).

In drought-prone areas of NRGB, there is also a need to curb anthropogenic water usage and hydrate the basin's ecosystems with the additional water. A fundamental lesson in this regard comes from the long spell of drought in Australia from the mid 1990s to around 2010 – known as Australia's Millennium Drought [Kendall, 2010; Gleick & Hebreger, 2012]. This extreme event clearly showed that droughts must be managed by strengthening ecosystems despite human difficulties. As noted by Gleick & Hebreger [2012], "Even in the midst of the drought, Australia moved forward with plans to restore water to severely degraded aquatic ecosystems. The government has continued with plans to restore rivers and wetlands by cutting withdrawals from the Murray-Darling river basin by 22 to 29 percent." If human water usage in the Murray-Darling basin can be can be reduced by 22–29% to strengthen the basin, a comparable measure is certainly possible to curb droughts in NRGB.

4.3 Forest Fires

Forests cover only some areas of NRGB. As per the 2013 India State of Forest Report, NRGB's forests are limited to high-altitude Himalayan regions, the south-eastern delta region and scattered in south-western parts of the basin, vide Figure 4.4 [FSI, 2013]. While the report gives India's total forest cover as 21.23% of her geographical area, it does not give specific figures for NRGB. But as per an assessment in the 1980s, the forest cover of Ganga Basin totalled

only about 13.25% including 0.25% mangrove forest cover [FSI, 2014]. Nonetheless, the forests play an important role in the basin's natural resource wealth and healthy basin performance. Of particular concern among various disasters affecting these forests is that of forest fires or wildfires, with about 54% of India's recorded forest area being considered fire-prone and 3.7% experiencing annual surface fires [FSI, 2013]. In fact, forest fires occur frequently and sometimes consume vast forest tracts in most parts of NRGB except in the Himalayan Alpine regions and mangroves of the delta region. Since regeneration of healthy forests may take decades, wildfires can deprive the basin of valuable ecosystem services for long durations; they may also change forest ecology in the regenerated system.

While forest fires may be naturally caused, accidental starting of forest fires by humans has become common in modern times. This has probably increased the frequency of forest fires in India, but it does not necessarily imply that the fire damages have increased. For, even after some trees have been ignited, it needs suitable conditions for the fire to spread over vast areas of forest. At a basic level, large infrequent forest fires have been attributed to high biomass density and low moisture content of forests [Meyn et al., 2007]. This is typical of the summer months in NRGB when major forest fires are reported; and it is due to their high moisture levels that the Sunderban forests are spared such fires. More importantly, global studies suggest that the average areal extent of a forest fire is inversely proportional to a power of its frequency [Moritz et al., 2005]. That is, if forest fires are frequent then they are smaller in extent, whereas very rare fires tend to consume vast forest tracts. Moritz et al. infer that "highly optimized (fire) tolerance suggests robustness tradeoffs underlie resilience in different fire-prone ecosystems." Such tolerance emanate from evolutionary strategies of individual plant species as well as from ecosystem processes. But the factors that govern ecosystem evolutions are yet to be well understood to relate them firmly with forest fire frequencies.

Fire regimes of forest biomes have been broadly related to rainfall [Mayer & Khalayani, 2011]: thus forests receiving more than 2500 mm annual rainfall have few fires and tend to be well-forested (with more than 60% tree cover) except when the rainfall is highly seasonal; on the other hand, regions receiving less than 1000 mm/year rainfall tend to have more frequent fires, and in such cases grasses outcompete trees by regenerating faster; and savannas (with 5 to 50% tree cover) are most common for rainfall between 750 to 2000 mm/year. But apart from climatic factors, other physical factors (such as topography and soil type) and ecological parameters (such as herbivores and plant pests) are also likely to affect forests' fire tolerance and resilience. Most importantly, anthropogenic factors have significantly affected forest fire regimes in the modern age, which demands a better understanding of human impacts on fire ecology, especially for tropical forests and savannas [Cochrane, 2003; Roberts, 2000; Staver, Archibald & Levin, 2011].

It is due to the high moisture levels that the Sunderban forests are spared such fires.

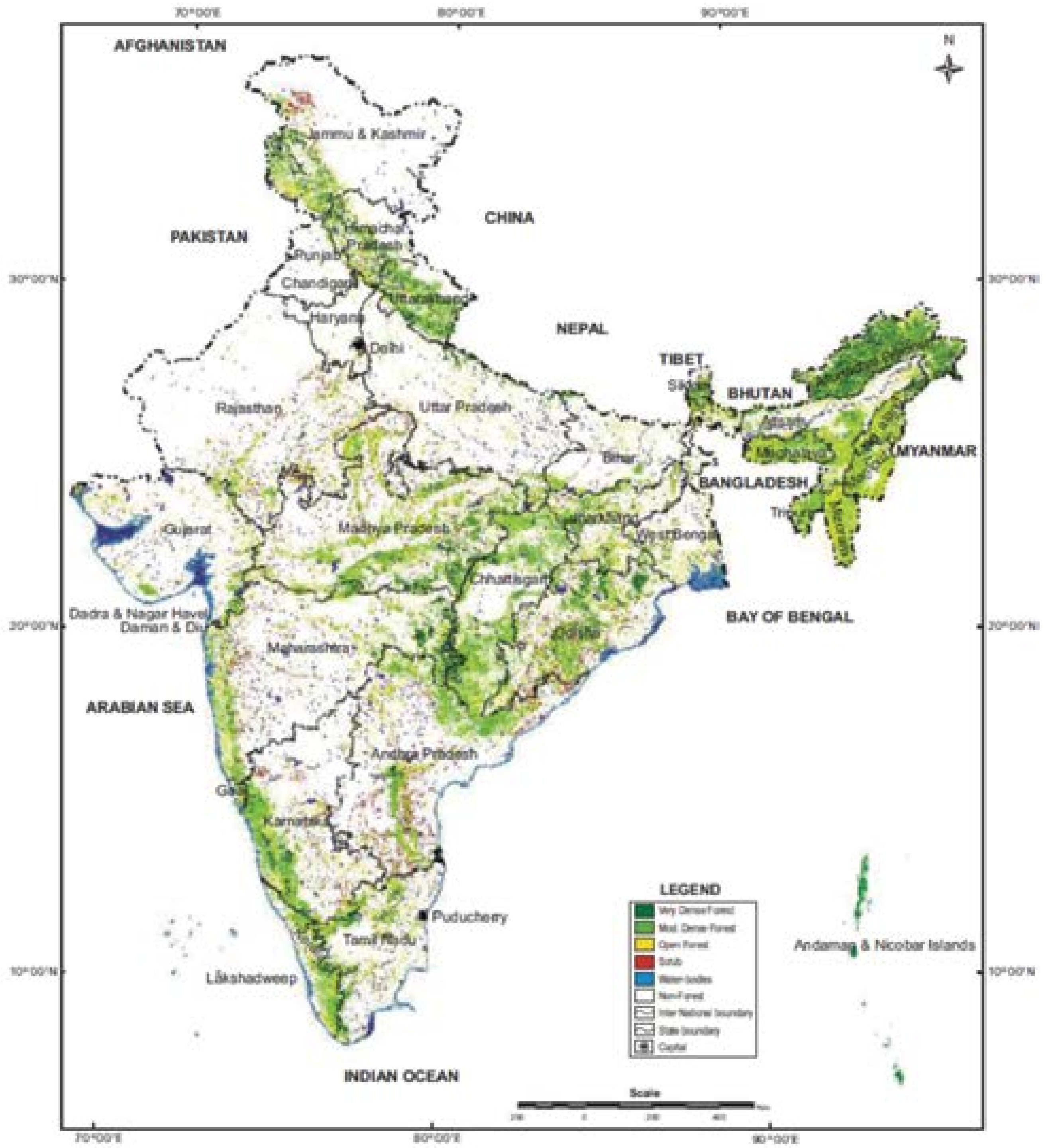


Figure 4.4: Forest Cover of NRGB [FSI, 2013]

Based on the above considerations, the main measures to contain forest fires and limit their likely adverse effects must include curbs on anthropogenic factors that tend to exacerbate forest fires – such as forest fragmentation and modifications by constructions, tree cutting and clearing, grazing by domestic cattle, and water abstractions from forested areas. Early regeneration of burnt forests may be attempted by planting of suitable indigenous species. Finally, a better understanding of the dynamics of forest fire and their long-term ecosystem implications need to be developed for different forest biomes of NRGB.

4.4 Cyclones

Tropical cyclones are a major natural disaster for India's coastal areas, particularly common between October and December in regions close to the Bay of Bengal [MHA, 2011]. Landfall of such cyclones with very high wind speeds – exceeding 200 km/hr in some cases – uproot trees and cause enormous damage to human life and property as well as to coastal and inland ecosystems. The high wind speeds may also produce tidal surges that affect the coastlands. The only part of NRGB directly exposed to cyclonic threats is coastal West Bengal, but this is also the region that hosts the Sunderban delta that plays a crucial role in the ecology of the Lower Ganga basin and that of the coastal sea. Cyclonic storms striking the NRGB coast or the nearby coasts of Odisha (formerly Orissa) and Seemandhra (formerly Andhra Pradesh) may also carry their storm impacts to inland regions of NRGB. Thus cyclones are an important natural disaster affecting the basin.

The main approach to combat the adverse effect of cyclonic storms and tidal surges on NRGB lies in dampening their energy when they strike the coast. The mangrove forests and coastal wetlands covering most of the Sundarban delta (stretching across Bangladesh and India) play a critical role in this process. Unfortunately, in recent decades the mangroves seem to have been affected by anthropogenic factors such as increasing timber production, causing them to degrade significantly: thus, while the forest area may not have decreased significantly in the last 30-40 years, soil erosion, aggradation, etc. have increased the turnover [Giri et al., 2007; Zoological Society of London, 2013]. There is thus an obvious need to ensure preservation of mangroves to resist cyclonic disasters in NRGB. But since the mangroves have been economically productive for human needs, they are also highly populated – the population being largely poor and dependent on ecosystem produce. Thus active participation of local communities may be a necessary step for the preservation of the Sundarban ecosystem [Datta et al., 2012].

In reviving and strengthening mangroves, other coastal forests and coastal wetlands in NRGB, the lessons of cyclonic impacts in other regions should be inducted. For instance, a major tropical cyclone – Cyclone Phailin – had struck the Odisha coast in mid-October 2013. With the aid of advance forecasts, an exemplary job of evacuation and saving of human lives was executed by national and state disaster management personnel [GEAS, 2013]. However, the cyclone reportedly destroyed a phenomenal 26 lakh trees in the state, and the forest authorities decided that they should replant the affected areas with wind-resistant local tree species rather than the easily uprooted trees that had been planted after the Odisha super-cyclone of 1999 [PTI, 2013]. Thus, promoting indigenous wind-resistant tree species is an important aspect of strengthening coastal forests in NRGB.

4.5 Landslides

Landslides refer to the sudden sliding down of a mass of soil or rocks from hill slopes. Landslides are a common occurrence in parts of NRGB, especially

in areas with loose and fractured rocks and soil. The Himalayan regions of NRGB are considered particularly prone to landslides, averaging about 2 per km^2 and with annual soil loss of about 2500 tonnes/km^2 [MHA, 2011]. The localized effects of landslides could perhaps be ignored in the overall ecosystem if they were sporadic. But their frequency and average soil loss are indications of the significant areal impact on the ecosystem. Moreover, at times they also cause damming of rivers [Sundriyal et al., 2007], leading to potentially major downstream floods when the dam breaks under mounting water pressure from the impounded water.

The Himalayan mountains being relatively young and geo-dynamically active than older mountain formations in India, landslides and landslips are partly natural – being caused by heavy rainfall on geologically fragile slopes. But a study in the Garhwal Himalayas found evidence to suggest that about 2/3rd of the landslides are initiated or accelerated by anthropogenic activity "primarily via the undercutting and removal of the toe of slopes for the cutting of roads and paths" [Barnard et al., 2001]. The impact of road constructions has also been noted by other observers. Thus, a survey of landslides in the aftermath of heavy precipitation in September 2010 in the Alaknanda river valley revealed "large scale slope destabilization along the roads where widening work was in process … (and) around 300 landslides of various dimensions riddled NH-58 (the national highway along the Alaknanda river)" [Sati et al., 2011]. Apart from unsafe and increased road construction, the authors also identified increasing deforestation and urban built-up areas on unsafe slopes as other major reasons for hill slope failures that caused landslides in the Alaknanda valley. It is also worth noting that in the wake of an unprecedented rainfall event in mid-June 2013 in the Upper Ganga basin that caused major floods and landslides in the region, the Indian Space Research Organization identified 2,395 landslides in the basin. In this case too, the major anthropogenic reasons for the landslides were attributed to large-scale deforestation, shoddy road building and illegal constructions [Chopra, 2014].

Although disease germs and pests can be harmful for individual species, they can play a positive role in maintaining ecosystem balance.

Landslides also occur in other parts of India, and their lessons need to be inducted in NRGB. A case in point is the major landslide that occurred in Malin village located in the Sahyadri mountain ranges (in Pune district, Maharashtra) in late-July 2014 that killed dozens of people and damaged most houses in the village. The environmental or ecosystem impacts are unknown, but the major anthropogenic cause of the landslide is widely believed to be deforestation and clearing of hill slopes to develop terraced agricultural plots [Waghmode, 2014]. The Malin landslide was probably more of a mudslide (or mudflow or debris flow) that may not be related to major rock fractures or lineaments. But even mudslides are known to be related to removal of vegetation. For instance, in a study of the after-effects of wildfires, it was found that "debris flows are likely from burned area for the first two years after a wildfire" [GSA, 2013].

As evident from above, deforestation, unsafe road construction and building constructions on unsafe slopes are major anthropogenic activities that need to be checked at the earliest. Apart from these measures, identification and checks are also needed on other potentially hazardous activities such as underground explosions and tunnelling in fault zones, improper disposal of excavation and construction debris, and land-uses on slopes that increase the chances of landslides. Mapping the basin's geological hazard zones is also required to systematically implement the needed measures in the region, keeping in mind that apart from high rainfall many other natural events (such as earthquakes and wildfires) heighten the chances of landslides in their aftermaths.

4.6 Epidemics and Biological Invasions

"Epidemics" and "biological invasions" are different types of phenomena in that the former refers to disease outbreaks that severely affect specific species, while the latter pertains to the invasion of an ecosystem by alien species that tend to replace some native species. The two phenomena are, however, linked by the fact of native species being vulnerable to other organisms that are generally absent or of limited presence in the ecosystem. Hence the two issues are covered together in this section.

Epidemics in natural ecosystems usually affect a few species among the entire spectrum of species contained in the ecosystem. The chances of a disease outbreak generally increase with the density of the species population. In most natural ecosystems, evolutionary processes ensure that different species are held in balance by disease germs, parasitic pests, symbiotic or mutualist organisms, and the food web. Although disease germs and pests can be harmful for individual species, they can play a positive role in maintaining ecosystem balance.

An example of such a role is evident from that of insect herbivores and fungal pathogens in preserving plant diversity in tropical forests. Thus, suppressing fungi and insect pests by means of fungicides and insecticides was found to significantly diminish forest biodiversity [Bagchi et al., 2014]. Conventional disease outbreaks affecting only some species of an ecosystem are therefore beneficial for the system. They become a matter of concern only when the disease afflicts a large number of species, which is usually the case when an alien pathogen or pest intrudes the system, or the physical environment is so greatly altered that existing pests gain overwhelming advantages. The latter is often due to modern anthropogenic factors.

In contrast to routine disease outbreaks in ecosystems, ecosystem invasions by alien species – and even the sudden spurt of indigenous species – can often have far-reaching and unforeseeable effects. To cite, in recent years wildfires in Colorado forests in USA have been surmised to be due to invasion by mountain pine beetles [Massey & ClimateWire, 2012]. As the beetles suck trees dry, the trees become highly prone to catch fires. Although the beetles are not alien, their invading large forest tracts are believed to have been aggravated by anthropogenic factors. In fact, most scientists now agree that it is high biodiversity areas that are most prone to invasion — due to heavy human traffic and more favourable growth conditions [Gewin, 2005]. Such high biodiversity areas in NRGB include the Himalayan, Terai and Sundarban regions, which as elsewhere in the world are highly human-affected.

