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Operational Research to Support Mainstreaming of Integrated Flood Management under Climate Change

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Basin Flood Management Plan for Burhi-Gandak, Bihar

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Deltares in association with RMSI and JPS

Cover photo:
Railway bridge over the Burhi-Gandak upstream of Muzaffapur

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Abbreviations

ADB	Asian Development Bank
BG	Burhi-Gandak river basin in Bihar
CE	Chief Engineer
CWC	Central Water Commission
DFID	Department for International Development
DPR	Detailed Project Report
ESM	Earth System Model
FGD	Focal Group Discussion
FMIS	Flood Management Information System
GCM	Global Climate Model
GFCC	Ganga Flood Control Commission
GoB	Government of Bihar
GoI	Government of India
IFM	Integrated Flood Management
IMD	India Meteorological Department
INR	Indian Rupees
MoWR,RD&GR	Ministry of Water Resources, River Development and Ganga Rejuvenation
NGO	Non- Government Organisation
RCM	Regional climate Model
SDRF	State Disaster Response Force
UNDP	United Nations Development Programme
WMO	World Meteorological Organisation
WRD	Water Resources Department

Units

MWh	Mega Watt hour – unit of Energy
m	Metre – unit of Length
cm	Centimetre – unit of Length
mm	Millimetre – unit of Length
Cumec	Cubic meters per second – unit of Flow
km	Kilometre – unit of Length
Sq.Km	Square Kilometres – unit of Area

Chapter 1 Introduction

This report describes the Burhi-Gandak river basin and its flood risks. It proposes plans for reducing flood risks using a mixture of structural and non-structural measures. Chapter 2 describes the geophysical and hydrological characteristics as well as recent flood history. Importantly, it does so from a macro-perspective as well as from the perspective of communities living in the flood prone areas.

In chapter 3, a flood risk assessment is given of the current situation as well as under potential climate change conditions for the years 2040 and 2080. Chapter 4 elaborates the entire gamut of existing and possible future flood mitigation measures. Next to embankments, dams and river offtakes also non-structural elements such as flood forecasting, land use management, community level measures and agricultural adaptations are discussed. Also the urban environment is taken into consideration, for which drainage designs and costings are described. Last but not least the economic and environmental considerations of all these interventions are presented.

Chapter 5 spells out the necessities of improvements in institutional and community activities in order to create a better enabling environment for flood management.

It is our sincere wish that this integrated approach will help to mitigate the recurrent flood problems in the Burhi-Gandak basin, for the benefit of millions of people living in these fertile but yet hazardous environments. This report will give no decisions, but choices and options. Options which work best when implemented in harmony. Not all options may be economically or socially feasible. This requires further study and discussions among stakeholders. We hope this report may assist in these discussions.

Chapter 2 The flood hazard and vulnerability in Burhi-Gandak basin

2.1 River characteristics

2.1.1 General description

The Burhi-Gandak river flows from its upper Nepal catchment through an almost entirely embanked river channel towards it confluence with the Ganga River (Figure 1). The river is thus characterized by slope changes and high sediment load ("silt") causing meandering and instability but generally do not appear to possess flash flood characteristics. The floodplain is cultivated between the flood embankments. There is a ribbon of settlements all along the outside of the embankments on both sides of the river.

The River originates from Chautarwa Chaur in the Someshwar range of hills at 300 m above mean sea level near Bishambharpur in the West Champaran district in Bihar (Figure 2). The main River course lies entirely in Bihar in Indian Territory. However, some left bank tributaries of the Sub-basin flow through Nepalese Territory. The total catchment of the Sub-basin is 12,500 km^2, out of which 2,350 km^2 lies in Nepal. The Sub-basin is surrounded in the North by the Bagmathi River system, on the Western side by the Gandak-Ganga River system, on the Southern side by the Ganga River and on the Eastern side by the Bagmathi-Kosi River system. The total length of the main river system is 320 km. The important right bank tributaries are Kunhra, Dhanauti and None Blan; and such important left bank tributaries are Masan, Belor, Pandai, Sikta, Uria, Tilawe and Teur. The River Burhi-Gandak outfalls in to Ganga near Khagharia Railway station (GFCC, 1992).

The upper portion of the catchment in Nepal and in the West Champaran district is hilly and associated with fairly dense forest. The rest of the catchment is highly fertile alluvial plain. The agriculture area is predominantly being used for paddy, wheat and maize. More details can be found in section 5.1.5. The area is well connected by rail and road ways. Also, good communication network exists. There are no major industries in the Sub-basin. There is a small aerodrome in Muzaffarpur.

Table 1 Characteristics of the Burhi-Gandak river

Sl.No.	Item	Quantity
1	Total Drainage Area	12021 Sq.Km
2	Drainage Area in Bihar	9601 Sq.Km
3	Population in Bihar	83.01 Lakh
4	Water resources	4040 MCM
5	Average annual rainfall	1283 mm
6	Total length of main river	320 Km
7	Cropped area in Bihar	7600 Sq.Km

Source: FMIS, Bihar.

Figure 1 Map of the Burhi-Gandak basin (Indian part)
(Source: Deltares&RMSI)

2.1.2 Hydrology

The average annual rainfall in the sub-basin is 1,283 mm, out of which the monsoon months (June to October) receive 1,155 mm, which is about 91 % of the above annual average rainfall. In general, the upper part of the catchment receives higher rainfall than the lower part. The South-West monsoon generally sets in the first or second week of June and withdraws in the second week of October. The high concentration occurs in the period from July to September. Storms of 1 to 3 days durations are common. One day storm at 50-year return period may vary between 280 to 400 mm from the lower to upper reaches. Similarly, the 100-year return periods one day rainfall increases from 320 to 440 mm from the lower to upper reaches. About 20 hydrological stations were operating in the sub-basin in the past. Out of these only 4 gauge-discharge stations and three gauge stations are maintained by CWC. The gauge-discharge stations are Champatia, Lalbegiaghat, Sikanderpur and Rosera; the gauge stations of CWC are at Ahirwalia, Samastipur and Khagaria. The Hydro-meteorological network in the catchment is more or less satisfactory as per WMO stipulations. The hydrological features of the four gauge-discharge stations are as below Table 2.

