# Ganga River Basin Management Plan - 2015

## Mission 7:
## River Hazards Management

*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**

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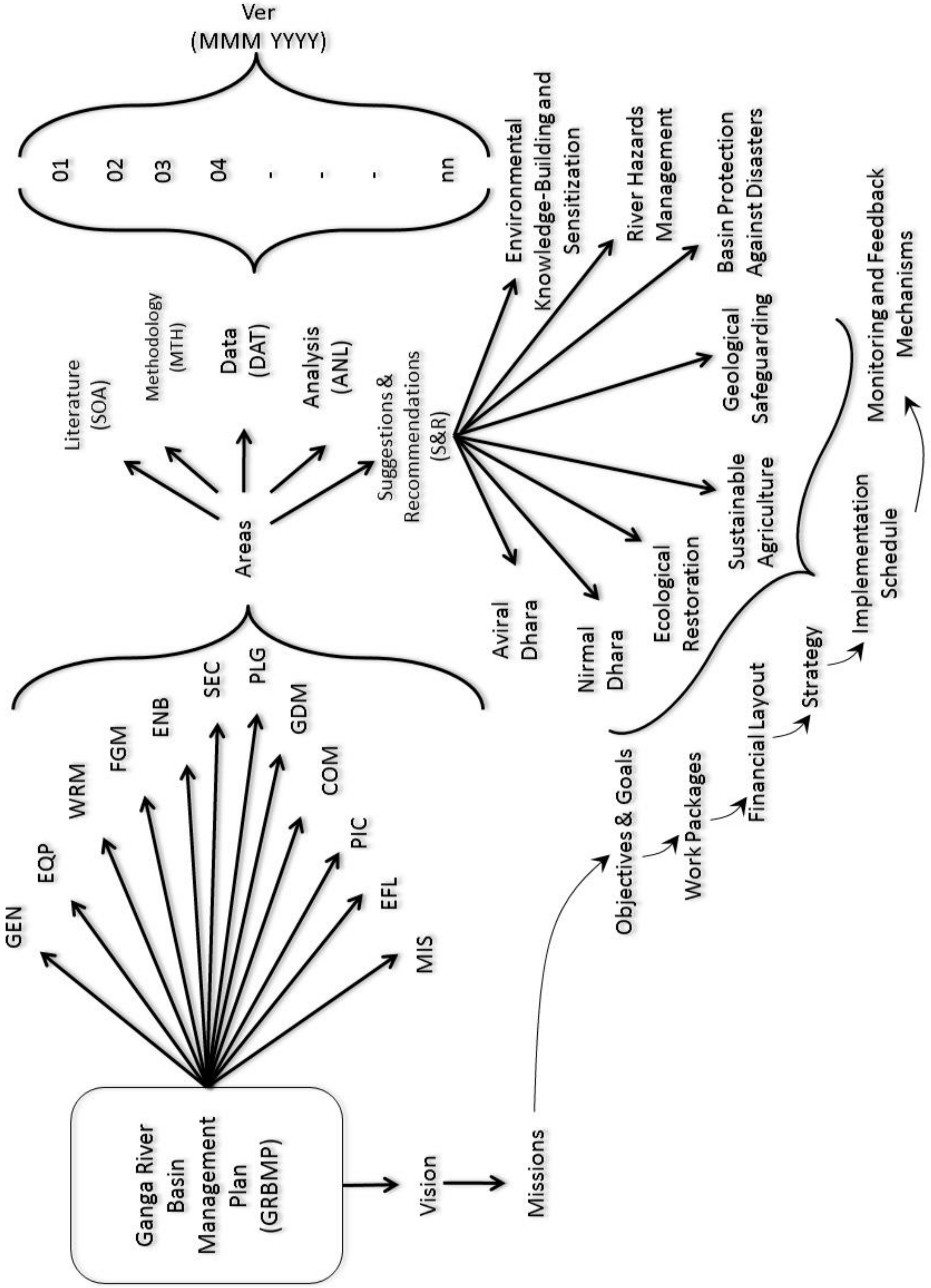
# GRBMP Work Structure



