Ganga River Basin Management Plan - 2015

Mission 6: Basin Protection Against Disasters

January 2015

by

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

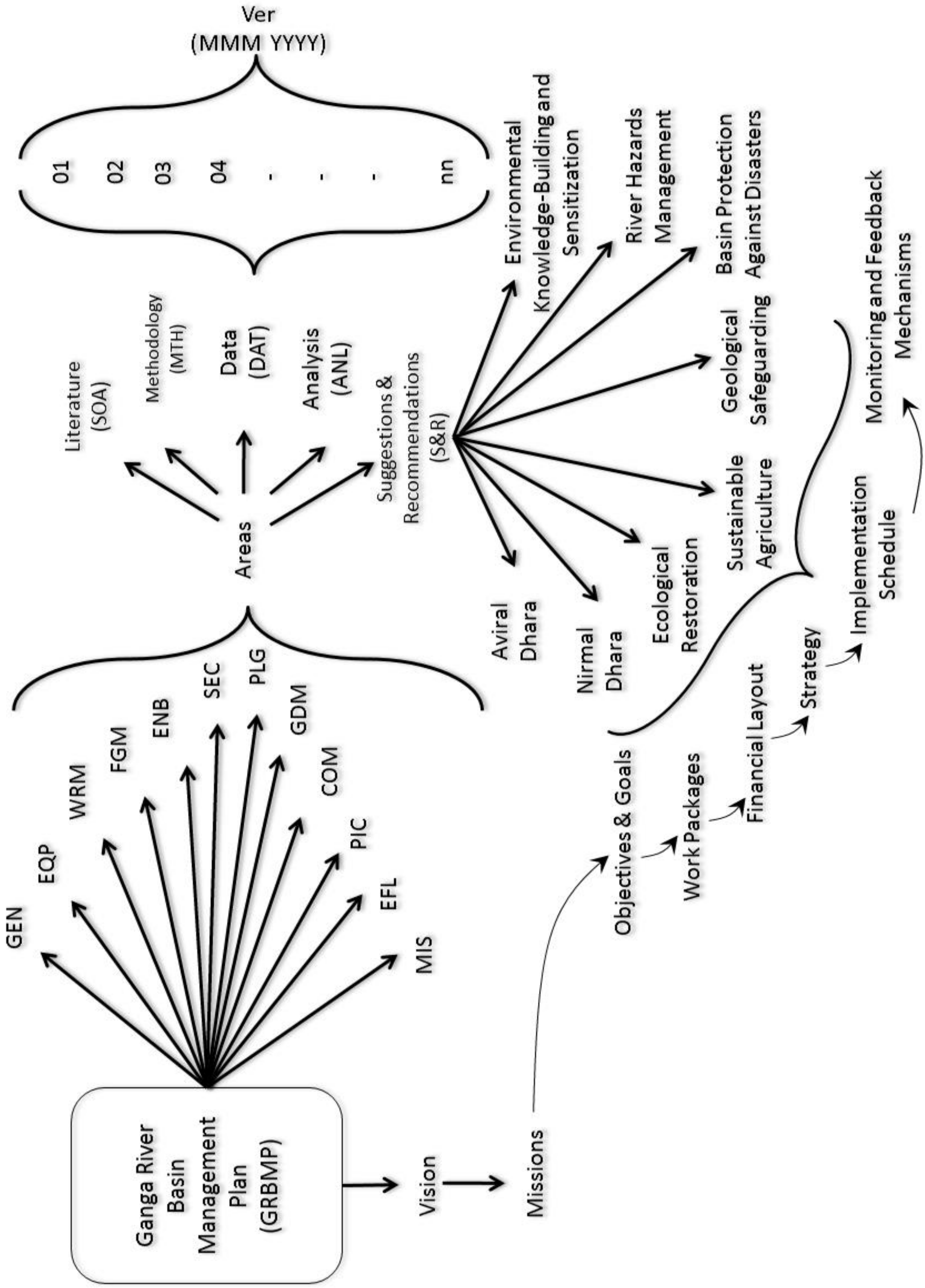
IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