In river ecosystems too, alien species invasions have been often surmised to be due to human activities. For instance, 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 fish from the mouth of the Danube river to regions far upstream [TUM, 2013]. In fact, the biogeography of alien fish invasions in most world rivers has been found to correspond to the impact of enhanced human activities in the respective basins [Leprieur et al., 2008].

5. SUMMARY OF RECOMMENDATIONS

The main conclusions and recommendations for protecting National River Ganga Basin against major natural disasters are as follows:

i) Many routine natural events conventionally considered as disasters – such as those of climatic origin and biological ones – are beneficial for the health of the basin and its ecosystems. Hence, such events should not be viewed as disasters and countered.

ii) Extreme Floods, Extreme Droughts and Powerful Cyclones are among meteorological events that can have catastrophic effects on the basin's ecosystems. To minimize chances of their catastrophic impacts, ecosystems need to be strengthened through preservation of water bodies/ wetlands, mixed indigenous forests and vegetation resistant to the specific disaster-type, and minimal land-use disturbances by humans. For high sediment-laden rivers, Extreme Floods are exacerbated over time by levees/ embankments, but dams are a possible longer-term structural option: extreme floods can probably be reduced by upstream dams if river sediments partially trapped behind dams can be periodically removed and sent to downstream floodplains.

iii) Forest Fires, usually ignited by lightning or by humans, are also dependent on climatic factors. Forest fires appear to be limited in extent when they are frequent, and vice versa. Since forest ecologies have evolved through natural fire regimes over thousands of years, the effect of major fires on specific ecosystems need to be studied on a long-term basis in different parts of the basin before any major intervention is designed to alter their fire resistance or resilience.

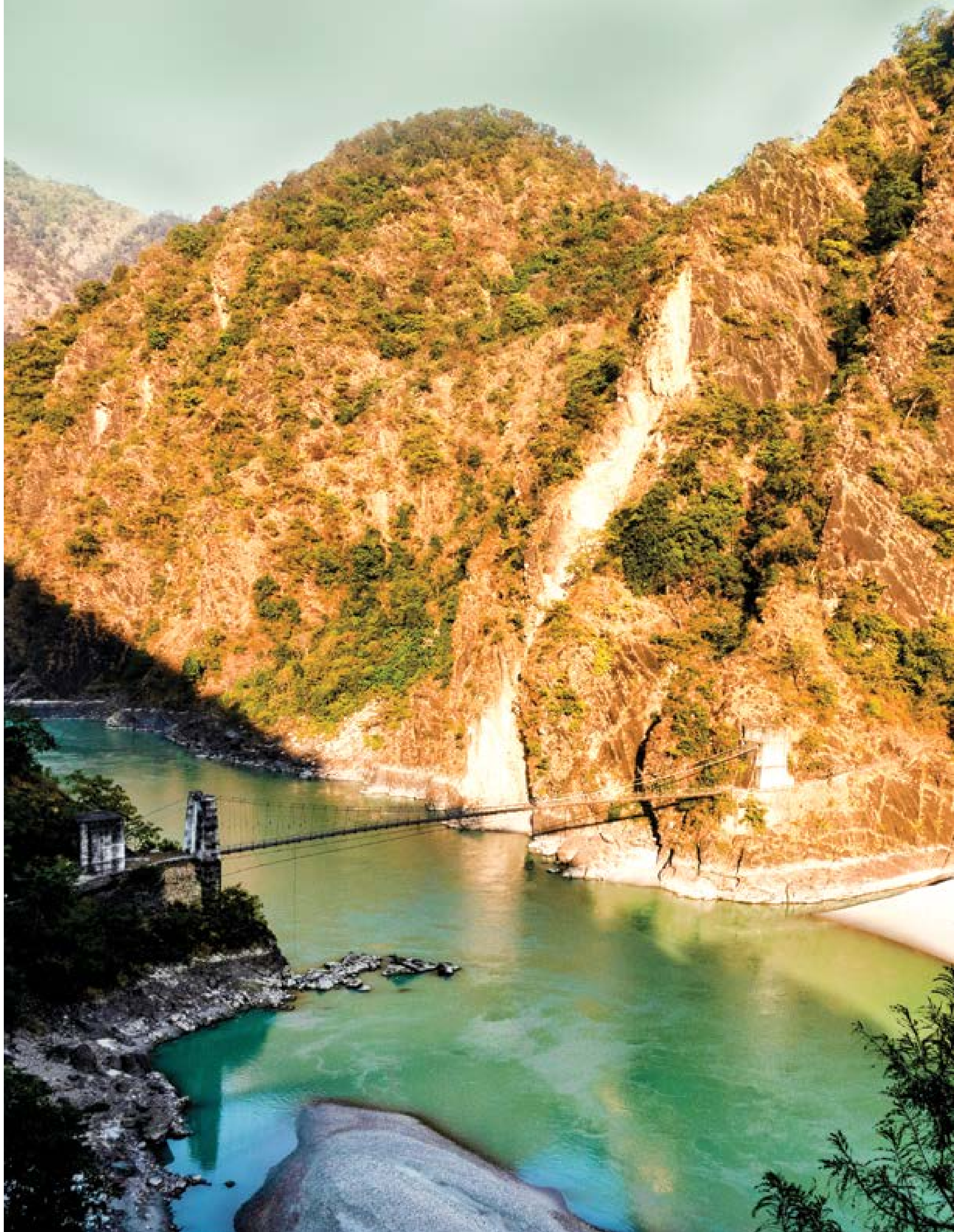
iv) The above four natural disasters are significantly exacerbated by modern human activities such as encroachments and deforestation, which need to be stopped.

v) Landslides are frequent events in the Upper Ganga Basin due to the litho-tectonic character of the

Himalayas, but their frequencies and magnitudes are highly aggravated by anthropogenic activities such as deforestation, road and building constructions, and unsafe debris disposal, which need to be firmly checked.

vi) Like Forest Fires the ecology of Epidemics and Biological Invasions in NRGB's ecosystems need to be studied extensively, and until their dynamics are properly understood, active interventions should be limited to checking harmful anthropogenic activities that introduce alien species or destabilize the ecosystems.

viii) If any ecosystem is catastrophically affected by a natural disaster, its early rejuvenation should be aided by re-introducing indigenous species in the affected zones and re-creating an enabling physical environment.



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GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 7: RIVER HAZARDS MANAGEMENT

by

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

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

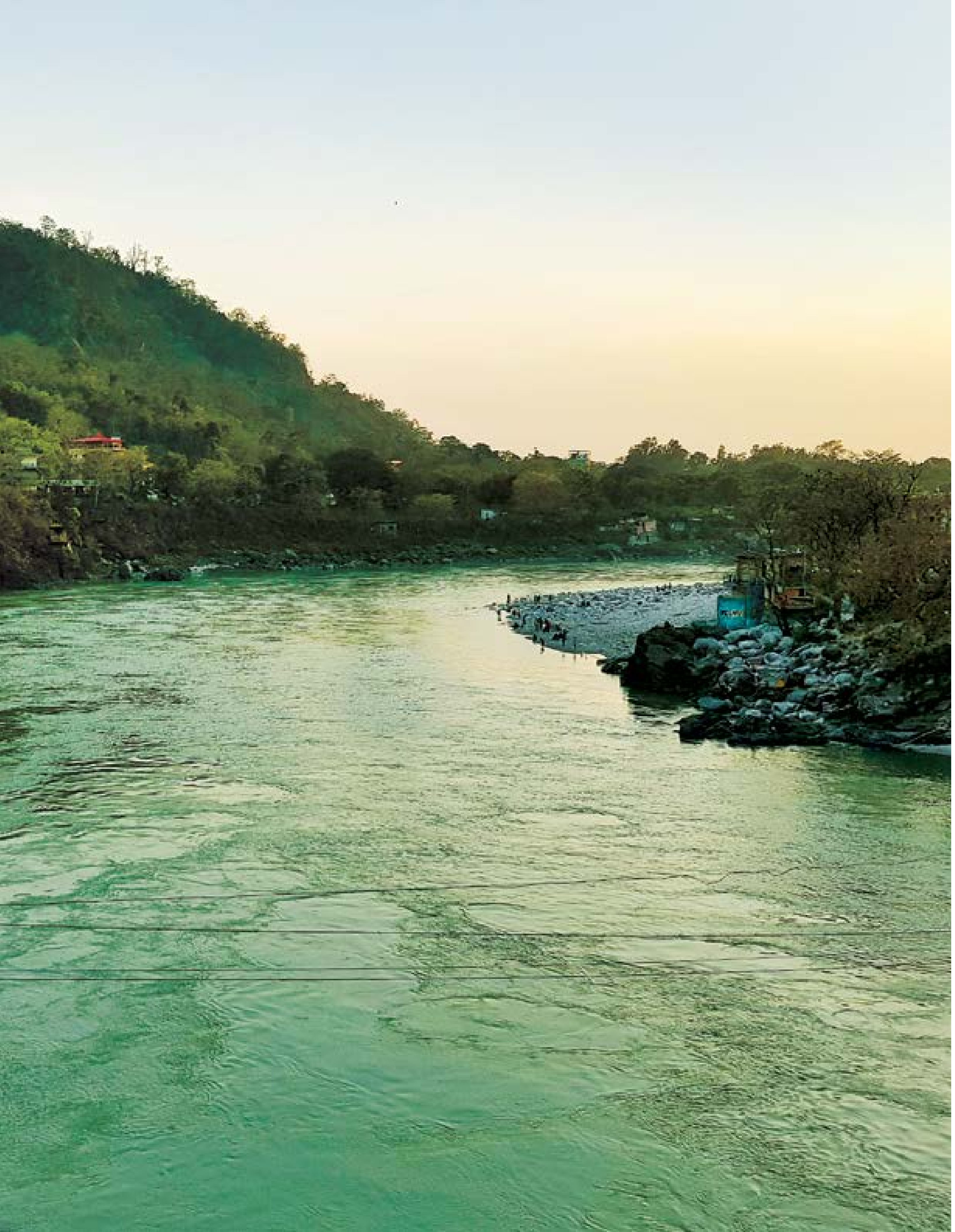
In Collaboration with

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

CONTENTS

ABBREVIATIONS AND ACRONYMS

1. **CGWB** : Central Ground Water Board
2. **CWC** : Central Water Commission
3. **DBFO** : Design-Build-Finance-Operate
4. **E-Flows** : Environmental Flows
5. **IITC** : IIT Consortium
6. **FAO** : Food and Agricultural Organization
7. **GRBMP** : Ganga River Basin Management Plan
8. **MND** : Mission Nirmal Dhara
9. **MoEF** : Ministry of Environment and Forests
10. **MoEFCC** : Ministry of Environment, Forests & Climate Change
11. **MoWR** : Ministry of Water Resources
12. **MoWR, RD&GR**: Ministry of Water Resources, River Development & Ganga Rejuvenation
13. **NGO** : Non-Governmental Organization
14. **NGRBA** : National Ganga River Basin Authority
15. **NIH** : National Institute of Hydrology (India)
16. **NMCG** : National Mission for Clean Ganga
17. **NRGB** : National River Ganga Basin
18. **NRGBMC** : National River Ganga Basin Management Commission
19. **PPP** : Public-Private Partnership
20. **SRI** : System of Rice Intensification
21. **UNEP** : United Nations Environment Programme
22. **URMP** : Urban River Management Plan



SUMMARY

Rivers draining the Ganga basin are prone to two major river hazards – river dynamics and floods – and these are intricately interrelated. Anthropogenic disturbance along the rivers such as landuse/ landcover changes, interventions such as barrages and dams, and developmental projects such as rail/ road networks, and even flood-control embankments have further increased the risks associated with these hazards manifold. The objective of Mission “River Hazards” is to identify the hazards related to anthropogenic disturbances on the rivers and to formulate suitable means to reduce the risk. River dynamics is a natural phenomenon, however, the frequency of migration events has been severely affected by anthropogenic disturbance along the rivers resulting into a sudden and disastrous migration affecting a large population. Flooding is another disastrous natural phenomenon in the eastern Ganga plains. Flood control strategies in most river basins in India are primarily embankment-based which have not only influenced the natural flow regime of the rivers, flood intensity, frequency and pattern but have also created a ‘false sense of security’ amongst people living in the region. The construction of barrages and other interventions has aggravated the problem further. Many Himalayan Rivers are highly sediment-charged and a major problem has been the rising river bed and reduction in carrying capacity owing to extensive sediment deposition in the reaches upstream of the barrage. Apart from embankments along the river, unplanned roads and bunds have resulted in severe drainage congestion and channel disconnectivity thereby increasing the inundation period significantly. Some specific recommendations are: (1) preparation of basin scale flood-risk maps, (2) drainage improvement and land reclamation in low-lying areas, (3) assessment of soil salinity and mitigation strategy, (4) alternatives to embankments for flood management with an emphasis on ‘living with the floods’ concept, and (5) understanding sediment dynamics and its application in river management projects.

Project planning should begin with preparation of detailed Urban River Management Plans (URMPs) for Class I towns, and subsequently also for Class II and Class III towns. The URMPs should be followed by preparation of DPRs, following which funds should be allocated for project implementation. Fund allocation should be prioritized for projects designed to prevent direct discharge of large quantities of liquid waste into the River System (Priority Level I), followed by projects designed to prevent direct discharge of large quantities of solid waste into the River System (Priority Level II), followed by projects concerning river-frame development and restoration of floodplain in urban areas along the Ganga River System (Priority Level III). All funds budgeted by the central/ state/local governments for Ganga Rejuvenation over the next 15 years must be only used for above types of projects.

Projects related to MND may be conceived by the central, state, local governments, NGOs and other private organizations/industries. Financing of these projects may be through funds budgeted by central/ state governments for Ganga Rejuvenation, local revenue, corporate and private donations and grants, low cost debt from multinational organizations, commercial debts from banks and private equity. Wherever possible, project implementation including operation and maintenance should be contracted to 'service providers', i.e., public/private agencies with relevant expertise. Payments must be released to the 'service provider' only after monitoring by an independent third-party.

1. INTRODUCTION

Several rivers draining the Ganga basin are prone to two major river hazards – river dynamics and floods – and these are intricately interrelated. The dynamics of the rivers is primarily driven by channel instability caused by extrinsic factors such tectonics or intrinsic factors such as excessive sedimentation and local slope variability rather than. Further, flooding in several rivers such as the Kosi river does not occur as classic overbank flooding due to excess inflow but is generally triggered by a breach in the embankments which have ironically been constructed for flood protection. In most cases, breaches in the embankments are associated with channel instability coupled with human factors such as poor maintenance.

2. OBJECTIVE

The objective of Mission "River Hazards" is to formulate suitable means to reduce the risk of hazards related to the rivers so as to save the population living on the floodplains.