# 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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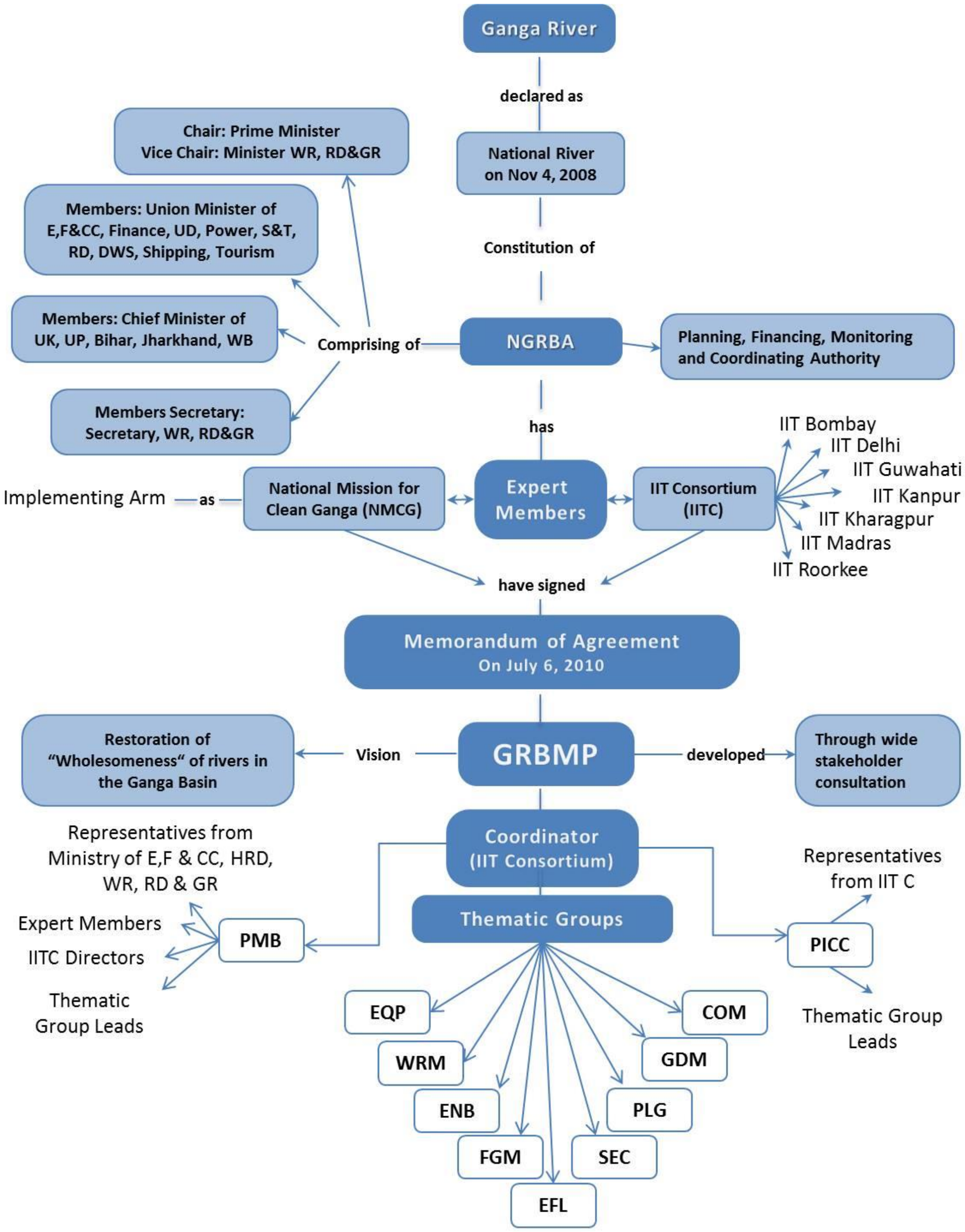
# Organizational Structure for Preparing GRBMP



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| **NGRBA:** National Ganga River Basin Authority | **EQP:** Environmental Quality and Pollution |
| **NMCG:** National Mission for Clean Ganga | **WRM:** Water Resource and Management |
| **MoEF:** Ministry of Environment and Forests | **ENB:** Ecology and Biodiversity |
| **MHRD:** Ministry of Human Resource and Development | **FGM:** Fluvial Geomorphology |
| **MoWR, RD&GR:** Ministry of Water Resources, River Development and Ganga Rejuvenation | **EFL:** Environmental Flows |
| **GRBMP: Ganga River Basin Management Plan** | **SEC:** Socio Economic and Cultural |
| **IITC:** IIT Consortium | **PLG:** Policy Law and Governance |
| **PMB:** Project Management Board | **GDM:** Geospatial Database Management |
| **PICC:** Project Implementation and Coordination Committee | **COM:** Communication |