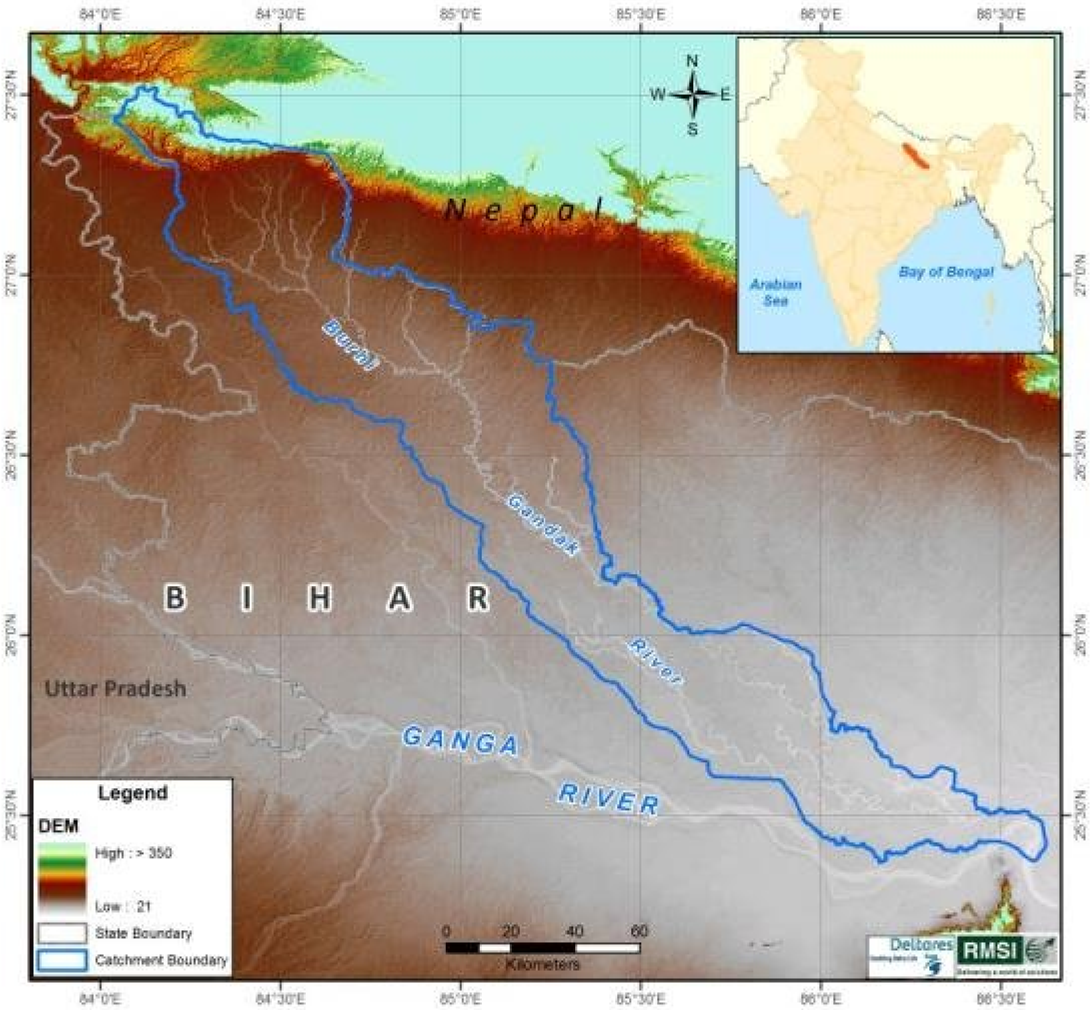

Figure 2 Elevation map of the Burhi-Gandak basin (Indian part)

Table 2 Discharges for specific return periods (according to GFCC, 1992)

Station	Data base	Catchment area Km ^{2}	Maximum observed discharge (m^3/sec)	25-year Return Period Discharge	50-year return period Discharge	100-year return period Discharge
Champatia	1960-90	1,464	1,469	1,941	2,300	2,690
Lalbagiaghat	1974-90	6,900	2,295	3,241	3,814	4,211
Sikanderpur	1961-90	8,510	3,787	4,040	4,646	4,927
Rosera	1960-90	9,580	2,890	2,735	3,102	3,489

The GFCC has estimated these return period floods based on a compilation titled 'Workshop on Flood Frequency Analysis by the National Institute of Hydrology-Roorkee-1987-88' (see also Section 4.1). The midstream station (Sikanderpur) shows higher values of peak discharge than upstream (Chanpatia) or downstream (Rosera). The increase in peak discharge between Chanpatia and Sikanderpur can be explained due to tributary influence. No major tributary seems to be joining the Burhi-Gandak between Sikanderpur and Rosera and therefore, flood peak is being attenuated (Sinha & Jain, 1998).

2.1.3 River morphology and behaviour

The effectiveness of any flood control scheme to a significant extent depends on the river morphology. Erratic behaviour of the river causes frequent changes in its course, lateral migration, heavy over bank spilling due to inadequate channel capacity, frequent carving of new or secondary channels, rise in river beds as well as frequent attacks on the river banks and flood embankments.

The Burhi-Gandak is a so-called “plains-fed” river, which has different morphological, hydrological and sediment transport characteristics compared to other rivers in Northern Bihar, such as the Kosi and Gandak (“mountain-fed”) and Baghmati (“foothills-fed”). It implies that the ratio between upland and plains is almost zero, i.e. hardly any catchment area above the so called mountain front. The Burhi-Gandak is a typical single-channel river with a high sinuosity (meandering), especially in the lower reaches, and is unbraided throughout its course (Sinha & Jain, 1998, GFCC, 1992). The meandering pattern is more pronounced in the lower reaches. Gradual building of point bars on the inner side of a bend and consequent lateral erosion of concave embankments is a common feature of the river. There are several erosion points spread over the reach downstream of Muzaffarpur.

Sediment flow measurements are available from Sikanderpur and Rosera. The downstream site Rosera has yielded higher concentrations of wash-load material in its suspended-load samples, suggesting the erosion of muddy material from the channel banks. The average annual sediment load at Sikanderpur and Rosera are 5.38 million tons and 14.45 million tons of which about 90 % is transported in the monsoon months. The fine sediment concentration is 0.247 gm/litre and 0.835 gm/litre respectively. Due to the high silt load and recurrent flooding, the floodplain is gradually accreting. At one point in the Burhi-Gandak floodplain Sinha & Jain (1998) found evidence of 1.4 m vertical accretion over a time period of 15 years. Deposition of sediments either within the channel or on the channel margin restricts the passage of water and thus reduces the carrying capacity of the channel. This results in overspilling of water on the adjacent plains. Although no quantitative estimates are available for north Bihar plains, it seems that low forest cover may be a significant factor influencing the high flows in their rivers draining the plains (Sinha & Jain, 1998).

Furthermore, the neotectonic movements in the north Bihar plains and Himalayan region contribute to the flood risk. The major parts of north Bihar are actively subsiding at a net rate of 0.2-0.3m per thousand year. Earthquakes in the Himalayan region have resulted in unstable slopes, loose and fragmented rocks and higher river gradients. All these effects contribute to high sediment load of the rivers and, as a result, the beds of these rivers are rising rapidly (Sinha & Jain, 1998)

In the course of the Burhi-Gandak River there is minor shift in the river course as most of the river length is embanked. However, spilling occurs during floods in the reach upstream of Motihari town where embankment constructions are not completed (see section 5.2.2). The embanked portions of the river reaches remain under constant threat of breach because of the improper alignments of the embankments in many places.

2.2 Flood characteristics

Before the embankments were constructed from near Motihari up to the confluence with Ganga, the river used to spill more or less throughout its length. But even now, when embankments have been constructed over most of the length, the area remains highly vulnerable to flood inundation not because of the floods of Burhi-Gandak alone. The Ganga River, which receives the floods of its tributaries in the upstream along with its own catchment generated floods, is in high stages in the monsoon in general and definitely during flood events. As such the backwaters push the Burhi-Gandak flood volume to its upstream channel. Thus the inundated waters spread up to even about 20 to 25 km upstream of the Burhi-Gandak river (Figure 3).