3. WHY RIVER HAZARDS MANAGEMENT IS IMPORTANT FOR GANGA RIVER BASIN MANAGEMENT

Several river-related disasters in India in recent years bear testimony to the fact that human disturbances have increased the intensity of these disasters and vulnerability of communities towards these. The year 2010 witnessed a series of unprecedented floods not just in India but globally. From floods in Himachal Pradesh (July 2010) and Leh (August 2010), floods occurred in several parts of Karnatka, Tamil Nadu, Andhra Pradesh and south Orissa during November- December 2010. Globally, severe floods in east China (May 2010), Rio Lorogo, Brazil (June 2010), Pakistan (August 2010) and Queensland, Australia (December 2010) hit headlines – pointing out very clearly that even developed countries are not quite free from flood risks. Notwithstanding the justification, we in India with a legacy of floods, need to rethink strategies of flood management. Most floods are caused by excessive rainfall spanning a very short time, cloudbursts or cyclones in coastal regions. Barring sudden cloudbursts resulting in floods, as in Leh and J&K, flooding due to excessive rainfall can be predicted - if proper monitoring of water gauging stations and communication systems is in place. However, it is pertinent to understand that flood control strategies in most river basins in India are primarily embankment based. Such man made structures have influenced the natural flow regime of rivers and modified the flood intensity, frequency and pattern. The construction of barrages and other interventions has further aggravated the problem. Many of the Himalayan rivers are highly sediment charged and the rising riverbed and reduction in carrying capacity due to extensive sediment deposition in upstream reaches of a barrage has been a major problem with them. The engineering assumption that jacketing the river would increase the velocity leading to scouring has instead resulted in silting of river beds and increased water logging and soil salinity in the adjoining floodplains. The construction of protective levees and dykes besides the large sediment flux from the Himalayan catchments has further complicated the flooding problem in these rivers. In many cases, large areas have been inundated due to breaches in embankments coupled with rapid shifting of rivers. Unplanned roads and bunds have also resulted in severe drainage congestion and channel disconnectivity, increasing the inundation period significantly.

4. PROBLEMS AND THEIR REMEDIATION

4.1 River Dynamics

The rivers draining the Ganga plain are quite dynamic in nature. Channel movements through avulsion and cut-offs have been recognized in most of the rivers albeit with a difference in scale and frequency. Fluvial dynamics in the Gangetic plains was initially reported by Shillingfield (1893) and followed by several workers. Many of these papers focussed on the westward movement of the Kosi river in north Bihar plains. Shillingfield (1893) opined that the progressive westward movement of the Kosi river would be followed by the eastward movement in one great sweep which proved to be true when the Kosi avulsed by ~120 km in August 2008 (Sinha, 2009; Sinha et al., 2014). On an average, the Kosi has shifted by about 100 km in the last 200 years and related the shifting process with the cone (megafan) building activity, sediment deposition, rise of bed levels (Gole and Chitale, 1966) and the unidirectional channel shifting occurs progressively form one edge of the cone to the other edge. The instability of Kosi river has also been related with a N-S fault with a throw to the west (Arogyawami, 1971; Agrawal and Bhoj, 1992). It was argued that the Kosi river is shifting as the rate of subsidence is very much in excess of sedimentation, giving rise to strong gradients and a regional tilt from east to west. It was also argued that with the progress of sedimentation, unequal loading of the downthrown (western side) of this fault will produce a tilt of the east, and the river will switch back to an easterly course. However, Wells and Dorr (1987) concluded that tectonic events and severe floods surely influence the Kosi system but their effects are neither direct nor immediate. The lateral shift of Kosi river is largely autocyclic and stochastic. More recent work has also confirmed that the dynamics of the Kosi river is primarily controlled by local slope changes influenced by excessive sedimentation in the channel belt and that the situation has become worse after the construction of embankments on both sides of the Kosi river (Sinha, 2009; Sinha et al., 2014). Apart from the major rivers such as the Kosi, the smaller rivers draining the north Bihar plains are equally dynamic. The migration histories of the Burhi Gandak river along with that of the Ganga around Samastipur (Phillip et al., 1989, 1991), decadal-scale avulsions of the Baghmati river (Sinha, 1996; Jain and Sinha, 2003, 2004) are well-documented.

Channel movements through avulsion and cutoffs have been recognized in most of the rivers albeit with a difference in scale Channel movements through avulsion and cutoffs have been recognized in most of the rivers albeit with a difference in scale and frequency.

Though the rivers of UP plains are not as dynamics as the north Bihar rivers, they do show some channel movement over a long time period. In the area between Bithoor and Kanpur Railway Bridge, the Ganga river shifted (Hegde et al., 1989). In 1910, the main channel of the Ganga river was flowing along the right bank; however, after 1945 the channel moved considerably and now it is flowing along the left bank. The historical records date the river flow along the right bank as early as 1857. This channel shift was attributed to the highly irregular shape of the valley in the area, the 1924 flood causing major changes in floodplain and the location of railway bridge on the extreme right of the flood plain. The Ghaghra river in UP plains has also shifted by ~5 km at certain places, on either side of the active channel over a period of seven years between 1975 and 1982 and was related with the neotectonics in the area (Tangri 1986; Srivastava et al., 1994). Chandra (1993) also noted an avulsion of Rapti river near Baharaich due to aggradation process in the old channel, which caused the SW diversion of the Rapti river. The Sarda river is characterised by several westward lateral shifts at different places in between Banbasa barrage (Nainital district) and Palliakalan village (Kheri district) (Tangri, 2000). Another, interesting observation was made by Tangri (1992) who showed that the major rivers such as Ghaghra, Gandak, Ganga, Son and Punpun rivers were all meeting at one point (few km upstream of Patna), but at present the confluence points are widely separated apart. Further, the Ghaghra-Chauka river confluence point has migrated upstream perhaps in response to the change in water budget of source area catchment (Himalaya). Tangri (2000) also delineated two major paleocourse near the Ganga as well as Gandak river, which suggest much higher discharge flux in the Himalayan river in the past. Roy and Sinha (2006) documented the upstream and downstream movements of two major confluence points in the Ganga plains namely, the Ganga-Ramganga and the Ganga-Garra confluences over a century scale period. The net movement of the

confluence points was shown to be as large as ~18 km in case of the Ganga-Ramganga confluence, and the major processes influencing the movement of confluence points are avulsion, local movements by cut-offs, river capture, and aggradation.

A good example to illustrate river dynamics in the Ganga river could come from the lower reaches of the Ganga in West Bengal which show significant dynamics in terms of channel position as well as form in the last 234 years (Rudra, 2010; Sinha and Ghosh, 2012; Rudra, 2014) even though the river flows through a rather narrow valley bounded by Rajmahal Hills and Barind Tract to its west and east respectively. Although the Ganga River has been naturally migratory in this region, the engineering interventions namely, the Farakka barrage and associated structures have made the situation worse. The river has been migrating to the east in the reaches upstream of the Farakka barrage and to the west in the reaches downstream of Farakka. The apprehension of the river flanking the barrage has forced more and more interventions in recent years. Unfortunately, these measures have only shifted the trouble to downstream reaches and have significantly increased the aggradation within the channel belt resulting in significant changes in channel morphology and position. The reaches of the Ganga downstream of the barrage also form the international boundary between India and Bangladesh and such large-scale dynamics adds to the land disputes between the two countries. It has been suggested that most of these changes are linked with natural delta-building processes but have been aggravated by the human intervention, the most important one being the Farakka barrage (Rudra, 2014). Several channels of the Ganga River have decayed beyond repair and all efforts to rejuvenate them have failed. In addition, coastal erosion has been a serious problem in the delta region and several islands have disappeared in the last 100 years. The Sunderban area is the worst affected where 430 km^2 of land has been eroded between 1917 and 2010. It is necessary that we advocate a policy "which works with seasonal inundation, land erosion and accretion will have to be much more sensitive and flexible, much more adaptive than the current system of standard engineering" (Rudra, 2014).

It is important to realize that river dynamics is a natural behavior of the river and it is crucial to accurately map the extent of migration and reaches prone to migration. This extent must be defined as the 'space' for the river and the concept of floodplain zoning must be seriously pursued. This is not only crucial for saving a large population from the misery of river dynamics and floods but is also important for improving the river health. The situation remains grim till date and long-term solutions incorporating geomorphic understanding of the river have been lacking in river management strategy.

4.2 Flood Hazards and Management

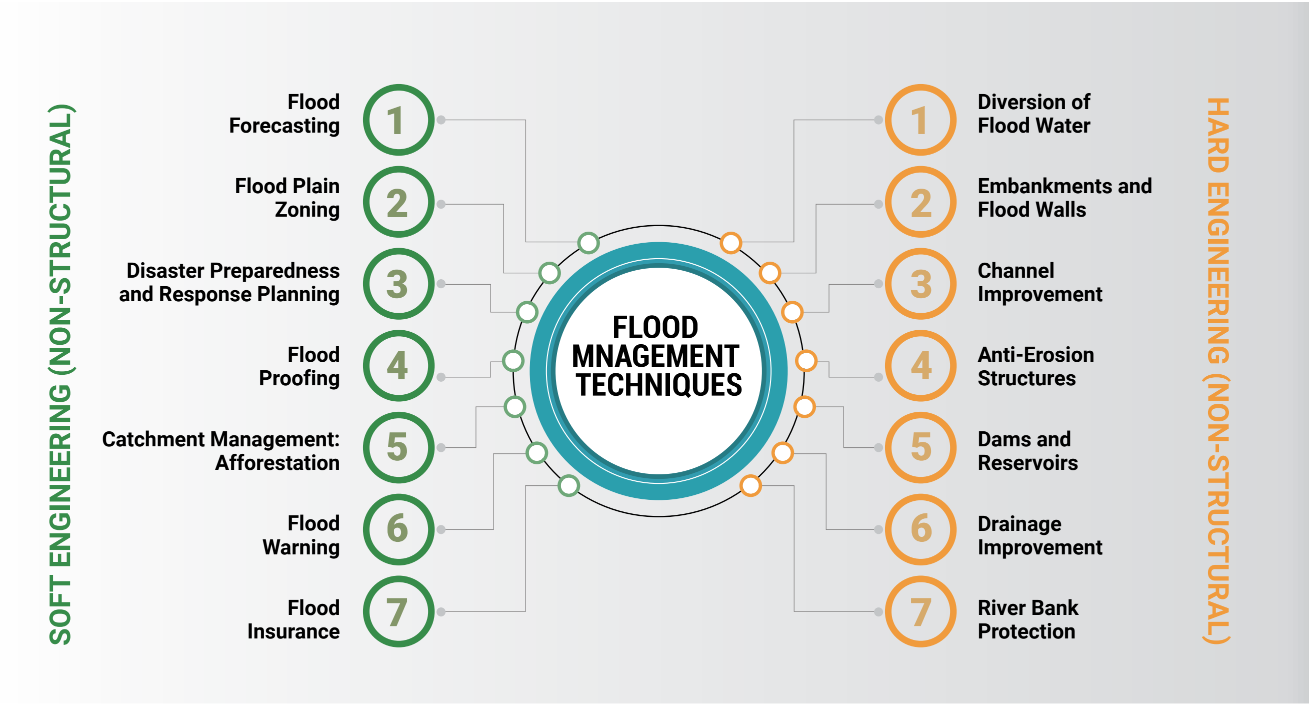
Flooding is one of the most disastrous natural phenomena in alluvial plains of the Ganges system particularly in the eastern parts, which are presently regarded as one of the worst flood-affected regions in the world (Agrawal and Narain, 1996). The plains of north Bihar have the dubious distinction of recording the highest number of floods in India in the last 30 years (Kale, 1997). An excess of 2700 billions of rupees have been spent on the flood protection measures in India but the flood damages and flood-affected areas are still on rise. The flood protection measures have largely failed and one of the important reasons for this has been that floods have long been considered as purely hydrological phenomenon. A geomorphic understanding of floods is lacking.

Recent research has emphasized the role of basin geomorphology on floods. The overall hydrological response of the basin depends upon, apart from the rainfall intensity and duration, the geomorphometric characteristics, neotectonics and fluvial processes. The dynamic behaviour of river channels and frequent avulsions caused by sedimentological readjustments or otherwise often divert the flow into a newly formed channel with low bankfull capacity causing extensive flooding. Often, people are not prepared for flooding along such newly formed channels and the flood damage is quite severe in such cases.

One of the most important geomorphic considerations in understanding the flooding behaviour of the rivers is the channel-floodplain relationship. In areas of modern sedimentation with continuous subsidence, such as the north Bihar plains, the frequency and extent of overbank flooding is considerable, and most of the rivers carry a very high suspended load and a simultaneous aggradation of the channel bed and the floodplain surface encourages flooding.

Presently, a typical flood control strategy aims to either modifying the floods in order to keep the flood waters away from developed and populated areas or modifying susceptibility to flood damage by keeping people and developed areas out of flood hazard areas or by ensuring that such developed areas are flood-proof. Additionally, they aim to modify the loss burden by reducing the financial and social impact of flooding by providing post-flood assistance and relief. Most strategies for ‘modifying the flood’ include physical measures and are termed structural measures, while those aiming to modify the damage or impacts can be classified as non-structural measures. The structural measures include the construction of flood embankments and anti-erosion structures for the protection of riverbanks. Flood cushions have also provided in some reservoirs. However, it has been realized that even though flooding could be reduced using these measures, it was never possible to control floods completely. It is also recognized that these measures are not sufficient to provide permanent protection to all flood prone areas for all magnitudes of floods. Providing protection would involve factors as diverse as the topographic limitations of the region as well as financial investment – and would entail prohibitively high cost of construction and maintenance. In most cases, these measures have proved to be very short-term solutions, and have merely transferred the problem from one region to the other. Apart from interfering with the natural fluvial processes in the region, these embanked areas have developed severe waterlogging problems. Large fertile areas have been destroyed due to drainage congestion and increased soil salinity.

One of the most important geomorphic considerations in understanding the flooding behaviour of the rivers is the channel-floodplain relationship.



On the contrary, flood management is described as a series of actions of regulating the vulnerability, designing of flood mitigation strategies and harmonizing the relationship between human and nature. Some inherent issues for flood managements include review of design parameters of flood control and drainage structures, review and redesign of canal system and pond assessment, and planning for climate change impacts. It is also important that post-project impact assessment of flooding in the floodplains, morphological changes in the peripheral rivers, drainage of storm water and sewage, water pollution in the inside rivers, depletion of groundwater and land use/ land cover changes are accounted for in a sustainable flood management programme. At the time of transformation from agricultural to the modern society, effective 'flood control' strategies are moving towards 'flood management' to meet the expectations of ensuring sustainable development. Further, an effective flood management strategy requires a strong community involvement and ownership approach which in turn assists the community in learning to live with floods. Flood risk mitigation and management is the individual responsibility of the community and therefore there is a need to understand natural systems and processes. Long-term sustainable and strategic flood management approach must respond to changes to the nature and extent of the risk and the level and type of protection desired by the community. At the same time, it should recognize the importance of cost benefit to the community and direct beneficiaries.

Flood control strategies in most river basins in India are primarily embankment-based which have not only influenced the natural flow regime of the rivers and have modified the flood intensity, frequency and pattern but have also created a 'false sense of security' amongst the people living in this region. The construction of barrages and other interventions has aggravated the problem further. Many of the Himalayan Rivers are highly sediment-charged and a major problem has been the rising river bed and reduction in carrying capacity owing to extensive sediment deposition in the reaches upstream of the barrage. The engineering assumption that jacketing the river would increase the velocity leading to scouring has been borne out in most cases and has instead resulted in extensive waterlogged areas and soil salinity. The obstruction of great volumes of water due the construction of a series of protective levees and dykes together with a large sediment flux from the Himalayan catchments has complicated the flooding problem in these rivers. In many cases, large areas have been inundated due to breaches in embankments coupled with rapid shifting of rivers. Apart from the embankments along the river, the unplanned roads and bunds have resulted in severe drainage congestion and channel disconnectivity thereby increasing the inundation period significantly.

Despite an astronomical increase in the expenditure on flood control in India, the recurrence of floods as well as damage due to them has only exacerbated. Floods pose a constant threat to engineering structures and public utilities with their repair/ restoration consuming significant chunks of flood relief and public money. There are also issues of poor planning and non-cognizance of river processes in designing these structures. An important case in this regard is the Kosi river in north Bihar plains. The Kosi river is an important tributary of the Ganga in the eastern India and one of the most distinctive hydrological characteristics of this river is a very high sediment yield (0.43 mt/y/km^2) The 'avulsive' shifts of the Kosi river have been well documented and a preferentially westward movement of 150 kms in the last 200 years has been recorded. Unlike the previous westward shifts, the August 18, 2008 avulsion of the Kosi River recorded an eastward shift of ~120 km which is an order of magnitude larger than any single avulsive shift recorded in historical times. This avulsed channel 'reoccupied' one of the paleochannels of the Kosi and carried 80-85% of the total flow of the river. Since the new course had a much lower carrying capacity, the water flowed like a sheet, 15-20 km wide and 150 km long, with a velocity of 1m/s at the time of breach. Interestingly, the new course did not join back the Kosi nor did this find through-drainage into the Ganga as a result of which a very large area remained inundated/ waterlogged for more than four months after the breach. This single event affected more than 30 million people. The breach of the eastern embankment took place at a discharge of 144,000 cusecs. Although the river channel could handle a maximum discharge of 950,000 cusecs, this point in the embankment was vulnerable for some time prior to the avulsion. The breach was caused primarily by poor strategies of river management, but also due to poor monitoring and maintenance of the embankment making the event partly a human-induced disaster.