In Collaboration with

IIT BHU | IIT Gandhinagar | CIFRI | NEERI | JNU | PU | NIT-K | DU

NIH Roorkee | ISI Kolkata | Allahabad University | WWF India

GRBMP Work Structure



Preface

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

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

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

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

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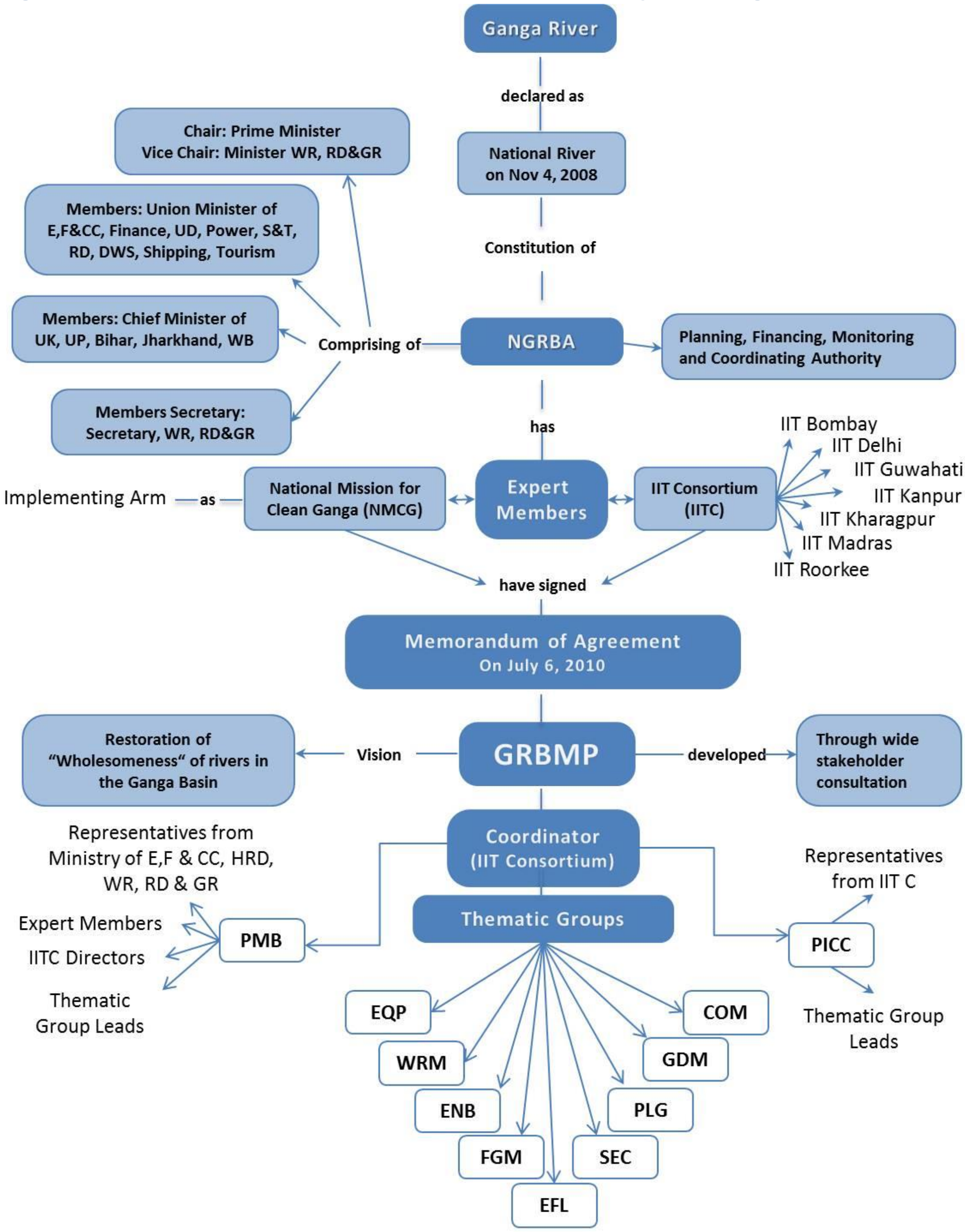
Organizational Structure for Preparing GRBMP