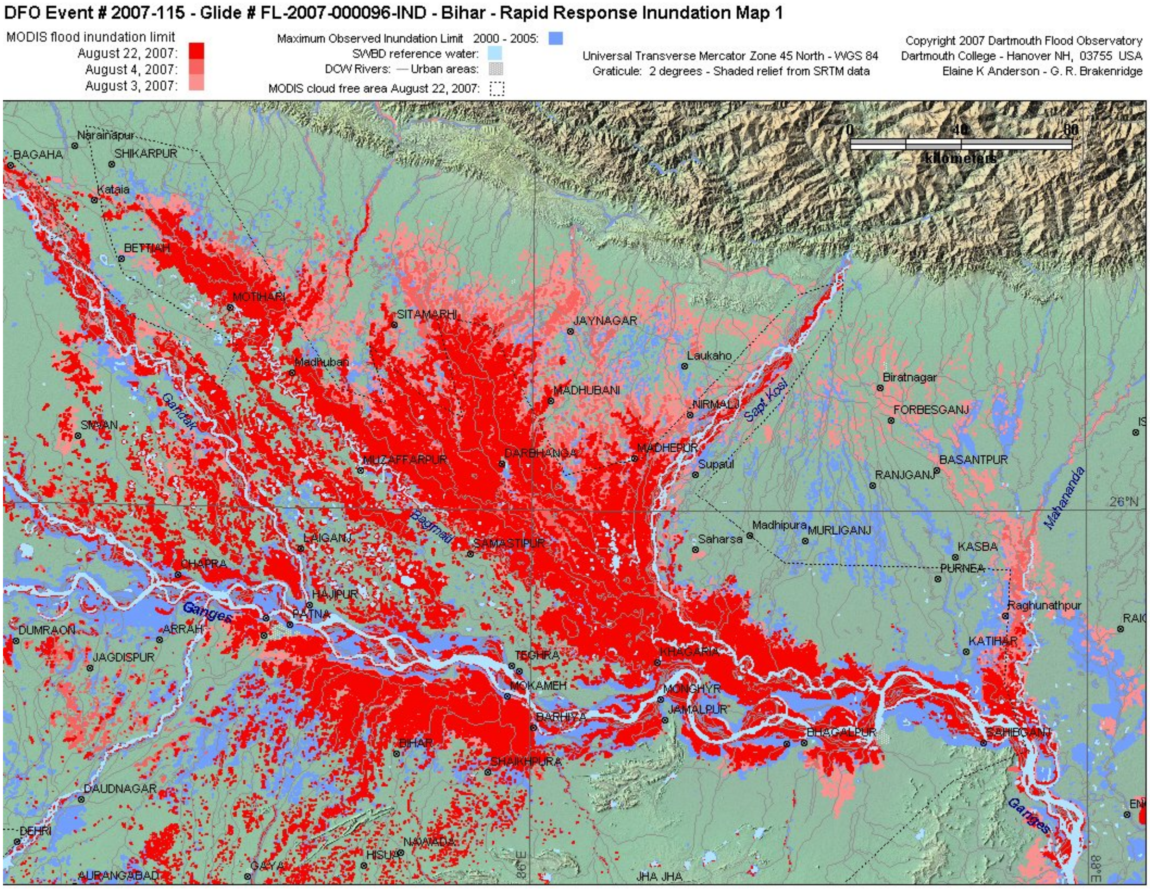

Figure 3. Flood extent in northern Bihar on August 2007
(source: Dartmouth Flood Observatory: http://www.dartmouth.edu/~floods/)

The flooding characteristics can be summarised as follows:

- A lot of flooding is due to water logging and impeded drainage, and not river flooding.
- Flooding also occurs through breaching of embankments, which is said to be often man-made.
- Downstream inundation is partly also coming from backwater effect of Ganges and overflowing water from other rivers (Koshi, Kareh).
- Bank erosion problems in the reach below Muzaffarpur
- Inundation due to spilling of the River in the upstream reaches
- Drainage congestion due to in-adequate waterway provided in the rail/road bridges, especially in the East Champaran district.

2.3 Recent floods and their impact

2.3.1 Community perspective

The BG basin is vulnerable to flood affecting the community and their livelihood. The river has embankment all along its course and the reason for most of the flood in the basin is either due to heavy rain causing flooding on the landward side of the embankment or due to breach of embankments.

The frequency of flood and its intensity has reduced in the BG basin during the last 10-15 years. According to the community, the water from Bagamati river was regulated from flowing into the BG river and that was the reason for reduction of flooding in the BG basin. According to the community the river has dried up now. However, during the community consultation we were informed that the basin has experienced severe flood during 1987, 2002, 2004, and 2007. The State statistics shows the 2007 flood was the recent flood which caused widespread damage and loss in the state. It has affected 17 out of 36 districts killing more than 500 people and damaging extensive agricultural lands. The flood condition of 2007 continued for more than 2 months severely affecting about 69 lakh people. The worst affected districts were Muzaffarpur, Sitamarhi, Saharsa, East Champaran, Darbhanga, Patna, Supaul, Bhagalpur, West Champaran, Katihar, Madhubani, Samastipur, Sheohar and Nalanda. Multiple breaches at 32 point in many rivers caused major havoc across the state.

In general, the nature of flood in BG basin upstream is more flashflood as water comes from Nepal, while the mid- and downstream it is a slow process. The midstream of the basin is exposed to more flood compared to the other parts. The tail end of the BG in Khagaria district and neighbouring region has the backwater effect of adjacent rivers like Ganga.

The midstream part of the basin experience standing flood water for about 25-30 days. In some areas water stays for 60 days. However, the flood height is mostly < 0.5 m or 0.5 – 1 m. Only some part of the basin reported to have 1 -2m and that too happened during heavy flooding.

Waterlogging is reported to be the most serious and widespread problem in the basin. It is extensive in the midstream (Muzaffarpur, Samstipur district) of the basin while the problem persists in the downstream as well. The upstream area experiences water scarcity during the non-rainy season. According to the community the construction of road infrastructure has affected the drainage channels causing waterlogging problems.

The community has a mixed response on the preference of embankment as flood protection structures. The midstream of the basin is experiencing heavy siltation and waterlogging. Heavy siltation in the irrigation channel and choked sluice gates made the irrigation channels ineffective. Communities are living on the river side of the embankment with pucca structure. The meandering nature of the river in the mid- and downstream sections deposits silt on the leeward side while it carves the agricultural land on the curved side leading to loss of agriculture land. Farmers either move back to accommodate the river or move to the other side of the river to cultivate in the newly formed land.

The coping capacity of communities towards flood is generally poor and particularly so for the poor people. The communities don’t have efficient early warning system, and no weather advisories. The communities have their own way of monitoring the flood height in the river and take own decision to protect life and assets. Community level preparedness is poor in the basin and households take whatever possible preparedness measures they can to protect their families.

The midstream communities are frequently affected by flood. Traditionally communities stock processed dry foods mainly for the rainy season, which can be eaten without cooking. They also stock fodder for the livestock and firewood for the kitchen. Some of the traditional food the community stocks includes *Chuda* (beaten rice), and Sattu (roasted Channa and made into powder mix with water and drink).

UNDP and the State jointly prepared DM plans and committees in all the villages of the State in 2007 with the support of the local NGOs. But none of them are active anymore. There are some initiatives by NGOs mostly on poverty reduction that work among the communities. However, the initiatives on flood management is less. The villages where NGOs work with communities in DM activities revive the DM task group before the onset of the rainy season and take necessary steps towards preparedness.

Communities see minor floods at the start of the Rabi season as good since it not only brings silt to improve the fertility of the soil but also helps improve the availability of water for the Rabi crops as many parts of the basin face water shortage after the rainy season. But long standing floods destroy crops, reduce yields, and affect livestock. The flood from the Bagmati river brings fertile silt which is useful while the flood from Gandak brings sand which affect the agriculture.

Based on the community survey and consultations, the following key issues and needs were identified in the BG basin.

Flood warning information dissemination

A majority of the communities do not have access to information from a flood early warning system in the basin and they have devised their own mechanism to monitor flood level. The efficiency of warning dissemination needs to be improved. The upper reaches experience flash flood due to heavy rain in Nepal and release of water from Nepal.

Access to information is mostly through radio (70% of the sample population). There is poor coverage of electricity and only 13% of the households sampled has TV. Communities also receive information through local billboard and neighbours.

Flood affecting assets

Floods affect livelihood (particularly agricultural crops) and household assets in the basin. There is a substantial number of people living within the embankment (hence unprotected) in permanent structures. The statistics on casualty of human and livestock are showing a decreasing trend during that last decades.

The choice of location (safe location) for housing is basically driven by affordability and poor people tend to live in the flood prone area (Figure 4). The poor people don't have the economic capability or rather they prioritise their needs with basic living needs (food) than increasing the plinth height of their houses. The plinth height of houses against the location of houses in the survey results shows that majority of the houses are at ground level or < 1 m height.

Loss of livelihood

Floods mostly occur during the Kharif season (July-Sept) due to monsoon rain. Cyclonic depressions hardly bring in heavy rains and floods in BG basin which is during Rabi season. Agriculture is the main livelihood in the basin. Community keeps livestock (buffaloes, cattle, goats) in small numbers at home as assets and sell when they need money. Economically poor people keep goats which is cheaper to buy while relatively better off people will have cows and buffaloes.The floods affect both agriculture and livestock.

Figure 4 Permanent occupation between embankment and river

Floods during July-Sept period are more damaging causing heavy loss particularly rice crops as Kharif rice is the main crop in the basin. Flood water normally stays in agriculture fields for 25-30 days and in some areas in the midstream part water stays for 60 days which are damaging. Flood water staying in agricultural fields for short duration affect the yield of the crops. Floods during Rabi season mostly affect pulses and vegetables and even short duration flood damages these crops.