Accurate flood hazard mapping is one of the first steps towards sustainable flood management. It can be based on fixed distance from river or bank, past floods or floods of a particular frequency e.g. 100 year flood and area inundated by largest flood recorded. High resolution, and repetitive remote sensing images can provide quick means to map flood hazard zones. These can then be combined with flood frequency analysis and inundation modeling to assign the flood magnitude associated with each zone or even to delineate areas of a particular flood magnitude. Based on this, a relationship between regulatory flood depth and readily measurable stream and/ or drainage basin characteristics can be developed.

In many parts of India large populations live close to the river. Where regulatory floodway and floodway fringe areas are occupied, floodplain regulations may require relocation. A National Flood Insurance Programme for people living in flood prone areas should be taken up. Such a programme could provide insurance cover for flood damage and would discourage people from living near flooding rivers.

A formal audit of the impact of engineering structures in terms of benefits accrued and degradation of natural equilibrium and ecosystem is yet to be taken up for any river system in India. Nevertheless, there is enough information to suggest that present systems have been unsuccessful in reducing flood risk and thus alternative methods must be explored. Flood management now and in the future must focus on a strategy of 'living with the floods' using an ecology based approach

There is enough information to suggest that present systems have been unsuccessful in reducing flood risk and thus alternative methods must be explored.

4.3 Sediment Dynamics and Management

The preceding sections on river dynamics and flood management bring out one strong point that excessive sediment flux of one of the most serious problems to be tackled for several tributaries of the Ganga River, particularly those draining the north Bihar plains such as the Kosi. The example of the Kosi river used in the preceding section once again emphasizes the need for sediment management. One of the serious consequences of the interventions in these sediment-charged rivers is the excessive sedimentation within the channel belt and rise of river bed leading to a series of breaches in the embankment over the years, which have often resulted in large floods. For a sustainable sediment management, it is important to know the spatial distribution of different sediment sources and their temporal variability. In the absence of such knowledge, it is difficult to assess the controlling factors of sediment production and transport – a key parameter for sediment management in rivers.

The understanding of sediment dynamics and its application in river management projects in India is extremely poor and some of the important research gaps include (a) spatial and temporal sediment dynamics in the river basins and (b) the relationship of sediment dynamics with several fluvial hazards resulting from river dynamics and floods. This research requires a highly multi-disciplinary approach ranging from remote sensing and GIS, sediment transport modeling and geochemical signatures (trace element and radiogenic Sr-Nd isotopic ratios) to understand sediment origin at the source, its transport and subsequent deposition elsewhere in the system. We strongly recommend that intensive research on sediment dynamics and management in major river basins of the Ganga system should be initiated very soon.

5. SUMMARY OF RECOMMENDATIONS

A sustainable solution to river hazards – river dynamics as well as flooding - in India needs an integrated approach employing modern techniques such as remote sensing data coupled with DEM, hydrological study and field observations to understand the causative factors of flooding. It is indeed ironic that despite large expenses on flood management, the recurrence of floods as well as flood damages has increased in most flood-prone basins such as north Bihar as noted in the Report of the Second Irrigation Commission. Most floods cause a huge loss of life and property and add to the misery of weaker sections of the society. The loss to the crops every year due to recurring floods is enormous. There are several other ways in which the floods have impacted the economic growth of the region. An astronomical expenditure on the maintenance of embankments every year has proved to be ineffective not only due to inherent characteristics of the rivers but also due large scale malpractices; this expenditure could have contributed significantly to the economic growth of the state. In addition, floods pose a constant threat to engineering structures and public utilities and a large expenditure on flood relief and repair/ restoration of embankments and public utilities uses a significant chunk of public money. There are also issues of bad planning and non-considerations of river processes and dynamics in designing these structures. For example, frequent abandonment of bridges even before they are completed due to river movements reflects a poor understanding of river dynamics, and therefore, has costed heavily to the exchequer of the state. Further, these embankments have blocked the inflowing drainages into the main river thereby resulting in extensive water logging and soil salinity. The seepage from bunds and canals adds to the problem. As a result, a sizable agricultural land has been lost.

River management in India has always been dominated by water allocation (considers rivers as 'conduits' of water) and pollution problems (considers rivers as 'sinks'). There is a strong need to consider rivers as a 'live natural system' meant for supporting not just human civilizations but also a complete eco-system. This means that we need to understand how river functions as a system and how does it maintain the 'dynamic equilibrium'. This is time to move from 'river control' to 'river management' that necessitates the appreciation of the role of geomorphology – the science of form and processes of rivers and the concepts of threshold, lag and complex response in river adjustment. Further, the impact of engineering structures on river systems must be assessed primarily focusing on natural equilibrium and assessment of degradation due to anthropogenic factors; this may include geomorphic assessment of rivers as well as impact on ecosystem. It is high time that we do a cost-benefit analysis (long term) of major interventions in the river basins and their utility in the present context; this should include the benefits accrued as well as the impact on livelihood and ecology. Some specific recommendations may include the following:

1. Basin scale flood-risk maps should be prepared based on scientific data and reasoning; such GIS based, interactive maps may be based on historical data analysis as well as modeling approaches and can be linked to an online data base and flood warning system.
2. Drainage improvement and land reclamation in low-lying areas should be taken up on an urgent basis; several successful case histories are available from different parts of the world but they need to be taken up systematically.
3. Assessment of soil salinity and mitigation strategy is an important task ahead and this may include the use of salinity resistant crops as well as soil improvement practices.
4. Alternatives to embankments for flood management with an emphasis on 'living with the floods' concept must be emphasized; this may include floodplain zoning and other non-structural approaches. There is an urgent need for a wide section of people from academia, governmental organizations, NGOs, social institutions and the society at large to get together to fight out the evils that are plaguing the flood management policies in the country.
5. Sediment dynamics and its application in river management projects form very important areas of future research for designing sustainable river management startegies. A classic case study could be the Kosi basin, which is one of the highest sediment load carrying river in the Ganga basin and is also flood-prone.

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GANGA RIVER BASIN MANAGEMENT PLAN

(GRBMP)

MISSION 8: ENVIRONMENTAL KNOWLEDGE-BUILDING AND SENSITIZATION

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

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ABBREVIATIONS AND ACRONYMS

1. **AK** : Available Potassium
2. **AP** : Available Phosphorous
3. **C/N** : Carbon : Nitrogen Ratio
4. **EU** : European Union
5. **GDP** : Gross Domestic Product
6. **GRBMP** : Ganga River Basin Management Plan
7. **IITC** : IIT Consortium
8. **MoEF** : Ministry of Environment and Forests
9. **MoEF&CC** : Ministry of Environment, Forests & Climate Change
10. **MoWR** : Ministry of Water Resources
11. **MoWR, RD&GR**: Ministry of Water Resources, River Development and Ganga Rejuvenation
12. **NFM** : Natural Flood Management
13. **NGRBA** : National Ganga River Basin Authority
14. **NMCG** : National Mission for Clean Ganga
15. **NRGB** : National River Ganga Basin
16. **SOM** : Soil Organic Matter
17. **SOC** : Soil Organic Carbon
18. **WWTP** : Waste Water Treatment Plant

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 aspects were factored in to assess the basin's resource dynamics. Basin planning and management combine diverse natural resources (water resources, land resources, biological resources, etc.) and processes (river dynamics, geological phenomena, atmospheric processes, etc.) with traditional wisdom and grassroots knowledge. Hence, it is necessary to build a comprehensive data bank to enable meaningful analyses and obtain quantitative indicators of NRGB's status. Moreover, since NRGB's welfare needs the co-operation and help of both formal and informal sectors of society, the data bank should be accessible to citizens to enable people's participation in the overall upkeep of NRGB. To adequately inform and sensitize stakeholders, the data bank also needs to be complemented with community-specific educational material and programmes on NRGB's environment. The main measures recommended are: (i) Establishment of a comprehensive Data Bank by continuous collection, processing and storage of information on natural resources, anthropogenic activities, and environmental monitoring data of the basin; (ii) Preparation of secondary results (charts, tables, etc.) based on primary data; (iii) Preparation of documents and materials for easy understanding by non-specialized people; (iv) Keeping all the above information in open domain for easy access by all interested individuals and institutions; and (v) Conducting workshops and educational campaigns with various stakeholders and interested citizens to enable their comprehensive understanding of basin processes and take meaningful action.

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 a seven-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 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 objectives of Mission "Environmental Knowledge-Building and Sensitization" are: (i) to synthesize environmental knowledge pertinent to the National Ganga River Basin, the anthropogenic factors affecting NRGB, and the remedial measures available to counter negative (resource-depleting) effects; and (ii) to disseminate such knowledge and sensitize stakeholders to enable their meaningful participation in NRGB's upkeep.

3. WHY ENVIRONMENTAL KNOWLEDGE-BUILDING AND SENSITIZATION IS IMPORTANT FOR GANGA RIVER BASIN MANAGEMENT

The National Ganga River Basin covers a large and diverse geo-climatic region that is both highly populated and home to a wide range of ecosystems. The consequent diversity of ecosystem services that goes into the making of a healthy NRGB is thus also subject to a variety of human influences, resulting in a complex web of ecosystem-human interactions that has caused significant environmental degeneration of the basin in recent times. Hence it is imperative to synthesize the entire gamut of ecosystem processes and human-environment interactions prevalent in NRGB in order to comprehensively restore and regenerate the basin. Moreover, the entire population of NRGB constitutes stakeholders that are served by the ecosystem goods and services of the basin and whose quality of life depends on the basin health. Thus it is also important to gather relevant information from stakeholders, disseminate available knowledge in the public domain, and enable meaningful participation of stakeholders in sustained upkeep of the basin.

4. ENVIRONMENTAL DATA BANK AND KNOWLEDGE-BUILDING FOR NRGB

Diverse human activities and developmental pressures have affected NRGB's environment in complex ways which need continuous monitoring and in-depth understanding of their linkages. Such understanding is dependent foremost on building a comprehensive bank of environmental data to help arrive at quantitative indicators of the state of the basin and its changing status with some degree of certainty. The importance of such a data bank has been repeatedly stressed by various agencies and experts. For water resources data such recommendations include the World Bank Report titled "India's Water Economy" [Briscoe and Malik, 2006], India's "Comprehensive Mission Document on National Water Mission – 2011" [MoWR, 2011], "National Water Policy – 2012" [MoWR, 2012], WWC's "Better Water Resource Management" [Sadoff and Muller, 2009], SANDRP's "Water Sector Options for India in Changing Climate" [Thakkar, 2012], UNICEF's "Water in India: Situation and Prospects" [UNICEF, FAO and SaciWATER, 2013], United Nations' "Water Security and the Global Agenda, 2013" [UN University, 2013], etc. Similar recommendations for other types of natural resource data pertinent to basin management include DST's "National Resource Data Management System (NRDMS)" brochure [DST, undated], Gundimeda et al. [2007], ICAR's "Vision 2030" document [ICAR, 2011], and Lenka, Lenka & Biswas [2015].

The government's "River Basin Plan Guidelines" [CWC, 2007] may be cited here as an example of water-related data needed for water resource planning:

"The exact data requirement will vary depending upon the particular study environments and approach chosen. In general, the data normally needed would be of the following category:

1. Topographical data such as topographical maps, aerial photographs etc.

2. Hydrological data such as stream flow, snow data, watershed characteristics, sediment inflow rate, duration of flooding for various reaches of rivers.
3. Meteorological data such as rainfall, evaporation, temperature, etc.
4. Geo-hydrological data such as aquifer characteristics, ground water elevation, etc.
5. Water quality data for both surface and ground water including sources of pollution and related information.
6. Environmental data such as flora, fauna, historical monuments, wildlife sanctuaries, fisheries etc.
7. Land resources data such as land use, soil survey, land classification, etc.
8. Agricultural data such as cropping pattern, crop water requirement, etc.
9. Demographic data including urban and rural distribution, grouping by age, sex, etc.
10. Power demand survey data including alternative sources available, demand centres, etc.
11. Natural disaster data primarily for flood and droughts. These include disaster-prone areas, damage statistics, mitigation measures, etc.
12. Seismic data, especially in the vicinity of probable storages and structures.
13. Industrial data especially for those which are water-intensive. The data include growth trends, water consumption, possible alternate sources etc.
14. Inland water navigation data such as demand, alternate transport system available, etc.
15. Data on recreational prospects related to water resources development.
16. Data on projects in the basin such as completed and on-going projects and their water consumption (planned as well as actually utilized), potential projects identified including reconnaissance reports for major and medium projects. Data on flood control works carried out in the past and their performance.
17. Drainage works executed, evaluation. Data on drainage congestion problems including near the confluence point of tributary/sub-tributaries with main river, behind of the embankment system due to continuous high stage of Main River.
18. Geologic data such as formations, mineral deposits etc.
19. Economic data related to project/plan evaluation.
20. Financial data such as those required for financial feasibility analysis and also data on sectoral allocation of plan outlays, etc.

21. Legal constraints such as inter-state/international agreements and tribunal awards.
22. Social environment such as water-related institutions, interest groups, public awareness.

Apart from these data, the change in the food intake pattern, virtual export of water, in terms of food grain export from surplus to deficit water basin/sub basin, is also the growing concern of the planners."

While the above list is recommended for river basin water resource management, much of the data may not be available at all with government bodies. As noted in IITC's hydrology report [IITC, 2014b], many basic data needed for hydrological analyses, such as precipitation data for higher elevation areas, dam operations (inflows, storages and releases), canal water diversions, and crop irrigation, were unavailable from government agencies. Likewise, data available on sediment concentrations in the Ganga river network are very limited rivers [IITC, 2015a]. It should be also noted here that the above list comprises only broad categories of data, while the actual data needed must meet their specific spatial and temporal resolutions. This is because the specific body of data needed for each type of data will depend on the intended analyses and the parameters of interest to be derived from them. Some redundant data is also often desirable – both to cross-check the data of primary interest and to enable other analyses that may be needed in future. Examples of some basic results covering mostly water quantity and quality aspects in different spatial and time domains are cited below for the Danube River Basin – an international river basin of Europe – in Figures 4.1 to 4.5 and Tables 4.1 to 4.4 [ICPDR, 2005]. These results indicate the wide variety and extent of data requirement even for a broad overview of a river basin.

While the list of data needed is recommended for river basin water resource management, much of the data may not be available at all.