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

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

Project Management Board [PMB]

Expert Members:

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

Representatives from IIT Consortium:

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- Dr A K Mittal, IIT Delhi
- Dr Mohammad Jawed, IIT Guwahati
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Thematic Group Leads:

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

Composition of Thematic Groups

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2. Water Resource Management (WRM)

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3. Fluvial Geomorphology (FGM)

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4. Ecology and Biodiversity (ENB)

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Members: A K Thakur, Vinod Tare (IIT Kanpur); Utpal Bora (IIT Guwahati); M D Behera (IIT Kharagpur); Naveen Navania, Partha Roy, PruthiVikas, R P Singh, Ramasre Prasad, Ranjana Pathania (IIT Roorkee); Sandeep Behera (WWF-India)

5. Socio Economic and Cultural (SEC)

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8. Communication (COM)

Lead: T V Prabhakar, IIT Kanpur

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

9. Environmental Flows (EFL)

Lead: Vinod Tare, IIT Kanpur

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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.	MoWRRDGR	:	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.	SRI	:	System of Rice Intensification.
20.	UNEP	:	United Nations Environment Programme.

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Summary

The Ganga River Network was adopted as the primary indicator of health of the National River Ganga Basin (NRGB) in GRBMP, and human-technology-environment 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 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, 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 both anticipate the occurrences and 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*]**:**

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

The above disasters are also among the major disasters in the Asia-Pacific region, vide Table 4.1 [*ESCAP & UNIDO, 2010*]. The ESCAP & UNIDO 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.

Table 1: Top 10 Disaster Types in Asia – Pacific region [*ESCAP & UNIDO, 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 & UNIDO, 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

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, 2012*]

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*].

Within India, much of the Ganga basin is flood-prone, especially along the Himalayan range (*vide Figure 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 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 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.