Post flood issues

The incidence of water borne and vector borne diseases is very high in the State. The State Government has constructed several tube wells with hand pumps on the embankment for protected drinking water during flood situation. However, there is no adequate flood shelter in the basin and people resort to embankment, elevated roads, and roof top of pucca houses. Availability of fodder for livestock and firewood are also key problems, which persist after floods.

Siltation and water logging

Sedimentation in the river channel and low lying agricultural land is high in the basin which leads to water logging conditions. During the survey community informed that flood from Gandak bring sand which is not good for the agricultural land while the flood from Bagmati bring in silt which is more fertile. Heavy siltation on the river and irrigation channel makes the irrigation not possible. During the FGD, community informed that the Damodarpur canal and Turhut Main Canal (Gandak Project) are abandon for years as they got silted up. About 10% of the responding households informed that they face the problem of heavy sand deposition on their agricultural lands.

Health
Particularly in the rural parts of the State there is poor access to health facilities. As per the district statistics there is one hospital/health facility per 2,593 people. Based on the household survey, many respondents (40%) informed that they have to commute 2-5 km to reach the nearest health post or clinic. For 76% of the respondents, they have to travel more than 5 km for referral hospitals. Urban areas have better access to health facilities.

The basin has a reasonably good road network. The community faces problems in adequate shelter and safe drinking water and sanitation facilities during floods leading to disease outbreaks.

Water and sanitation
Drinking water and sanitation problem is common to all villages vulnerable to flood. Lack of toilet facilities lead to open defecation. The water and sanitation issues often cause high incidence of water borne diseases in the villages.

Education
During disaster situations, schools are used as shelters, which also cause disruption in studies. The community uses schools as shelters till the water recedes completely, which sometimes takes more than a month.

2.3.2 Economic impacts

The plains of north Bihar have experienced extensive and frequent loss of life and property over the last several decades (Sinha & Jain, 1998). Based on the years 1968 to 1990 the GFCC estimated the average annual flood damages to crops, houses and public utilities as INR 1,141 lakhs, 168 lakhs and 233 lakhs, respectively. The annual loss of human life was 11 and that of cattle was 62. The average annual area affected was 2.13 lakh hectares. From 1991 till 2012 the damages and fatalities are given in Table 3 for the districts of West Champaran, East Champaran, Muzaffarpur , Samastipur, Begusarai and Khagaria (based on the Disaster Management Department of Bihar). Although it is tricky to compare these figures because of possible differences in data collection, they suggest a significant increase in damages in the last two decades.

Table 3 Damages and fatalities for Burhi-Gandak over the period 1991-2012.

year	Number of people affected (lac)	Affected land (lac ha)	Estimated Crop Damage (Lac INR)	Estimated House Damage (Lac INR)	Estimated public property damage (Lac INR)	Number of fatalities
1991	6.88	1.88	642.4	193.91	27.7	16
1992	0.34	0.09	2	9	0	0
1993	18.88	3.12	7293.8	1982.59	72.76	21
1994	15.33	1.93	2567.32	290.57	2046.05	20
1995	7.35	1.26	738.82	160.85	58.01	28
1996	17.67	2.39	3062.98	202.09	16.5	50
1997	0	0	0	129	1.45	25
1998	35.66	8.9	12267.14	1859.35	1090.43	60
1999	15.01	2.14	9409.34	190.94	91	46
2000	11.44	1.95	1488.13	79.87	129.56	41
2001	31.09	3.31	10139.12	2117.22	1784.94	80
2002	35.98	4.37	16306.16	4054.22	9116.63	185
2003	21.88	5.44	4372.01	1296.41	247.07	97
2004	60.67	7.46	24616.4	23614.78	35821.12	316
2005-2006	9.2	2.96	370.98	60.43	16	20
2006-2007	3.78	177.152	818.28	1480.76	7456.17	14
2008	3.6	0.1402	336.94	799.85	80.03	18
2009	4.88	0.64	1151.55	21	55	22
2010	4.47	0.7	115.5	152.85	100	5
2011	2.84	15.25	435.51	50.92	0	42
2012	1.2	0.27	135.8	0.6	141	9
Average	15	11	4,584	1,845	2,779	53

Chapter 3 Flood risk assessment

3.1 Current flood risks

Figure 6 to Figure 10 show the flood inundation maps for the different return periods in the Burhi-Gandak river. The table below shows the flood extent, volume and maximum water levels for different return periods, as calculated by the model. Interestingly, the flood extent increase flattens after 1:75 year flood, but flood volume still increases. This implies that the flood depths increase as well (Figure 5). It can also be seen that most of the flood increase is due to the backwater effect of the Ganga, as water levels at Khagaria (downstream) are increasing more than at the upstream locations.

Table 4 Flood extent, volume and maximum water levels for different return periods

Item	unit	2 years	25 years	75 years	100 years	150 years
Max. flooding extent	Km^2	674.3	1571	2115.2	2184	2289.8
Max. flood volume	Mm^3	983.3	2590	3881.6	4119.8	4460.5
Max. water level Sikandarpur	m	57.6	58.7	58.9	58.9	58.9
Max. water level Rosera	m	50.0	51.1	51.2	51.2	51.3
Max. water level Khagaria	m	42.3	43.9	44.6	44.8	45.0

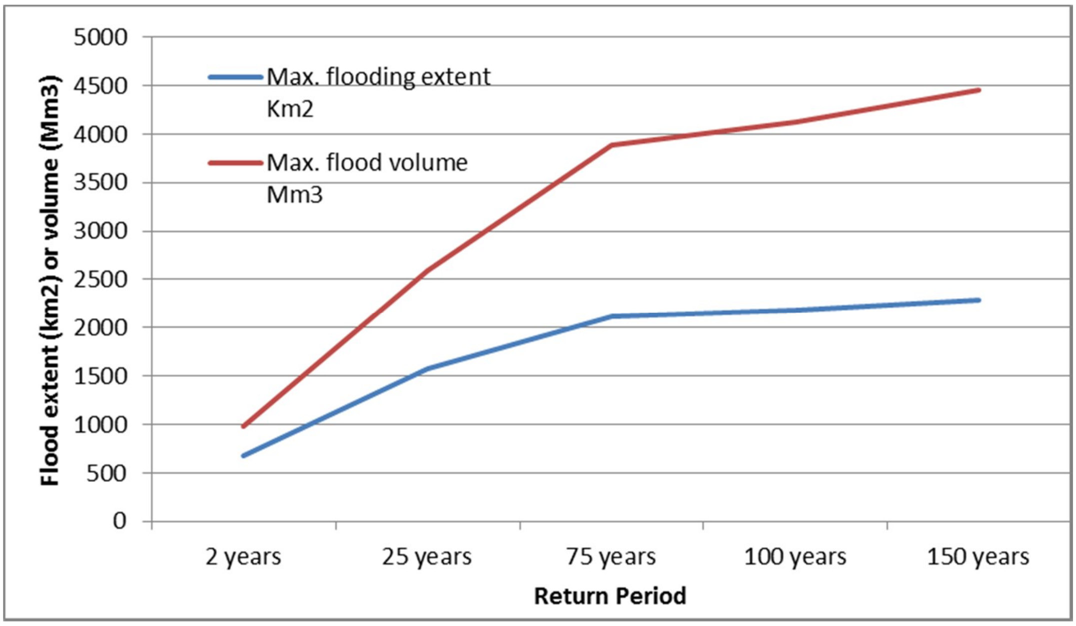

Figure 5 Flood extent (in km2) and flood volume (in Mm3) for different return periods

The next table present the damages corresponding with the different flood frequencies. These results show that current damages to houses and crops occurring almost every two years is around 2000 crores. Actual damages may be higher because damages to public infrastructure and household assets other than the house replacement cost are not included in the calculation.