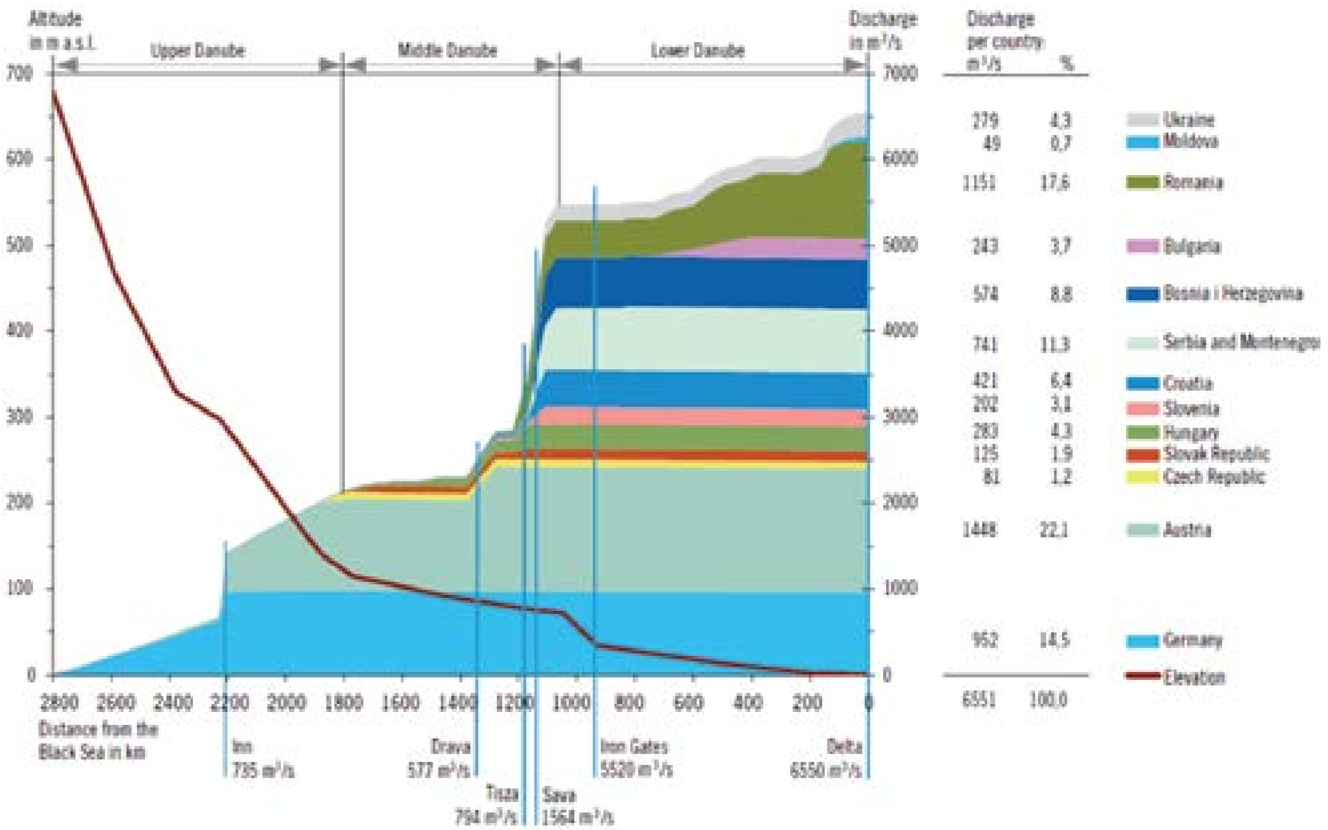


Figure 4.1: Longitudinal Profile of River Danube and Contribution to Danube River Flow from each Country of the Danube Basin during 1994–1997 [ICPDR, 2005]

Table 4.1: Significant Point Sources of Pollution in the Danube River Basin [ICPDR, 2005]

		DE	AT	CZ	SK	HU	SI	HR	BA	CS	BG	RO	MD	UA
Municipal Point Sources:	WWTPs	2	5	1	9	11	3	10	3	4	6	45	0	1
	Untreated Wastewater	0	0	0	2	1	3	16	15	14	31	14	0	0
	Industrial point sources	5	10	10	6	24	2	10	5	14	5	49	0	5
	Agricultural point sources	0	0	0	0	0	1	0	0	0	0	17	0	0
	Total	**7**	**15**	**11**	**17**	**36**	**9**	**36**	**23**	**32**	**41**	**125**	**0**	**6**

** Two of these water bodies are shared by SK and HU*

Table 4.2: Population (%) Connected To Wastewater Treatment Plants in Different Countries of the Danube River Basin [ICPDR, 2005]

	Total (in%)	Primary treatment (in%)	Secondary treatment (in%)	Tertiary treatment (in%)
Austria	86ᵃ	1ᵇ	17ᵇ	64ᵇ
Bosina i Herzegovina	na	na	na	na
Bulgaria	38ᵃ	1ᵃ	37ᵃ	0ᶜ
Croatia	na	na	na	na
Czech Republic	68ᵃ	na	62ᵈ	na
Germany	91ᵇ	1ᵇ	6ᵇ	83ᵇ
Hungary	32ᶜ	2ᶜ	24ᶜ	6ᶜ
Moldova	na	na	na	na
Romania	na	na	na	na
Serbia and Montenegro	na	na	na	na
Slovak Republic	49ᵇ	na	na	na
Slovenia	30ᵈ	15ᵈ	15ᵈ	0ᵈ
Ukraine	na	na	na	na

a: 2001; b: 1998; c: 2000; d: 1999

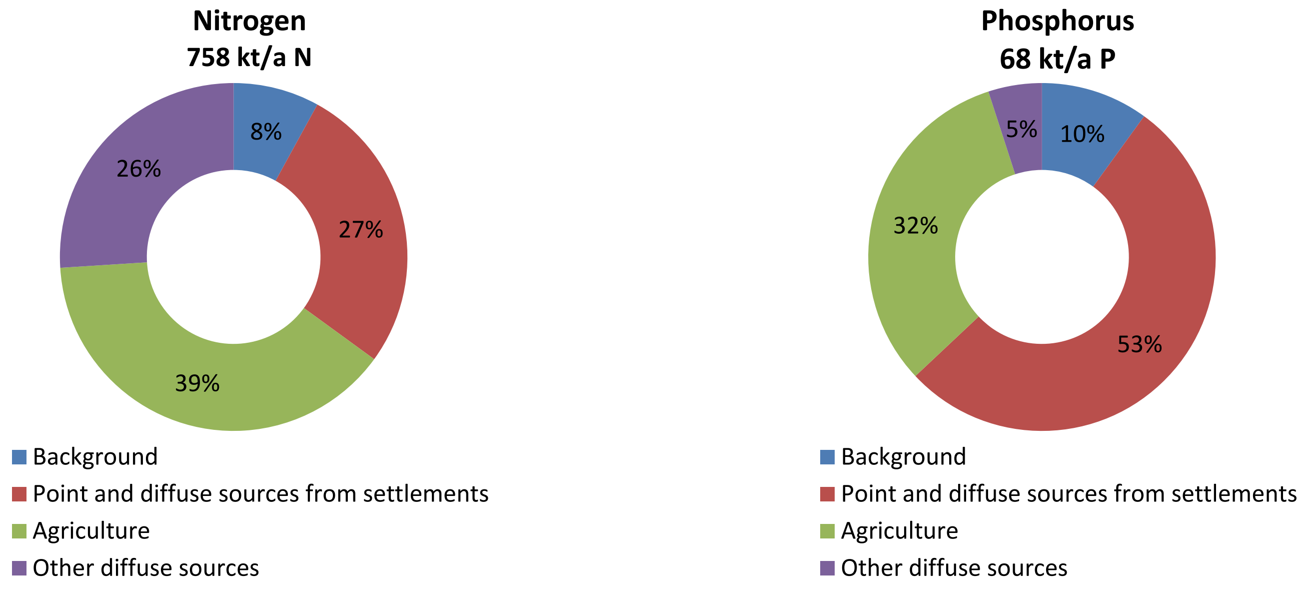


Figure 4.2a: Total N & P Emissions by Human Sources in Danube River Basin during 1998–2000 [ICPDR, 2005]

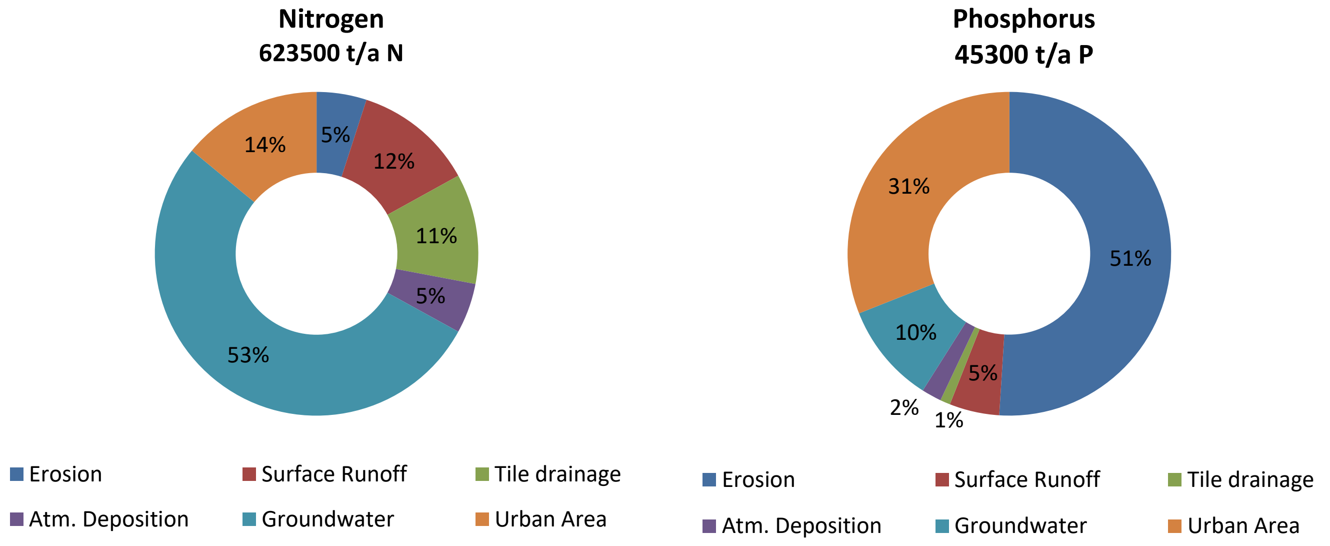
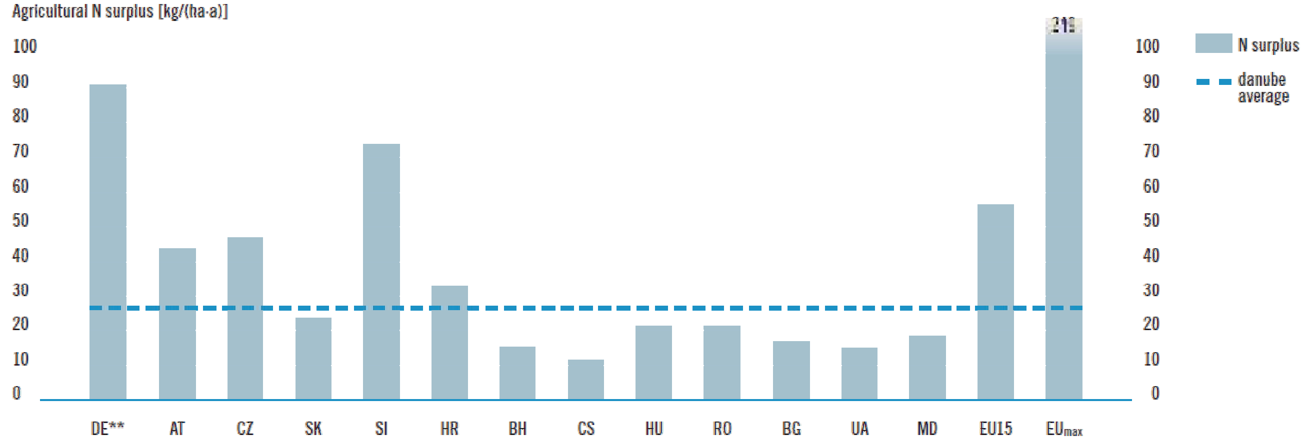


Figure 4.2b: Diffuse N & P Pollution Emissions by Pathways in the Danube Basin during 1998–2000 [ICPDR, 2005]



* *Data sources: SCHREIBER et al. (2003), based on data of FAO and national statistics for the German "Bundesländer";*
data source for EU15 and EU_{max}: FAO (2004). The data of these sources are not directly comparable, but give a general indication.

Figure 4.3: Nitrogen Surplus per Unit Agricultural Area in the Danube Countries during 1998–2000 [ICPDR, 2005]

Table 4.3: Pesticide Consumption in Some Danube Countries in 2001 [ICPDR, 2005]

	DE	AT	CZ	SK	HU	SI	RO
Pesticide Category Sources:	t/a	t/a	t/a	t/a	t/a	t/a	t/a
Fungicides and Bactericides	7,912	1,336	1,050	537	1,637	921	2,802
Herbicides	14,942	1,436	2,590	2,136	3,149	362	3,960
Inorganics	1,959	99	272	0	684	504	0
Insecticides	1,255	0	157	175	298	81	1,110
Rodenticides	80	1	162	34	20	19	0
Total	**26,148**	**2,872**	**4,231**	**2,882**	**5,788**	**1,887**	**7,872**
Pesticide Consumption	kg/ha-a	kg/ha-a	kg/ha-a	kg/ha-a	kg/ha-a	kg/ha-a	kg/ha-a
Specific Pesticide consumption per ha agricultural area and year	1.53	0.82	0.99	1.18	0.94	3.77	0.53

**according to the FAO database on agriculture*

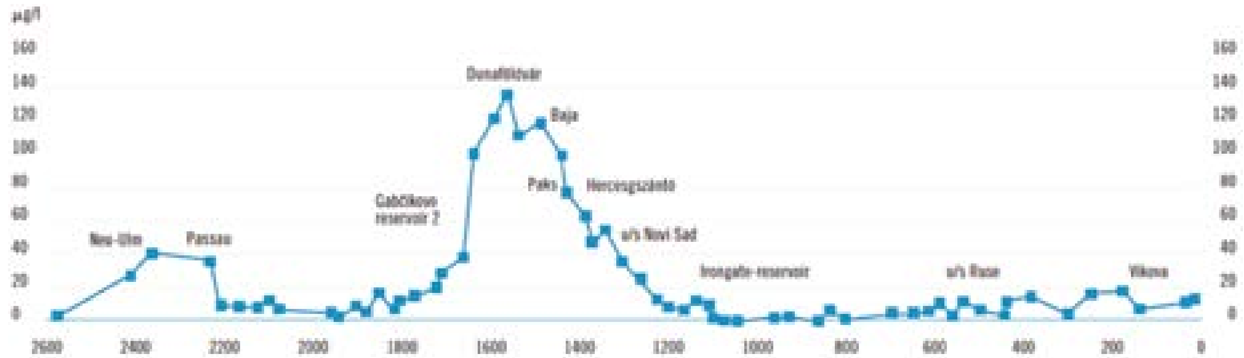
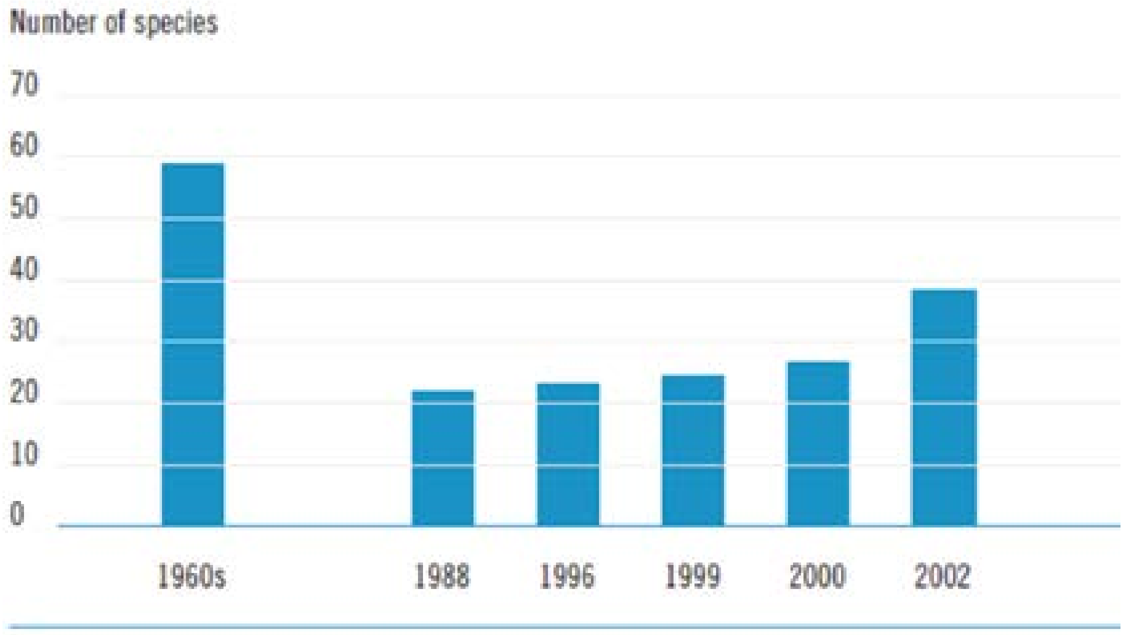