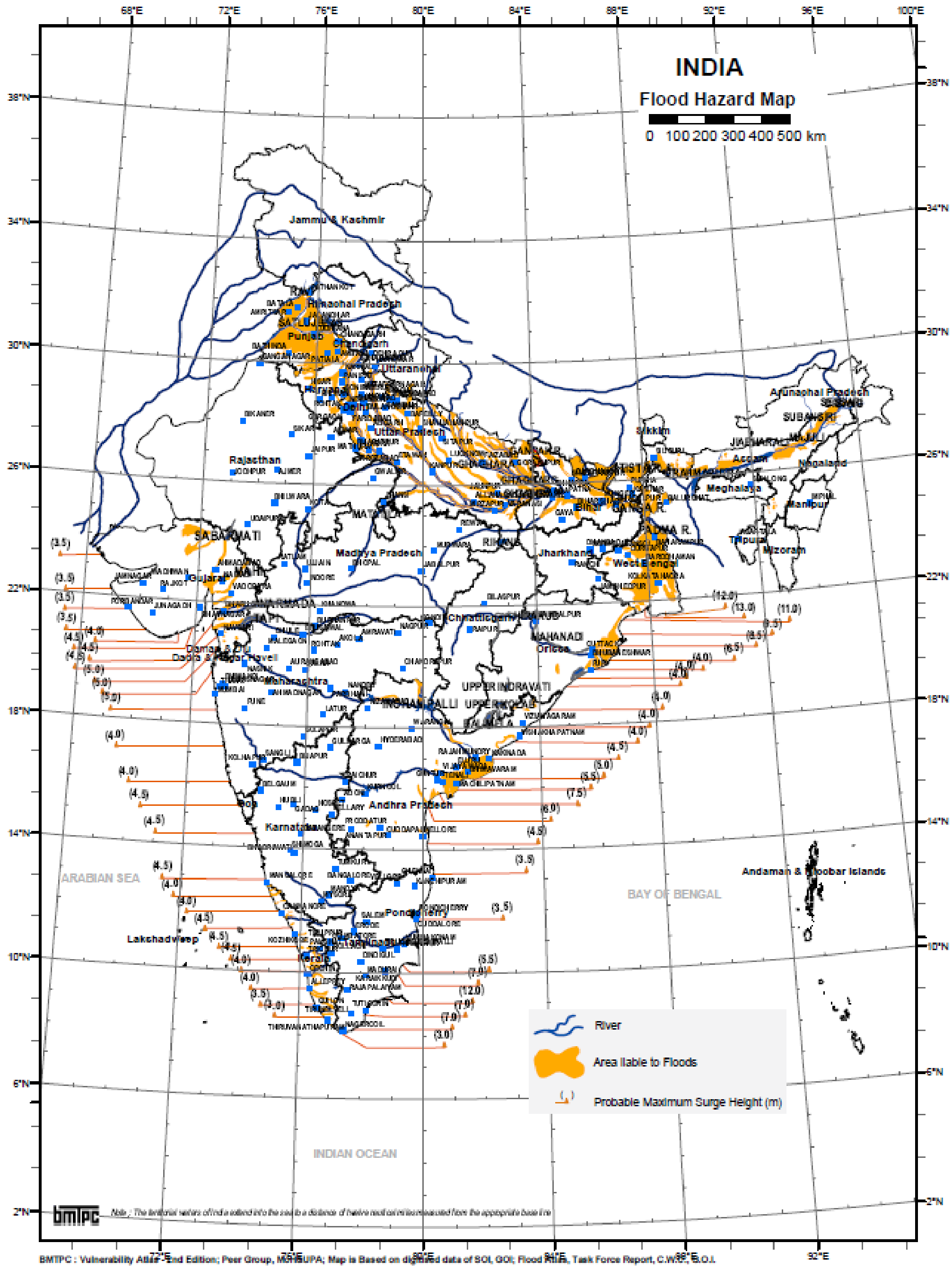

Figure 1: Flood hazard map of India [*MHA, 2011*]

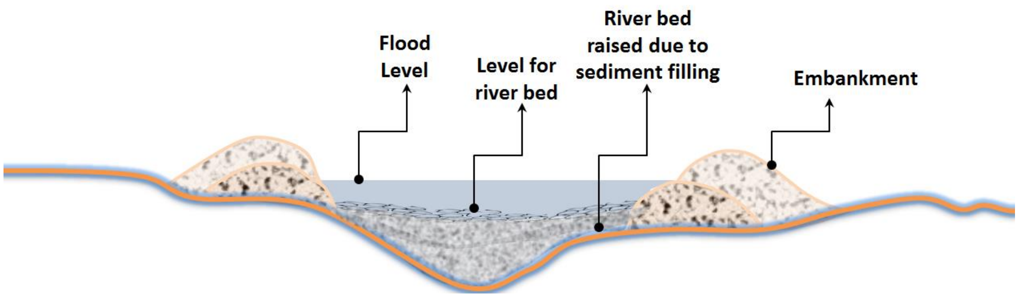

Figure 2: Cross-sectional Profile of Kosi river [adapted from *Valdiya, 2011*]

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 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.

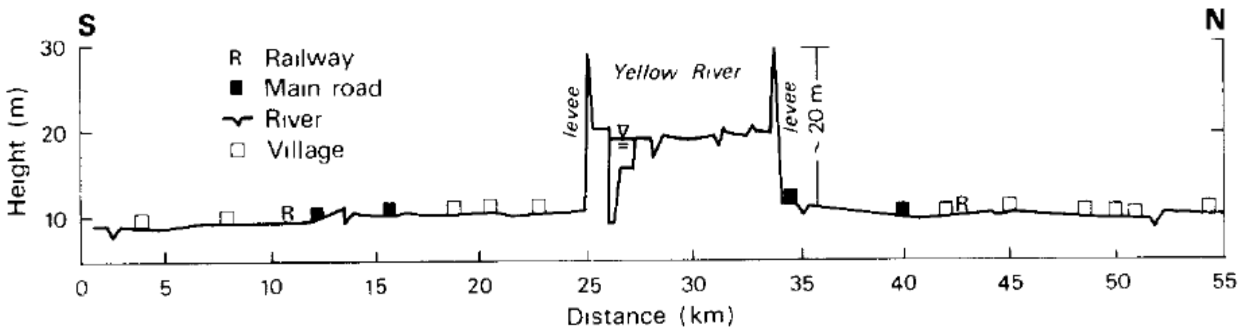

Figure 3: Cross-sectional Profile of Yellow river [*Shu & Finlayson, 2011*]

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*].