Table 5 Damages for different return periods in Lakh Rupees

Item	Unit value (Rs)	1:2 years (Lakh INR)	1:25 years (Lakh INR)	1:75 years (Lakh INR)	1:100 years (Lakh INR)	1:150 years (Lakh INR)
Huts	25000	12,883	24,639	29,045	30,079	31,382
Kacha_HS	100000	17,971	40,417	50,973	54,031	57,545
Pucca_HS	350000	187,571	367,831	428,024	446,290	463,857
Maize	13100 INR/t	1,827	3,228	3,736	3,890	3,998
Rice	28191 INR/t	8,736	15,752	17,872	18,339	18,743
Pulses	42187 INR/t	2,074	3,295	3,790	3,867	3,902
TOTAL		*231,062*	*455,163*	*533,440*	*556,497*	*579,426*

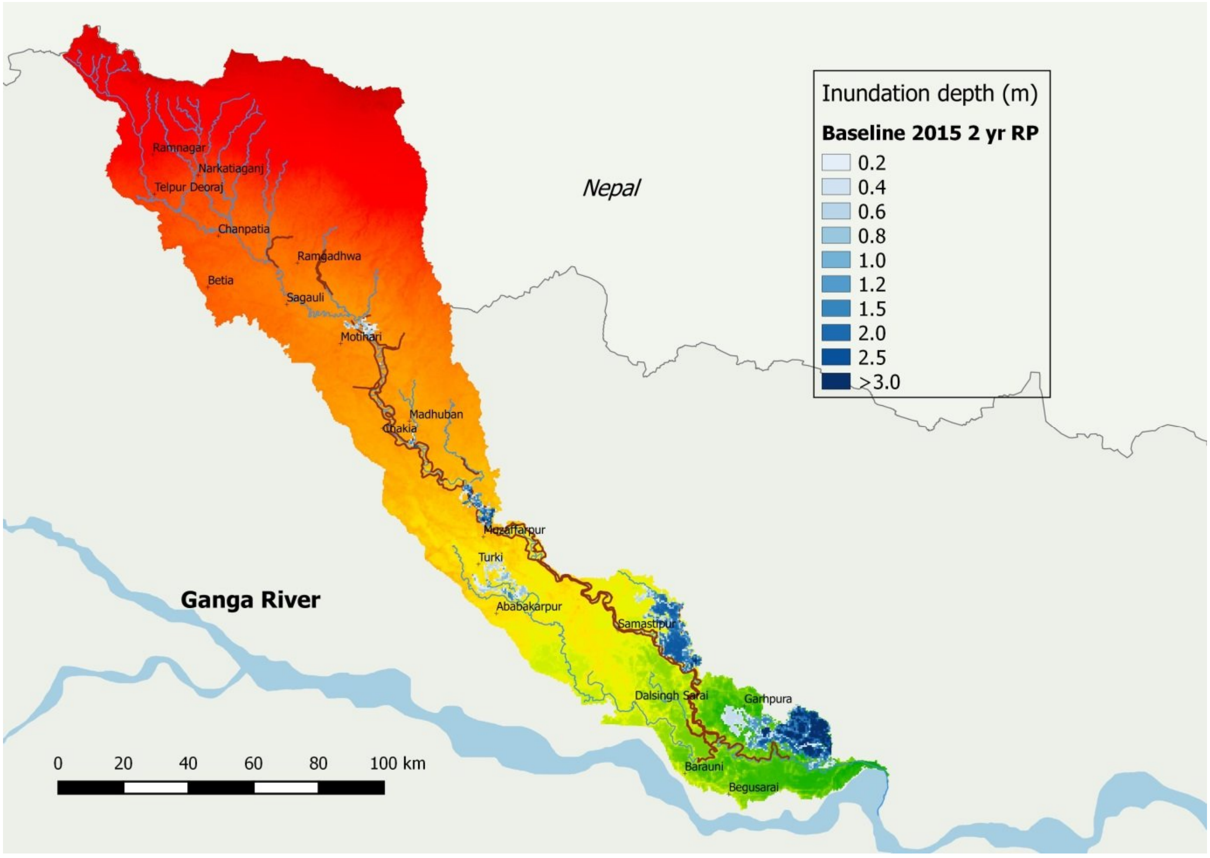

Figure 6 Flood inundation map for Burhi-Gandak for 1:2 year flood (SOBEK model result)

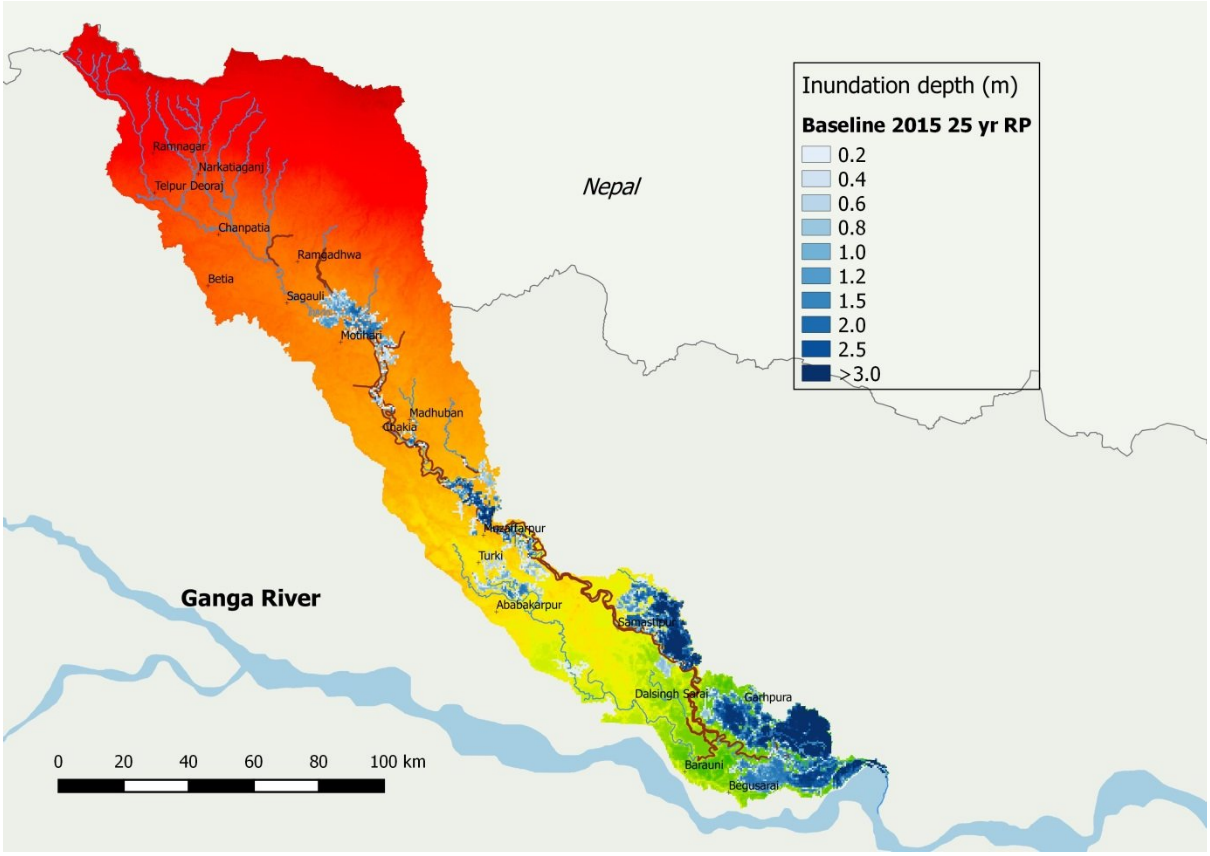

Figure 7 Flood inundation map for Burhi-Gandak for 1:25 year flood (SOBEK model result)