Figure 4.4: Chlorophyll Concentrations in River Danube at Different Locations during 1998–2000 [ICPDR, 2005]

Table 4.4: Annual Mean Saprobic Index Based on Phytoplankton during 1997–2000 [ICPDR, 2005]

	Saprobic index (phytoplankton)			
D-Danube site (rkm)	**1997**	**1998**	**1999**	**2000**
R001-Bazias (1071); D	2,03	1,86	1,83	2,06
R002-Pristol/Novo Selo; D Harbour (834)	2,12	1,92	1,88	
R004-Chiciu/Silistra (375); D	2,07	2,02	2,08	1,96
R005-Reni-Chilia/Kilia arm; D	2,08	2,11	2,11	2,17
UA01-Reni-Chilia/Kilia arm; D				
R006-Vilkova-Chiliaarm/Kilia; D arm		2,08	2,06	2,17
R007-Sulina-Sulina arm; D			2,05	2,13
R008-Sf.Gheorghe arm; D Gheorghe arm			2,03	2,32



10 stations on 3 transects off Constanta, data from C. Dumitrache, IRCM Constanta

Figure 4.5: Number of Macro-Benthic Species In Front of the Danube Delta [ICPDR, 2005]

For river basin management it should be clearly noted that the data types listed above are required mainly for water resource management in the basin [CWC, 2007; CWC, 2010]. For comprehensive environmental management of NRGB, the data needs are much more – especially those pertaining to other natural resources such as soils, nutrients and biota, as well as those of harmful substances and wastes. Among non-material substances, energy is an important resource for inclusion. Many forms of energy abstracted for anthropogenic needs are also needed by ecosystems – especially renewable energies such as solar energy, wind energy, hydropower and tidal energy, but also other forms of energy that may readily available to ecosystems such as geothermal energy (e.g. by hot springs). However, many other commercial resources (such as fossil fuels) and commercial minerals are often ecosystem-neutral. Naturally, inclusion of environmentally significant biodiversity, soils, nutrients and energy resource data and related anthropogenic activities will increase manifold the data requirement of a basin. In fact, many data needs other than those of water resources have been highlighted by various agencies and experts such as DST [undated], EEA [2011b], Gundimeda et al. [2007], ICAR [2011], Lenka, Lenka & Biswas [2015] and SLUSI [undated] for purposes that overlap with basin management needs.

To illustrate the data needs of natural resources other than water, the ICAR Vision Declaration [2011] for sustainable agricultural growth by 2030 in India may be cited. The ICAR document emphasizes the improvement of "knowledge management system to act as an efficient clearing-house of technology, knowledge and information in agriculture and allied sectors." Such a system would obviously need an exhaustive information bank to be effective. Such information may also need spatial analysis and be easily comprehended by spatial representation. For instance, land degradation has significant implications for agriculture as well as for NRGB's overall status. Thus land degradation maps can clearly indicate the considerable degradation in different states of NRGB, vide sample results for two states [ICAR, 2010] shown below.

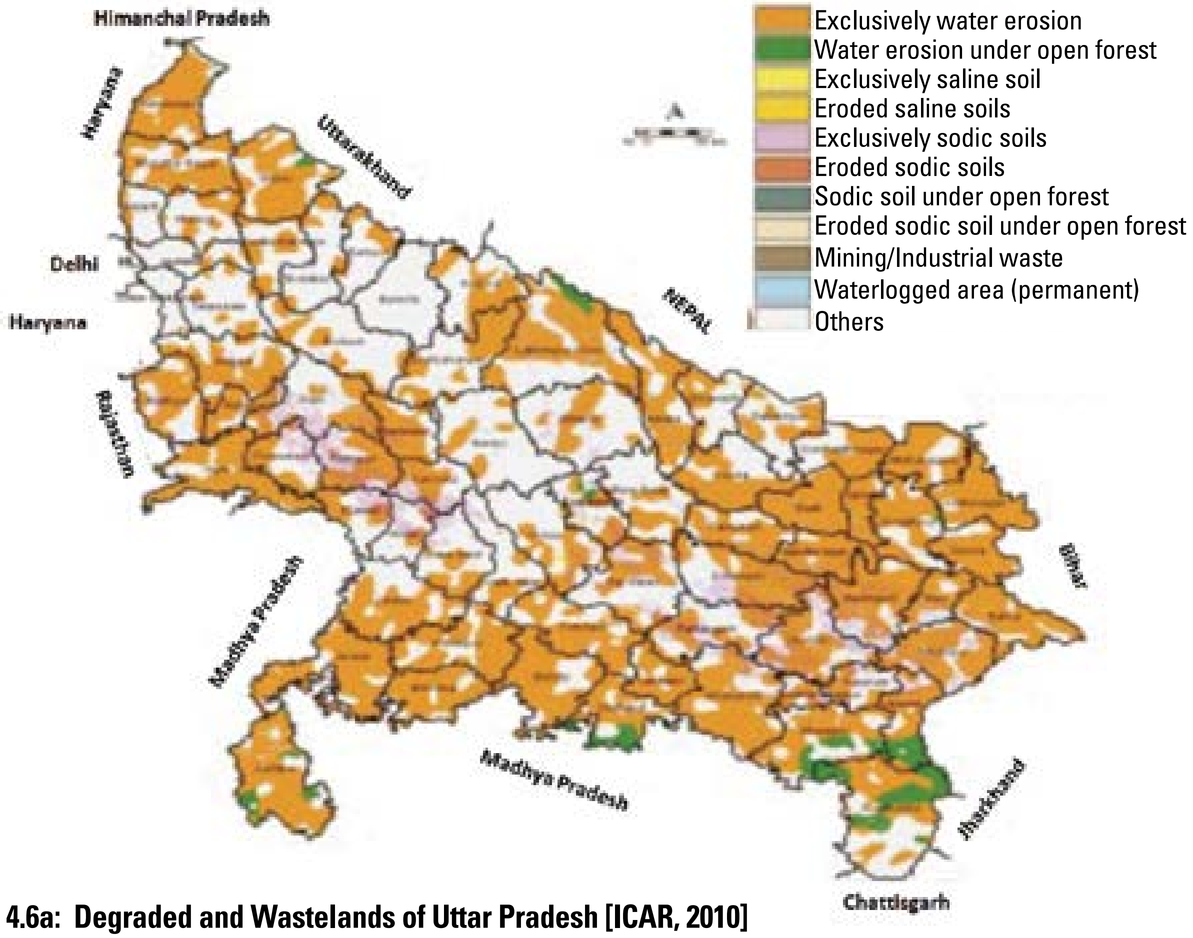


Figure 4.6a: Degraded and Wastelands of Uttar Pradesh [ICAR, 2010]

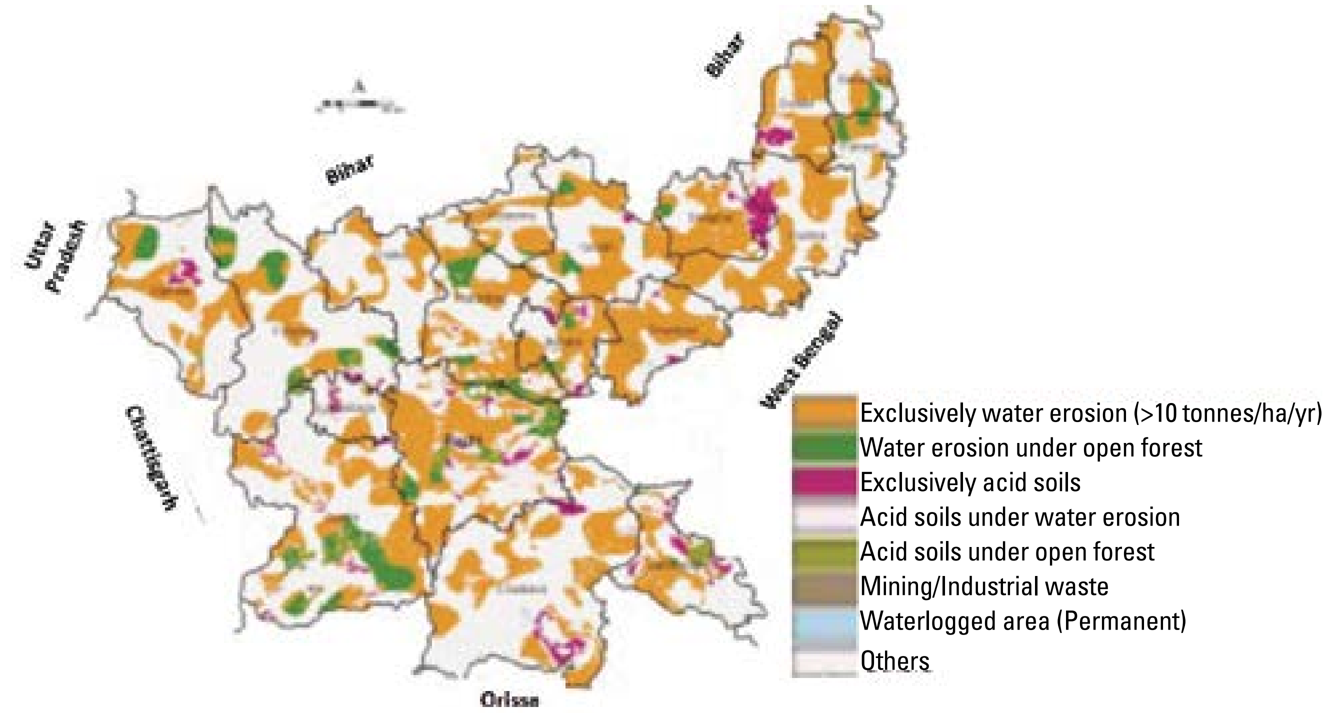


Figure 4.6b: Degraded and Wastelands of Jharkhand [ICAR, 2010]

While the above figures give only a broad overview of state-wise land degradations, a much finer resolution may be needed in field-level planning of land improvements and assessing the impacts on water bodies. SLUSI [undated] proposes to attempt such detailed Land Degradation Maps and Tables. For comprehensive basin data handling the National Spatial Data Infrastructure – 2006 [DST, undated] initiated by the government may provide a useful geo-spatial data management system. But the foremost task would be to systematically collect the data needed.

In sum, while there is considerable data collection by national and state agencies focussing on specific themes such as water resources, forest resources, agriculture, industry, land-use, etc., comprehensive management of NRGB needs the integration of disparate groups of data into a cohesive whole. Planning and management of NRGB must combine diverse fields such as water resources, land resources and biological resources (plus energy and other extractable resources) with fluvial dynamics, geological phenomena and atmospheric processes as well as grassroots knowledge and traditional wisdom – the experiential essence of generations of people – to account for NRGB's interactions with human activities. For, until all relevant data are brought together and made easily available, the planning, monitoring and maintenance of NRGB can only be a fickle endeavour. But important data needs – even for natural resources – are presently unavailable. For instance, apart from the paucity of water resources data mentioned earlier, data on biodiversity of River Ganga are available only "in fragments in geospatial terms" and "in different time domain and isolated stretches" of the river [IITC, 2014a]. Likewise, there is limited information on pesticides and heavy metals loading in the Ganga river system and quanta of anthropogenic pollution of rivers through municipal sewage, industrial effluents and solid wastes [IITC, 2015b].

> **Planning and management of NRGB must combine diverse fields such as water resources, land resources and biological resources as well as grassroots knowledge and traditional wisdom – the experiential essence of generations of people – to account for interactions with human activities.**

To start with, therefore, the actual data available with various central, state and private agencies should be collected and compiled in a single environmental data bank. The additional data needs should be then identified and a program for such data collection initiated. Over time, the data bank must be developed into a multi-dimensional archive with historical and regularly collected basin information, intermittent monitoring data, as well as specific observations and interpretations covering a wide and eclectic data field to transform it into an open-ended knowledge system. For only such knowledge systems can fulfil NRGB's developing needs as envisioned, for example, in the European Environment Agency's "Forward-Looking Information and Services (FLIS)" whose primary aim is to "introduce forward-looking components and perspectives into existing environmental information systems to expand the knowledge base" [EEA, 2011].

5. ENVIRONMENTAL SENSITIZATION FOR NRGB

The proposed Environmental Knowledge Bank (or Data Bank) combining comprehensive basin data, their significant parametric, tabular and graphical representations, relevant scientific reports, and meaningful individual observations will cater to various users – not only to specialised analysts, researchers and policy-makers, but also to other NRGB residents (ordinary stakeholders) whose well-being depends considerably on the basin status and whose interactions with basin processes may be significant. Thus, there is a need to make the Data Bank accessible to all stakeholders and hence organize it in an easily searchable and retrievable format. While the need to access the Data Bank by professional users – such as government agencies, private industry and research institutions – can be easily anticipated from their institutional functions, the needs of common stakeholders of NRGB are less well defined. The difficulty in pinpointing the needs of common stakeholders is because their interactions with NRGB occur in a great variety of ways depending on their locations, professions, life-styles and cultural traditions. But it is also because of these variations that they can play a significant role in reversing the NRGB degradation processes if equipped with proper understanding and knowledge of pertinent environmental processes. For, just as good road sense depends on knowledge of "traffic rules", knowledge of "environmental rules" (or environmental processes) is essential for meaningful contribution to NRGB. Moreover, since basin-wide monitoring would be needed in NRGB and since environmental concerns are always open to fresh insights, much can be gained from sensitizing people and motivating them to participate in the monitoring and environmental upkeep of NRGB. Such sensitization can be achieved by complementing the environmental data bank with target-specific educational and training material on NRGB's environment for community education and sensitization.

In attempting to inform and sensitize the common stakeholder, a key point to be disseminated is the spatial and temporal linkages between various natural resources in the basin. The EEA monograph on "Sustainable use and management of natural resources" {EEA, 2005] may be cited here though it is based on a regional perspective and not from a river basin perspective. The report focuses on only a handful of natural resources of commercial value, namely fisheries, forestry, water, fossil fuels, metals and construction minerals, and land use (and excluding the environmental impacts of agriculture). But it throws meaningful light on the anthropogenic impacts of extraction of these resources. Thus, it reports that with "total material consumption in industrialised countries between 31 and 74 tonnes/person/year largely for housing, food and mobility" there is considerable pressure on natural resource and on sinks for harmful wastes (from domestic and industrial wastes and mining) in the European Union. However, the GDP growth rate significantly exceeds the growth rate in weighted material consumption, vide Figure 5.1. Regarding water resource, the water consumption of the region was found to be gradually decreasing since 1990, except for agricultural water consumption, vide Figure 5.2. The pollutant loads in European rivers also showed essentially decreasing trends (vide Figure 5.3), suggesting effective control on anthropogenic pollution of rivers. For land use, a significantly increasing trend of built-up areas was observed (due to urbanisation and infrastructure development), leading to significant sealing of land surface (vide Figures 5.4 and 5.5 and Table 5.1). But soil erosion (mainly water erosion) and contamination were also caused by certain land uses. While agricultural impacts on natural resources may not have been estimated, some key impacts were identified, vide Table 5.2. The composite effects of various processes on local contamination were also identified as shown in Figure 5.6. Overall these results illustrate some key factors of natural resource management that are likely to have significant implications for river basins.