# Project Management Board [PMB]

## Expert Members:

- Sri Swami Avimukteshwaranand Saraswati
- Sri Madhav Chitale
- Dr Bharat Jhunjhunwala

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# Project Implementation and Coordination Committee [PICC]

## Representatives from IIT Consortium:

- Dr Shyam Asolekar, IIT Bombay
- Dr A K Mittal, IIT Delhi
- Dr Mohammad Jawed, IIT Guwahati
- Dr Vinod Tare, IIT Kanpur
- Dr D J Sen, IIT Kharagpur
- Dr Ligy Philip, IIT Madras
- Dr I M Mishra, IIT Roorkee

## 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)

**Lead: A K Gosain, IIT Delhi**

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## 3. Fluvial Geomorphology (FGM)

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## 4. Ecology and Biodiversity (ENB)

**Lead: R P Mathur, IIT Kanpur**

**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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## 7. Geo-Spatial Database Management (GDM)

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**Members:** N L Sharda, Smriti Sengupta (IIT Bombay); A K Gosain (IIT Delhi); Arnab Bhattacharya, Kritika Venkatramani, Rajiv Sinha, T V Prabhakar, Vinod Tare (IIT Kanpur)

## 8. Communication (COM)

**Lead: T V Prabhakar, IIT Kanpur**

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

## 9. Environmental Flows (EFL)

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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. PPP : Public-Private Partnership.
20. SRI : System of Rice Intensification.
21. UNEP : United Nations Environment Programme.
22. URMP : Urban River Management Plan.

# Contents

# 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.

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 km2 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).

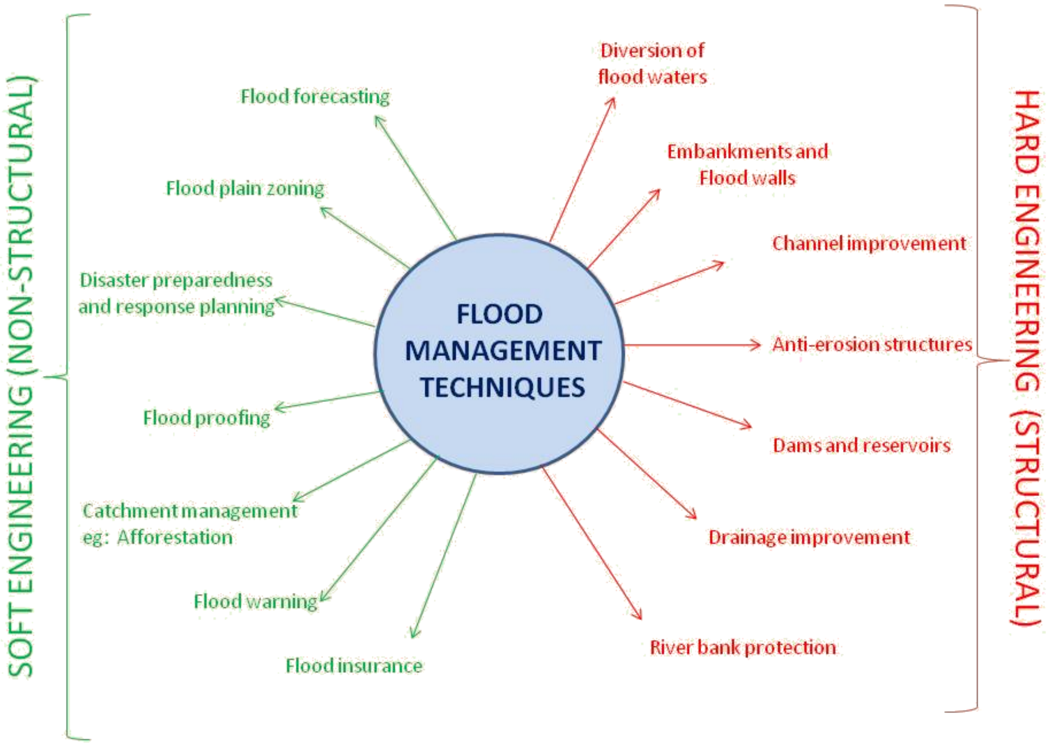
It is important to realize that river dynamics is a natural behavior of the river and it is crucial to accurately map the extent of migration and reaches prone to migration. This extent must be defined as the 'space' for the river and the concept of floodplain zoning must be seriously pursued. This is 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 (Figure 1). 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.



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/km2) 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

## 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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