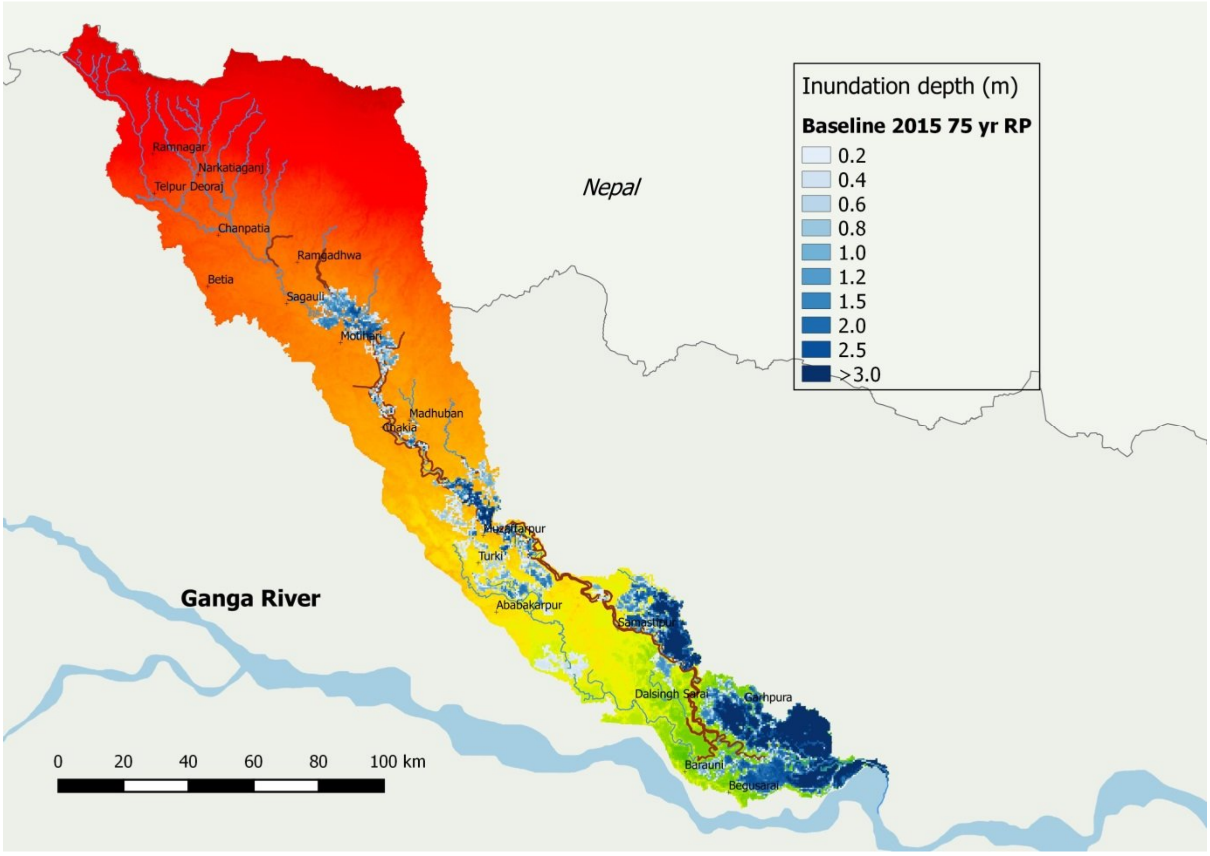

Figure 8 Flood inundation map for Burhi-Gandak for 1:75 year flood (SOBEK model result)

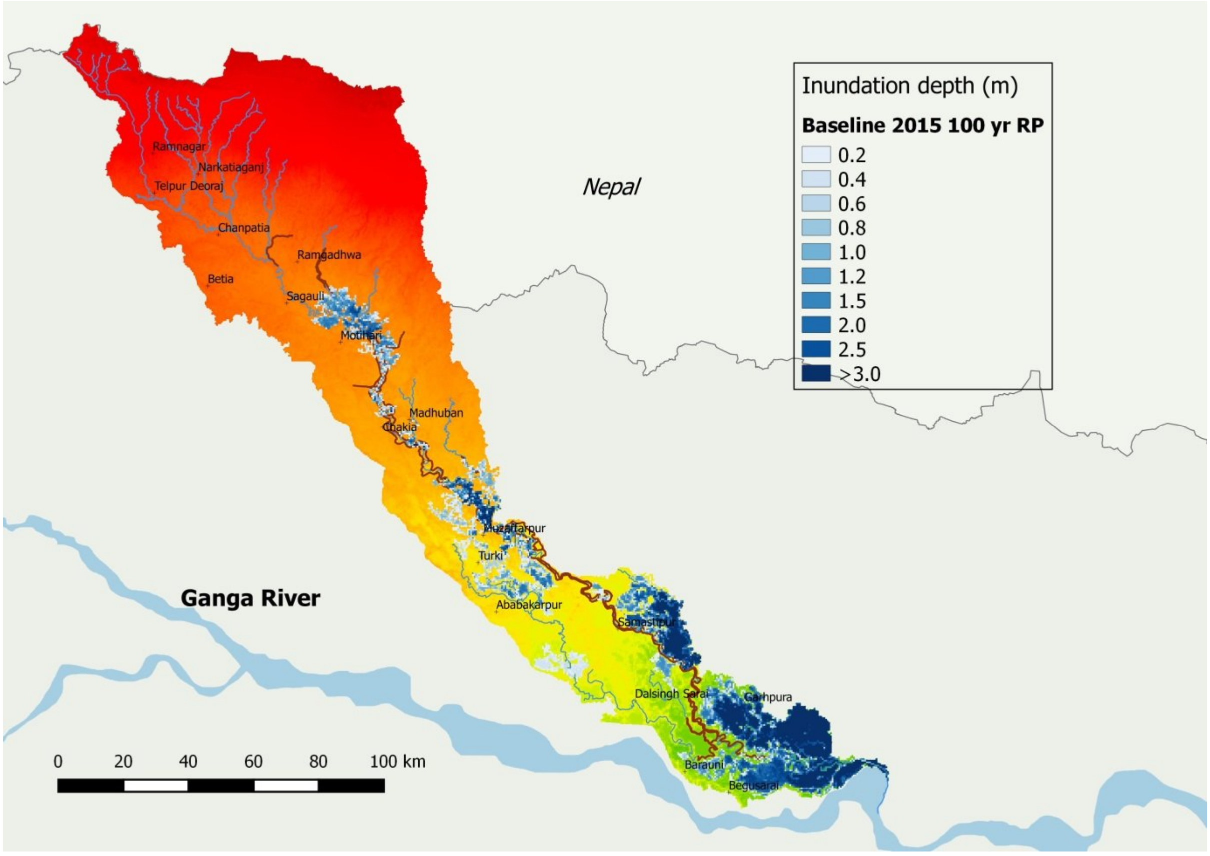

Figure 9 Flood inundation map for Burhi-Gandak for 1:100 year flood (SOBEK model result)