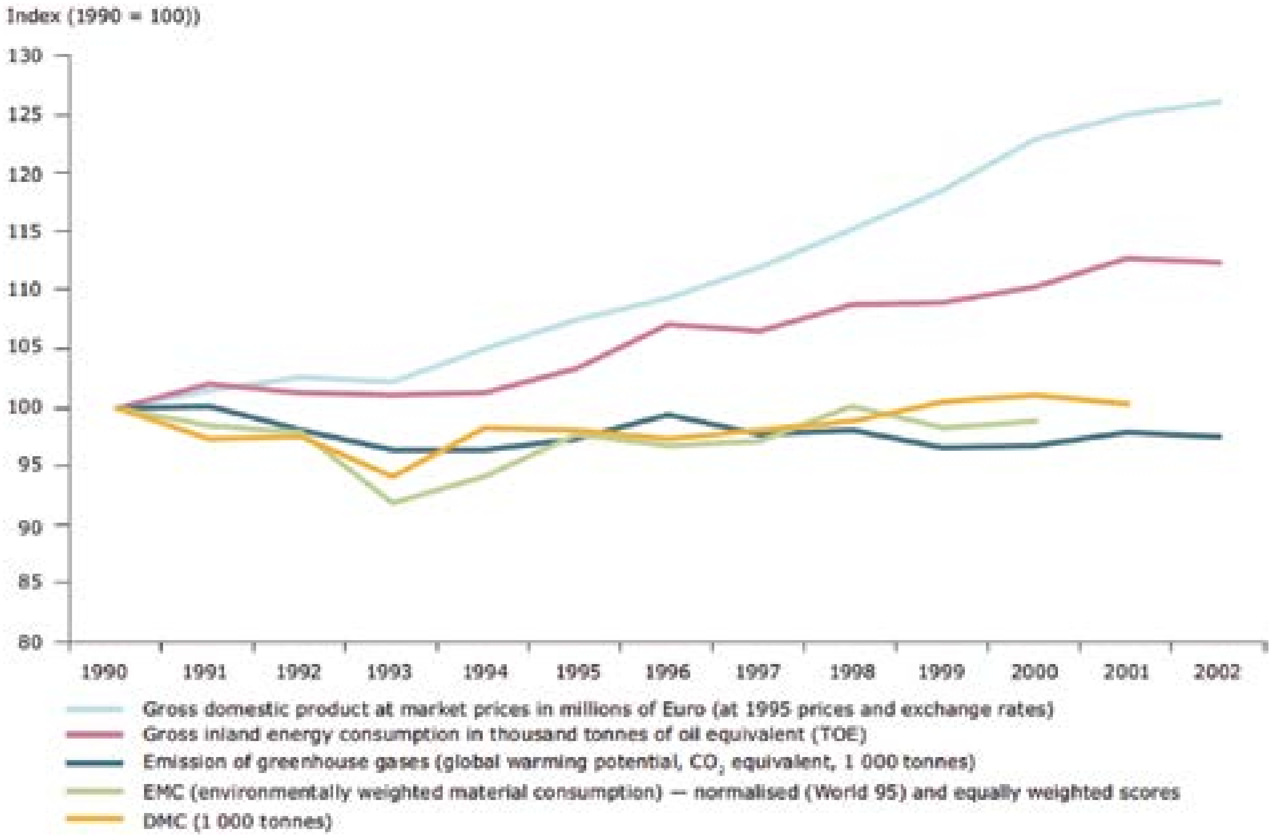


Figure 5.1: Comparison of Growth in GDP and Resource Use in EU-15 Countries [EEA, 2005]

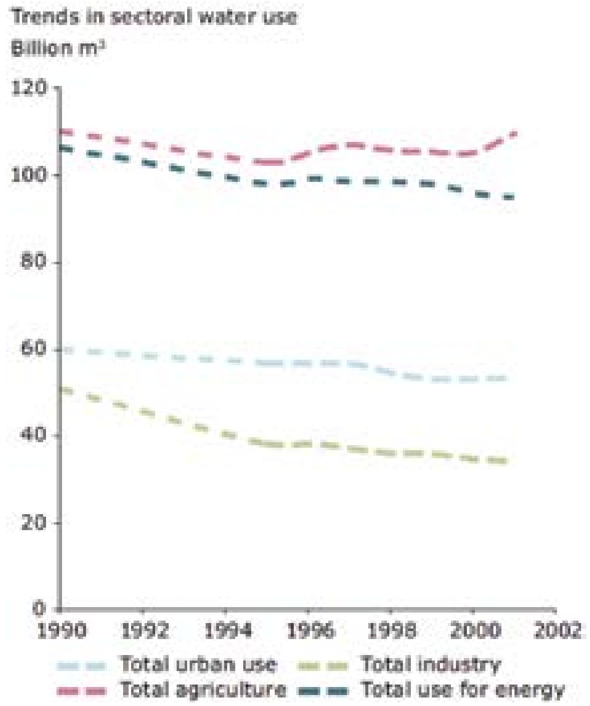


Figure 5.2: Trends in Sectoral Water Use in Europe [EEA, 2005]

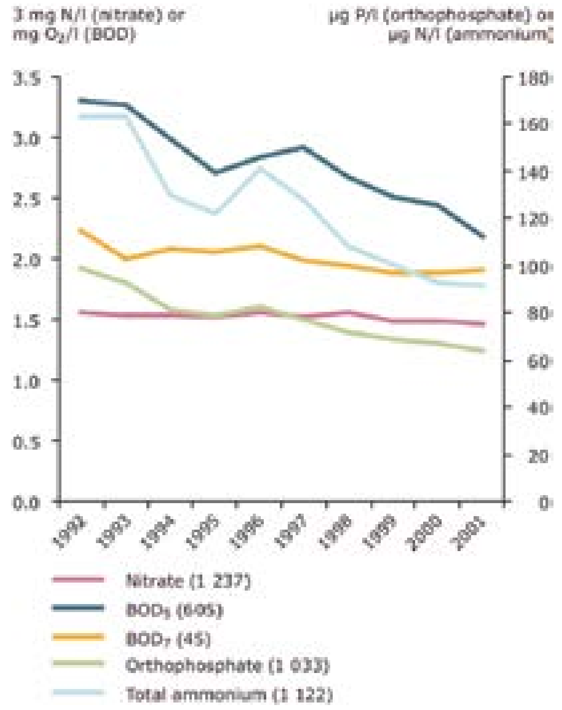


Figure 5.3: Concentrations of Some Pollutants in European Rivers between 1992 and 2001 [EEA, 2005]

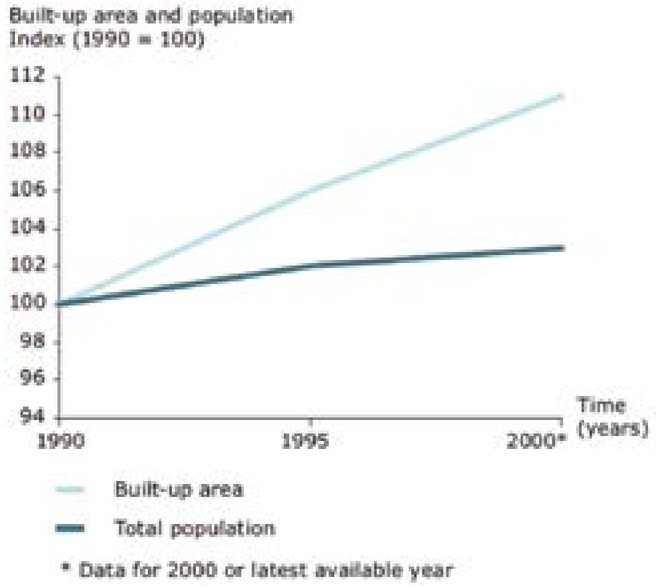


Figure 5.4: Built-Up Land in Relation to Population [EEA, 2005]

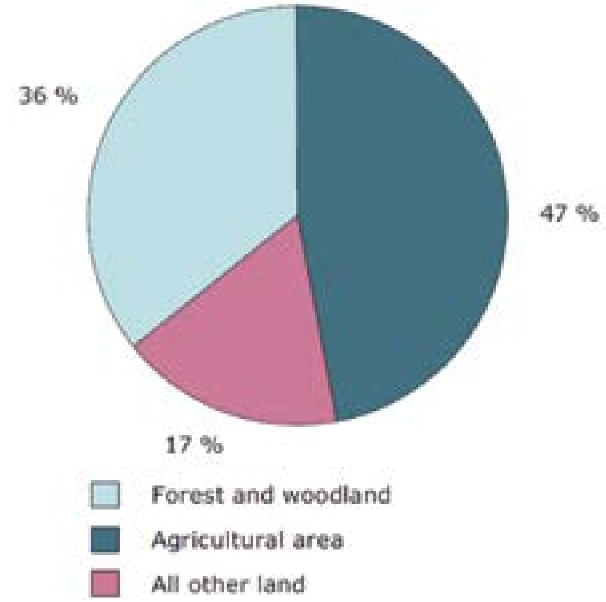


Figure 5.5: Land Use in EU-15 Countries [EEA, 2005]

Table 5.1: Soil sealing and land use [EEA, 2005]

In 2000, the rate of increase in areas for settlements and infrastructure in Germany was a staggering 130 ha per day. This fell to 93 ha per day in 2003 due to economic conditions. Settlements account for about 80% of this growth and transport infrastructure for the remaining 20%. About half of this area, equivalent to eighty football fields per day, is effectively sealed. In the 2002 Sustainability Strategy, the German government set the target of reducing the increase of areas for new settlements and infrastructure to a maximum of 30 ha a day by 2020.

Source: Federal Government of Germany, 2003.

Table 5.2: Land use for agriculture [EEA, 2005]

Agriculture uses soils and water as a resource for food production, and at the same time impacts these resources. The impact of agriculture is demonstrated by the fact that more land has been converted to cropland since 1945 than in the eighteenth and nineteenth centuries combined. The extent and causes of the environmental impacts of agriculture, notably by arm and crop type, vary significantly across Europe. Nevertheless, the continuing search for efficiency, lower costs and increased scale of production is resulting in substantial pressures on the environment, landscapes and biodiversity, particularly in the most intensively farmed areas. At the same time, agriculture remains essential to the maintenance of many cultural landscapes.

Agricultural production throughout the continent continues to rely on non-farm resources such as inorganic fertilisers and pesticides. However, there has been a decline in the use of these resources and, particularly in Eastern Europe, a reduction in the pressure on the environment. Recent shifts to environmentally-friendly production systems are apparent, for example to organic production or conservation tillage systems. Organic framing covered about 4 % of the total agricultural area of the EU-15 in 2003. The development of certified organic farming in other European regions still lags significantly behind this figure.

In terms of resource conservation the most important impacts of arable and livestock production are those relating to soil erosion and nutrient leaching, respectively. Soil erosion is particularly severe in the Mediterranean region and parts of eastern Europe, and increases with share of arable land of total land use, mitigated by physical background factors (slope, soil type rainfall patterns) and farming practices. Nutrient leaching is caused where the application of livestock manure and mineral fertilizers exceeds the nutrient demand of crops. The highest nutrient surpluses are found in areas of intensive livestock production, particularly in north-western Europe.

While agriculture can exert significant pressure on the environment, It Is Itself subject to negative environmental Impacts linked to air pollution and urban development. Soil sealing by transport or housing infrastructure eliminated many thousand hectares of agricultural land every year, particularly in western Europe.

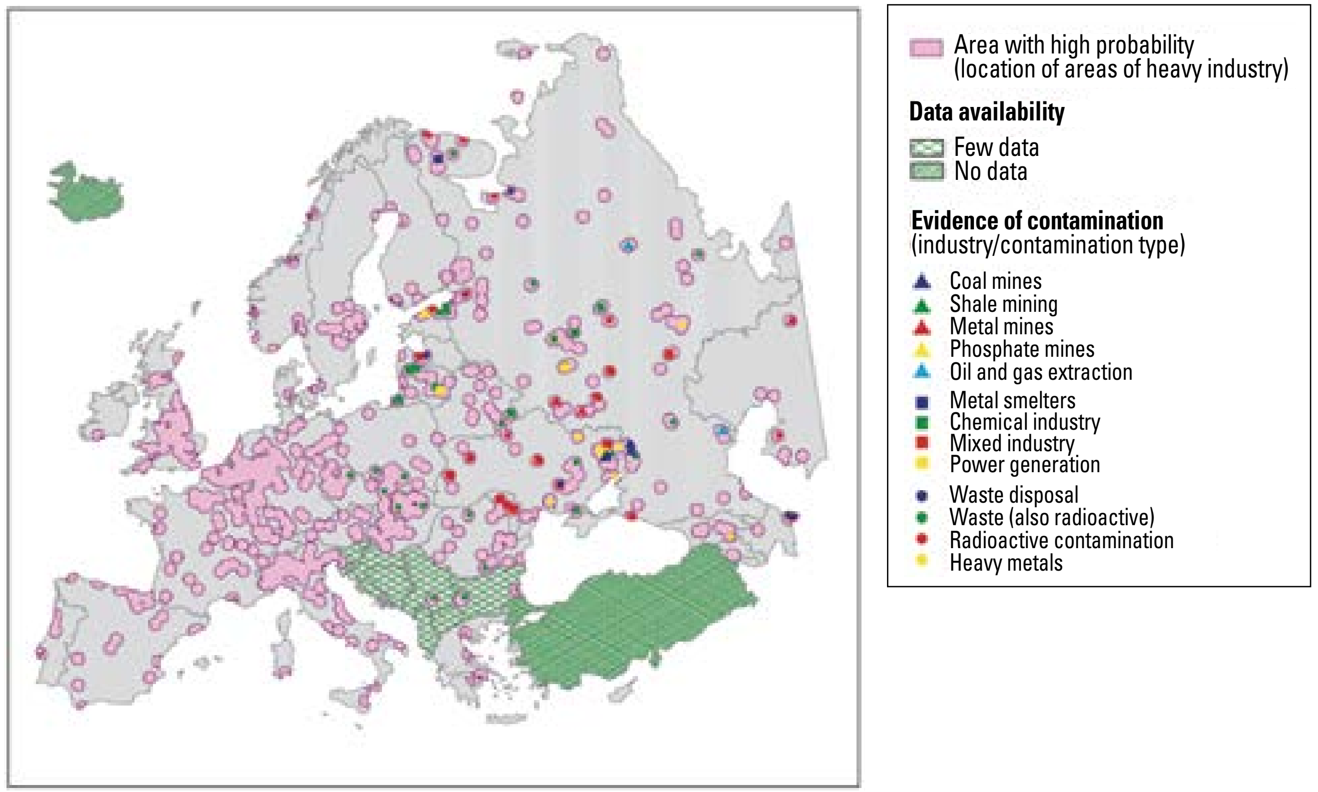


Figure 5.6: Probable Problem Areas of Local Contamination in Europe [EEA, 2005]

While results such as the above presented for NRGB can be useful for advanced users and policy-makers, the common stakeholders' sensitization would depend more upon informing them about ground-level processes and results suitable for their active participation. The first three chapters of Main Plan Document and the Mission Reports of GRBMP can provide useful material to inform and sensitize common stakeholders. For specific community actions to be carried out on the ground such as monitoring of water bodies or rejuvenation of the basin's ecosystems, specific material and information fine-tuned to such tasks need to be created. For example, flood damages to human life and property are a recurring feature in several sub-basins of National River Ganga. While large-scale engineering measures have their drawbacks and potentially negative impacts on ecosystems (as discussed in Mission "River Hazards Management" and Mission "Basin Protection Against Disasters"), they are beyond the control of ordinary citizens. However, Natural Flood Management (NFM) can involve the populace to minimize flood damages

without compromising the ecosystem services of sub-basins. Some basic material on NFM in Scotland may be cited in this regard. The NFM approach to increase water infiltration and storage and to decrease soil erosion and flow velocities, identifies the following key techniques [Johnson, Watson & McOuat, 2008]:

1. Reforestation of upland hill-slopes.
2. River channel restoration, especially restoration of channel meanders.
3. Restoring wetlands and enhancing floodplain storage.
4. Agricultural modifications, especially to increase soil infiltration rates.
5. Planting dense woodlands in gullies and watercourses.
6. Enhancing riparian vegetation.