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 flood-ways 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*].

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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.

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 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 southern and south-western parts of the basin, vide Figure 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 eco-sytem 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.

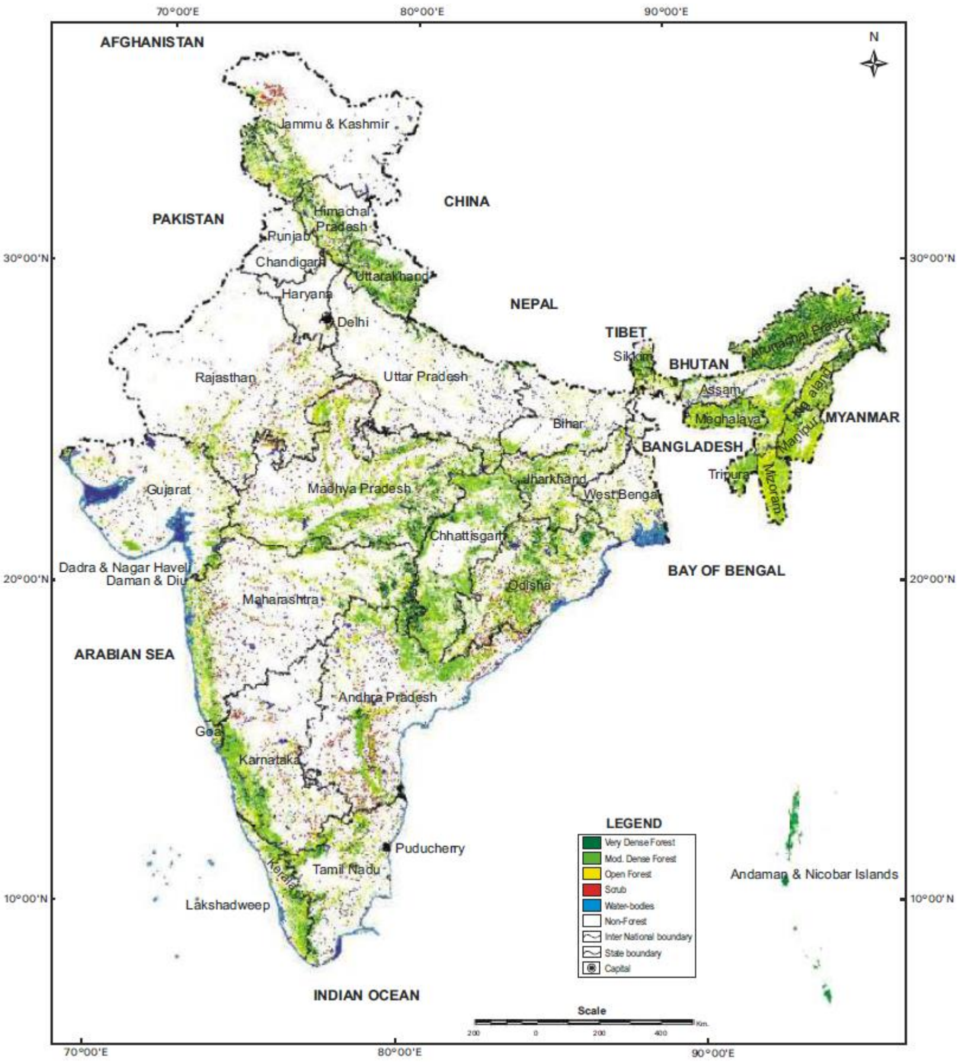

Figure 4: Forest Cover of NRGB [*FSI, 2013*]

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*].

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 geological 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*].

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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