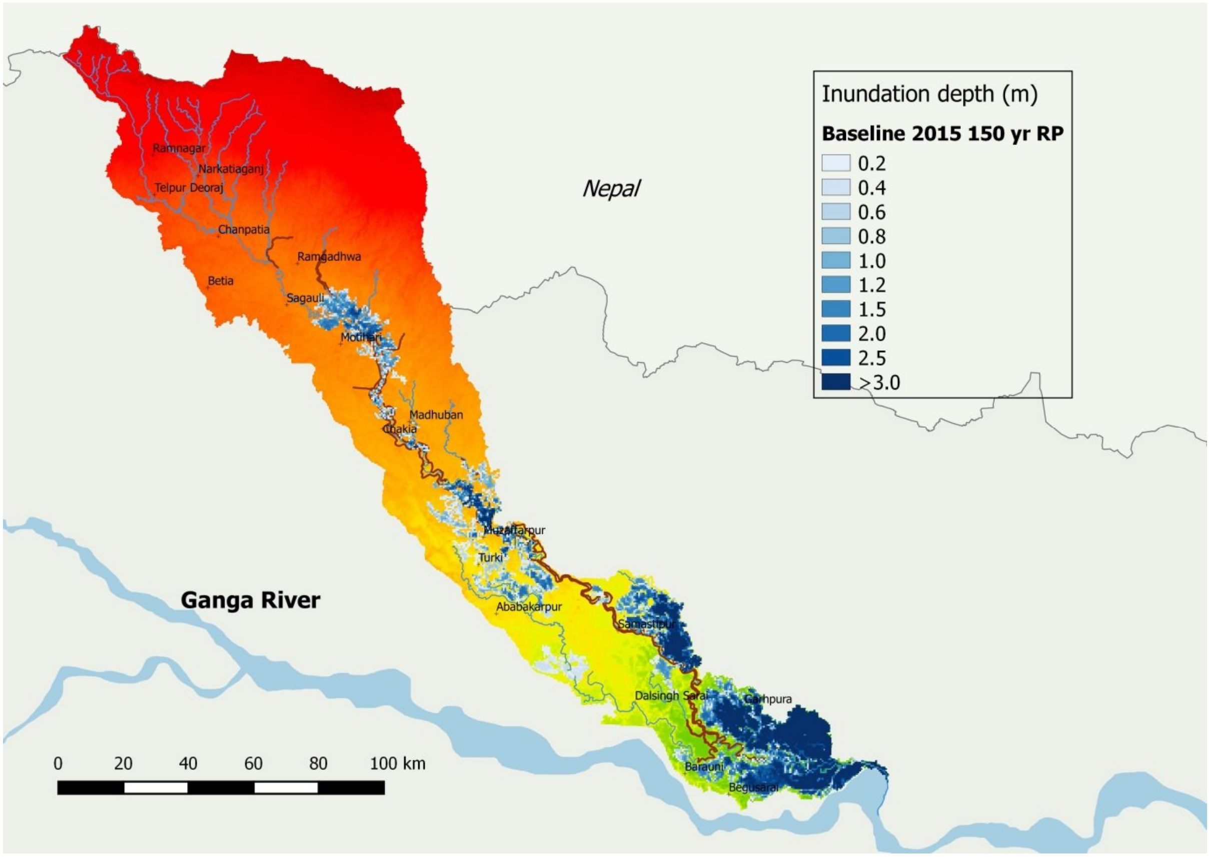

Figure 10 Flood inundation map for Burhi-Gandak for 1:150 year flood (SOBEK model result)

3.2 Climate change scenarios for flood modelling

3.2.1 Introduction

Given that weather extremes (e.g. drought and flood) are directly affected by climate change, it is important to understand the degree to which the adverse impacts of these on flooding intensity and frequency in major river basins could be exacerbated in the future. Varying spatially and temporally, these impacts are likely to have considerable implications for water resource planning, as well as adding to the risks to water infrastructure systems. Attention is increasingly being paid to flood hazard adaptation strategies at the regional and basin levels. However, no assessment of the likely changes in rainfall over the flood prone river basins have yet been undertaken in India which could be effectively deployed to evaluate the potential risk to hydrological systems at this scale and thus facilitate in the development of an effective water resources planning and investment strategy. Against this background and with the objective of assessing the possible impacts of climate variability and climate change on the flood hazards in the Burhi-Gandak river basin of Bihar, investigations have been attempted to: (i) validate the new CMIP5-based climate projections (temperature and rainfall) for the Bihar State by comparing the CMIP5-based model simulated climate (Knutti, R. & J. Sedláček, 2013[1]) for the baseline period (1961–1990) with that of APHRODITE-based observed climatology (Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of Water Resources, Japan) over the same period; (ii) assess CMIP5-based short (2040s representing climatology over 2030–2059) and long-term (2080s representing climatology over 2060–2099) climate change projections (temperature and precipitation) for Bihar; and (iii) assess the projected change in frequency of extreme rainfall events in the Burhi-Gandak river basin of Bihar based on CMIP5 projected climate change.

3.2.2 Selection of CMIP5 climate models, emission scenarios, and time slices

The climate models that could be considered for downscaling the climate scenarios at local scale must skillfully replicate the statistics of the current climate at local scales. Many of the global climate models used in Fifth Coupled Model Inter-comparison Project (CMIP5), the findings of which are detailed in IPCC AR5 (now called as Earth System Models or ESMs) with their current horizontal resolutions are not tuned to provide realistic climate simulations at sub-grid scales particularly in regions characterized by non-uniform topography and near the coastal locations. The main source of skill in new ESM simulated temperature and rainfall is the seasonal and annual cycle in rainfall and the warming trend with time, which is primarily forced by greenhouse gases and aerosols.

We have identified three better performing climate models and downscaled the model-simulated near surface air temperatures and rainfall for Bihar State and compared these with the actual average monthly observations for the baseline period of 1961-1990 (Table 6). The findings of this validation exercise suggest that there still are problems in simulating the local climate with respect to current model statistics in most of the models. The standard deviation of model simulated

[1] Knutti, R. and J. Sedláček, 2013: Robustness and uncertainties in the new CMIP5 climate model projections, Nature Climate Change, Volume: 3, Pages: 369–373, DOI: doi: 10.1038/nclimate1716.

monthly mean surface air temperature and rainfall over India (averaged over land points only) as compared with CRU-based rainfall and temperature climatology (Climate Research Unit, Norwich-UK) for the period 1971-2000 suggests a fairly reasonable performance of almost all the models in simulating the annual cycle of surface air temperature. However, MIROC5 is one of the individual models that is closer to the observations in terms of simulation of surface temperature over Indian subcontinent. For precipitation variable, the model simulations, invariably, deviate significantly from observations. The RMS errors are large and the correlation is weak, it ranges from 0.30 to 0.75 among the models analyzed here. GFDL-CM3 is the best-performing individual model for simulation of precipitation, followed closely by others over India. A further analysis of daily data generated by these two model simulations demonstrated a high skill in simulated surface air temperature and its annual cycle in the State of Bihar when compared with Indian climatological data base (least bias) and a closer resemblance with the climatologically observed behavior of rainfall associated with monsoon onset, progression with time across India and its withdrawal with the end of monsoon season. It is therefore crucial that we apply systematic bias corrections to the model simulated surface air temperatures and rainfall for obtaining meaningful future projections for Bihar. The said corrections are least in the identified three ESMs ($<2.0^oC$ on point scale). The three state-of-the-art Global Climate Models used for CMIP5 experiments, namely, HadGEM2-ES Model (UK), GFDL-CM3 Model (USA), and MIROC-ES Model (Japan) reproduce current mean annual and seasonal monsoon rainfall over the land grid points of Indian sub-continent in the acceptable uncertainty band over India as compared to a total of 18 ESMs used in validation exercise (Kumar & Goswami, 2014). The simulations of daily intensity of rainfall in some of the ESM are also in significant error in that the model does not realistically simulate the high daily rainfall episodes. Some models produce precipitation approximately twice as often as that observed and make rainfall far too lightly. Therefore we consider the choice of three ESMs adopted in this study as most appropriate for obtaining climate variability and climate change scenarios at a time scale of a century or shorter.

Of the many CMIP5 GCMs with daily fields available, three ESMs simulate the key regional aspects of climate over the Indian sub-continent sufficiently fairly well (and hence narrow the range of uncertainty) in that we consider the projections from those models ‘plausible’ (GFDL-CM3, HadGEM2, and MIROC-ESM). The data generated by simulations from these three models have been deployed for generating downscaled climate change information for a consistent multi-regional/local assessment of hydrological impacts to climate change in this study. It is also noteworthy here that, even though a majority of climate change impact assessment studies have been performed in India and some selected States using the future projections from previous version of the Hadley Centre Global Climate Model and the regional climate models including PRECIS, the latest version of MIROC and GFDL Earth System Models have performed better in terms of monsoon rainfall simulation irrespective of relatively coarser horizontal resolution. Whilst each of the three models captures the July–August peak in rainfall over the region of interest, HadGEM2 model has a tendency to over/under estimate the magnitude in June and/or September). We have also examined the rate of total precipitation explained by convective and stratiform precipitations in observations and in these three CMIP5 models. It is found that the models produce too much (little) convective (stratiform) precipitation compared to observations. In addition, we also find stronger precipitable water—precipitation relationship in the models as compared to observations. Hence, the atmospheric moisture content produced by the model perhaps immediately gets converted to precipitation even though the large-scale thermodynamics in models weaken. Therefore, under global warming scenarios, due to increased temperature and resultant increased atmospheric moisture supply, these models may tend to produce unrealistic local convective precipitation often not in tune with other large-scale variables. This may question the reliability of the Indian summer monsoon rainfall projections in climate models and highlight the need to improve the convective parameterization schemes in coupled models for the robust future projections.