The practical application of NFM is briefly explained for ordinary rural stakeholders through a poster with short, boxed texts as cited below [RSPB, undated].

Natural flood management presents a shift from our predominantly piecemeal and reactive approach to flooding towards a strategic, catchment-based approach. Natural flood management is achieved by:

- Adopting a strategic, source to sea (catchment) approach
- Protecting and using natural systems and habitats
- Promoting soft engineering techniques.

CATCHMENT-SCALE PLANNING

- Consider the whole catchment from source to sea.
- Ensure better co-ordination of flood management by local authorities, individual landowners and farmers.
- Use river basin management plans to provide a strategic forum to consider natural, sustainable flood management.
- Encourage neighbouring farmers to work together for more coherent management.

PROTECTING AND USING NATURAL SYSTEMS AND HABITATS

- Restore bogs and keep them healthy so they retain water.
- Manage uplands to reduce run-off and erosion.
- Protect and restore natural floodplains both inland and at coasts.
- Use natural forests to store water and slowly release it back into rivers.
- Use wetland habitats such as bogs, fens and saltmarsh to soak up water and release it slowly back into rivers.

WETLAND WILDLIFE BENEFITS

- A natural approach to sustainable flood management helps to achieve national and local biodiversity action plan targets.
- Lochs and rivers provide habitats for threatened species such as the Atlantic salmon, the freshwater pearl mussel the osprey and the water vole.
- Ponds and pools support the rare medicinal leech, the northern blue damselfly and the great crested newt.
- Blanket bogs support a rich diversity of invertebrates and breeding wading birds such as greenshanks, dunlins and golden plovers.
- Floodplain wetlands support farmland wading birds and wildfowl, including lapwings. Snipe, teals and pintails.

ECONOMIC BENEFITS

- Hard engineered, concrete flood defences are expensive to construct and maintain.
- Soft engineered schemes are cost-effective and sustainable, fulfilling many roles as well as flood defence.
- Wetlands act as natural cleansers and improve water quality by storing pollutants.
- Soft engineered solutions are cheaper in the long-term and provide sustainable adaptation to climate change.
- Healthy wetland systems are vital to our economy, supporting industries such as freshwater fisheries, the whisky industry and tourism.

PROMOTING AND IMPLEMENTING SOFT ENGINEERING TECHNIQUES

- Recognise the role that wetlands play in helping to alleviate flooding.
- Re-connect rivers with their natural floodplains.
- Establish more demonstration sited to test the effectiveness of natural flood management.
- Protect and restore wetland habitats through the programme of measures.

FLOODWATER STORAGE AREAS

- Avoid embankments that divorce the river from the floodplain.
- Let water stand on low-lying fields when the rivers overflow, reducing pressures on urban areas downstream.
- Store floodwaters in natural habitats to release them back into the river system.

URBAN AREAS

- These will require only modest flood embankments to defend them against flooding, thanks to protection by sustainable management of the catchment.

SOCIAL BENEFITS

- People living and working in urban areas downstream are protected from floods.
- Wetland habitats and landscapes are good for ecotourism and education.
- Recreation opportunities encourage a healthy lifestyle.

UPLANDS

- Manage uplands to reduce erosion and run-off.
- Keep bogs healthy so they retain water.
- Restore gullies and natural forests.
- Avoid overgrazing by sheep and deer to prevent damage to upland habitats and peatlands.

FLOODPLAIN MANAGEMENT

- Consider grazed grassland rather than intensive arable cropping.
- Allow shallow flooding or surface flashes of water in spring for the benefit of breeding wading birds.
- Leave wet corners or patches within fields, as these are good for wildlife.
- Manage native wet woodlands as an alternative to crop production.
- Make sure that agricultural incentives reflect the important flood alleviation role.

The above information set is worth emulating in NRGB as useful advice to rural communities for Natural Flood Management. Similar issues of specific concern to urban communities can also be brought to their attention. For instance, given the rapidly increasing urbanization in NRGB, the status of urban ecosystems and their impact on the basin as a whole are becoming increasingly important. Thus, urban drainage and urban flooding are issues that are best tackled with the participation of urban communities. To give an example, the Sustainable Urban Drainage brochure of SUDSWP [2002] of Scotland identifies 3 key targets, namely Water Quantity, Water Quality and Amenities as depicted in Figure 5.7. "Water Quantity" targets the reduction of flood peaks due to rapid urban runoff from rainfall events as depicted in Figure 5.8. "Water Quality" targets pollution carried into rivers by urban drainage, which can be a significant source of river pollution as depicted in Figure 5.9. "Amenities" targets several ecological, social and environmental issues. Based on the 3 considerations, four broad methods were identified in the document for Sustainable Urban Drainage, viz. filter strips and swales; filter drains and permeable surfaces; infiltration devices; and basins, ponds & wetlands. The techniques were further explained with illustrations for easy understanding by urban communities.

Figure 5.7: Key Targets of Sustainable Urban Management [SUDSWP, 2002]

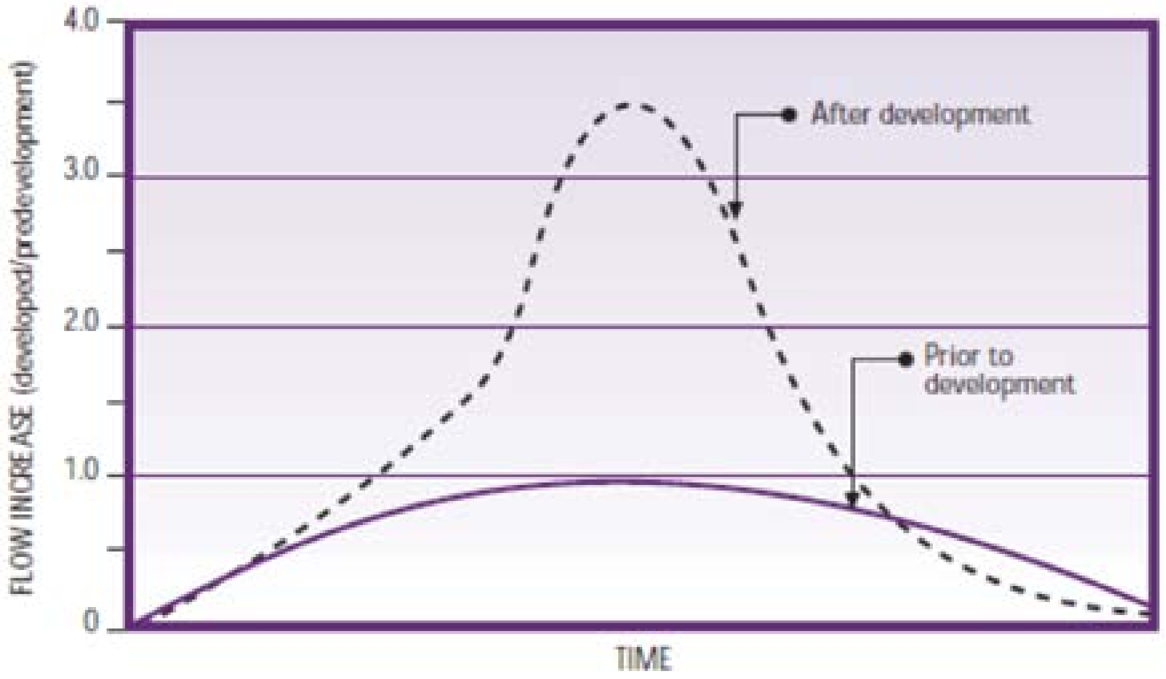


Figure 5.8: Typical River Flood Peaks due to Urban Storm Water Runoff [SUDSWP, 2002]

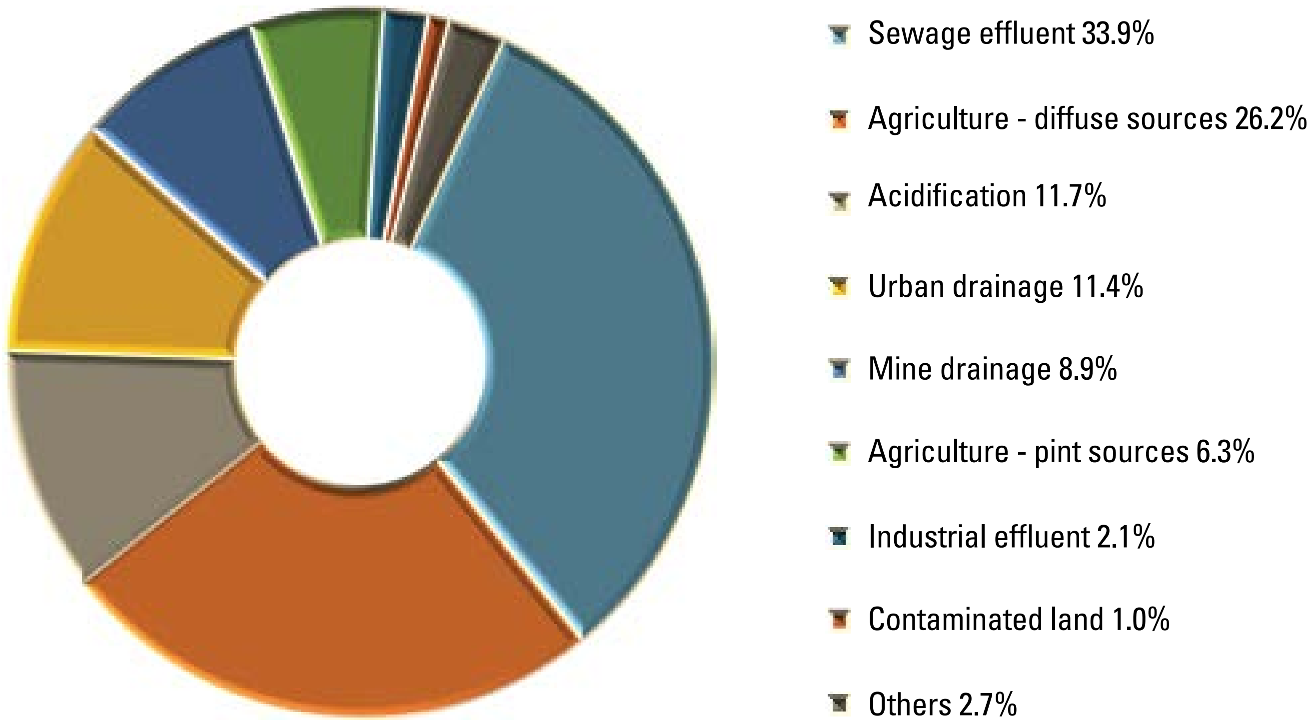


Figure 5.9: Main causes of Pollution of Scottish Rivers in 1996 [SUDSWP, 2002]

Apart from anthropogenic factors in drainage, there are many other urban issues of concern that affect river basins where informed citizens can readily play a corrective role. As in other river basins, urban ecosystems in NRGB may be expected to be highly modified ecosystems whose functioning can be significantly improved by urban residents. A simple example is that of urban soils. As noted by Pavao-Zuckerman [2008], "urban soils represent a distinct taxonomic class that differs with respect to their morphologic structure and function from nonurban soils." The uniqueness of urban soils are related not only to changed soil developmental trajectories but to many direct and indirect impacts on soil properties and processes such as land surface sealing and compaction, urban heat islands and altered hydrological regimes, near-surface atmospheric ozone and carbon oxide levels, and other chemical effects (often with elevated heavy metals, nitrogen and sulphur in soils.) These changes have consequent effects on the activities of soil organisms and biotic compositions, which ultimately shifts the ecosystem functions and processes related to biogeochemical cycling. The effects of urbanization on urban soils also tend to vary with urban size. For example, the effect of urbanization on some soil properties was found to differ greatly among three U.S. cities with different orders of magnitude of population [Pavao-Zuckerman, 2008], as shown in Table 5.3.

Table 5.3: Comparison of Soil Characteristics and Nutrient Cycling Rates in Three US Cities [Pavao-Zuckerman, 2008]

	NEW YORK CITY		BALTIMORE		ASHEVILLE	
Polulation	**7,420,166**		**7,420,166**		**7,420,166**	
Soil Variable	Rural	Urban	Rural	Urban	Rural	Urban
pH	4.7	4.5	4.6	5.2	4.9	4.9
SOM (g/kg)	75	108	110	90	97	79
Mean Annual Temperature (^{0}C)	8.5	12.5	12.8	14.5	11.9	13.0
N Mineralization (mg-kg-d^{-1})	4.02	10.3	2.2	8.0	0.11	0.26
Leaf Decay (mg/day)	0.0068	0.0113	n.a.	n.a.	0.0012	0.0009

The populations of the cities range over three orders of magnitude, and although all exhibit impacts of urbanization on soil properties, the nature and degree of these impacts vary from city to city. Such comparisons suggest that urban soil ecological knowledge for restoration will be to a large degree city specific. Some data sets were not available (n.a.) for comparison.

Specific examples pertinent to the above aspects of urban ecosystems is the study of urban soil nutrients in China, China being a rapidly urbanizing country like India with numerous plant nutrient deficiencies observed in cities. In Mao et al's [2014] study of soil in China's capital Beijing, the authors found that "Urban soils in the Beijing metropolitan region are considerably alkaline and compacted. Soil TN, SOC, and AP are in deficit, while AK is abundant and sufficient for supporting plant growing. Heavy metal pollution in Beijing is low. … Soil AP, AK, SOC, C/N, Pb, and Cu increase from suburbs to the urban core, while other elements showed no significant difference. … Roadsides and residential areas are the two land uses characterized by higher soil nutrients and heavy metal pollutants." (Note: The terms AP, AK, SOC and C/N denote Available P, Available K, Soil Organic Carbon and, Carbon:Nitrogen ratio respectively.) Mao et al. recommended further research with the conclusion, "it is critically important to enumerate the different ecosystem services (and disservices) provided by urban soils."

Another significant study was reported for Hubei Province of China by Li et al. [2013]. Li et al. found that "in general, urban soils in Hubei Province had a higher pH than natural soils, were deficient in organic matter, and low in available N, P, and B concentrations." Moreover, "nutrient concentrations were significantly different among land use types, with the roadside and residential areas having greater concentrations of calcium (Ca), sulfur (S), copper (Cu), manganese (Mn), and zinc (Zn) that were not deficient against the recommended ranges. Topographic comparisons showed (that) … concentrations of N, Ca, Mg, S, Cu, and Mn in plain cities were greater than those in mountainous cities and show a negative correlation with city elevation."

The above studies indicate the need for detailed studies, monitoring and amelioration of urban soils in NRGB, since urban soils invariably affect the functioning of these ecosystems with consequent effects on other ecosystems of the basin. To a large extent such activities can be effectively conducted with the involvement of the urban populace through informative discourses, motivation and training. Likewise, a host of data collection, monitoring and corrective measures needed in NRGB will be best carried out by informing, sensitising, training and involving ordinary stakeholders in basin upkeep. At the very least, stakeholder sensitization will lead to automatic self-corrective measures rather than their contributing to basin degradation processes out of ignorance. And a more positive approach to stakeholder sensitization can certainly be expected to pay richer dividends in rejuvenating the National River Ganga Basin.

6. SUMMARY OF RECOMMENDATIONS

The main conclusions and recommendations for Environmental Knowledge-Building and Sensitization are summarized below:

i) Establishment of a comprehensive Data Bank by continuous collection, processing and storage of information on natural resources, anthropogenic activities, and environmental monitoring data of the basin.

ii) Preparation of secondary results (charts, tables, etc.) based on primary data and conducting advanced studies and analyses for advancing the knowledge base of NRGB's developing needs.

iii) Preparation of documents and materials for easy understanding by non-specialized ordinary stakeholders of NRGB.

iv) Keeping all the above information in an open-access library for easy access by all interested individuals and institutions.

v) Conducting workshops and educational campaigns with stakeholders, interested citizens, special–interest groups and rural/urban communities to enable their comprehensive understanding of basin processes and participate in basin rejuvenation through meaningful action.

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