Table 6: The validation statistics of climate models used in this study

Technical specifications	Observed Climatology	HadGEM2-ES Model (UK)	GFDL-CM3 Model (USA)	MIROC-ES Model (Japan)
Horizontal Resolution	-	Longitude: 1.87°; Latitude: 1.25°	Longitude: 2.50°; Latitude: 2.00°	Longitude: 2.81°; Latitude: 2.79°
Number of model layers in vertical	-	Atmospheric component: 38; Oceanic component: 40	Atmospheric component: 48; Oceanic component: 50	Atmospheric component: 80; Oceanic component: 44
No of Grid points within Burhi-Ghandak Basin	6	6	4	3
Annual mean surface air temperature in Bihar State (°C)	24.0	-*	21.00	-*
Annual Rainfall (mm) within Burhi-Ghandak Basin (percent deviation from observed)	1063	1835 (72.6%)	1400 (31.7%)	1262 (18.7%)
Monsoon Season Rainfall (mm) within Burhi-Ghandak Basin (percent deviation from observed)	895	1394 (55.8%)	1057 (18.2%)	866 (-3.2%)
* *Data not available*				

The GHG scenarios followed through Representative Concentration Pathways (RCP) in ESMs are a step evolving away from the non-mitigation SRES scenarios considered previously in IPCC AR4. They are compatible with the full range of stabilization, mitigation and baseline emission scenarios, represent consistent sets of projections of only the components of radiative forcing that serve as input for climate modeling, pattern scaling, and atmospheric chemistry modeling and span a full range of socio-economic driving forces. RCPs allow climate modelers to test different social, legislative and other policy initiatives, and see the economic effects as well as environmental; mitigation results as well as adaptation. In the current scenario of uncertainty in global agreement on mitigative actions for restricting the greenhouse gas emissions, the RCP6.0 represents the most plausible concentration pathway for the future. As policy makers and decision makers at country level and at municipal level in a developing country are not so much interested in a range of possibilities as regards the absolute local climate change but in the scale of vulnerability due to nature of future extremes and adaptive actions to be mainstreamed in their future development plan, we have opted for considering the best choice of RCP6.0 in our vulnerability assessment. Hence, in this study, RCP 6.0 representative concentration pathway was considered for the generation of the climate change projections as it follows a stabilizing CO_2 concentration close to the median range of all the four policy pathways. The climate change data analysis for inferring projections of future climate change in this study has been done on three time scales, namely, baseline (1961-1990), near term (2040s i.e., 2030 to 2059), and long term (2080s i.e., 2070 to 2099). Figure 11 to 13 depict the location of grid points in the data sets obtained from three climate models over the Burhi-Gandak river basin.

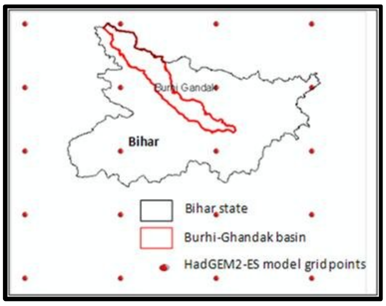

Figure 11: Location of HadGEM2-ES model grid points over the Burhi-Gandak basin

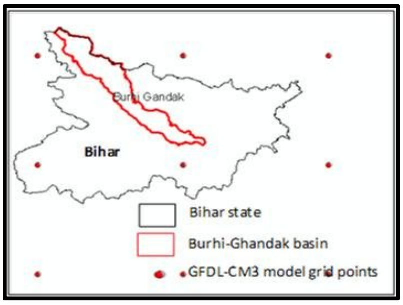

Figure 12: Location of GFDL-CM3 model grid points over the Burhi-Gandak basin

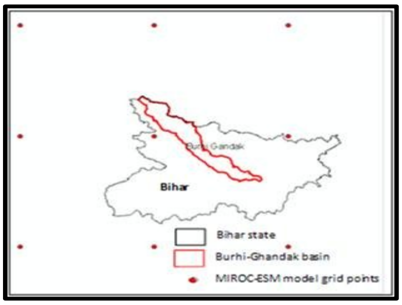

Figure 13: Location of MIROC-ES model grid points over the Burhi-Gandak basin

3.2.3 Bias correction in rainfall data

The focus of the great majority of climate change impact studies undertaken thus far are based on changes in mean climate. This is primarily due to the fact that these changes are more robust than changes in climate variability In terms of the ability of the climate models. However, by concentrating on changes in climate means in impact assessment studies available in literatures, the full impacts of climate change on hydro-meteorological systems are probably being seriously underestimated. Climate change is inevitably resulting in changes in climate variability and in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events. Changes in the frequency and severity of extreme climate events and in the variability of weather patterns will have significant consequences for integrated flood management in a river basin among other human and natural systems. The possible impacts of changes in climate variability on hydrological systems in the tropical countries such as South Asia could be significant with human populations rising unabated throughout the present century, where the deleterious impacts of anthropogenic climate change are generally projected to be greatest.

Unfortunately GCMs are of rather coarse resolution to directly infer climatology of high-impact weather at local scales and it is common to downscale over regions of interest using statistical techniques or nested regional climate models (RCMs). Significant biases or systematic errors in the model are common due essentially to nonlinear nature of climate when compared to observed climatology at smaller spatial scales. These biases can be problematic for these downscaling applications to regional and extreme weather climate scales. In practice, statistical bias correction is applied independently across time and space, without taking into account feedback mechanisms between atmospheric processes. It is important to remember that the GCM data were generated at a coarse resolution, where local processes and terrain heterogeneity were not taken into account. It also is possible that statistical downscaling methods developed on past climate might not hold true under climate change conditions. An alternative, widely-used approach is to nest a RCM within GCM boundary conditions. RCMs can operate at higher resolution than GCMs to enable simulation of much finer scale features, which are required for assessment of many extreme weather phenomena. One shortcoming of this approach is the transmission of GCM biases through the RCM lateral and lower boundaries, which may have a severe impact on the interior climate. This approach suffers from the same limitations as the aforementioned statistical bias correction of GCMs and has the additional complication that GCM biases may irretrievably change—or even destroy—the high-impact weather signal of interest. An alternative bias-correction approach is to construct boundary conditions from a current climate reanalysis plus a climate change perturbation, a technique known as pseudo-global-warming. This approach is simple to apply and takes advantage of the improved ability of GCMs to simulate trends compared to absolute climates. However, there are substantial disadvantages arising from the inherent assumption of no change in synoptic and climate variability. Biases from current GCM simulations also may change into the future (arising from a possible non-stationarity of the bias) and alias into the imposed climate change perturbation.

In view of the limitations of obtaining precise climate change scenarios of future changes in rainfall at river basin scale as desired in this study, bias correction will need to be applied to model simulated future projections of daily rainfall data. For this, first the model simulated baseline period daily rainfall data has been validated against high resolution global gridded rainfall climatology for the 1961-1990 period developed at MRI, Japan. Subsequently, the 30 year mean bias correction factor (multiplication factor) for each month is obtained and this has been applied to projected 30 year daily rainfall data series centered around 2040s and 2080s. The bias-corrected daily rainfall data series for the future time slices has subsequently been used for inferring a number of rainfall indices to understand the nature of future changes in rainfall variability and extremes over the identified river basin in Bihar at two future time scales (such as events of light rain, moderate rain, heavy rain, maximum rainfall intensity). These inferred changes in indices are applied in the hydrological modeling exercise to assess the future flood intensity potentials during different time horizons.

3.2.4 Future climate change data analysis

Spatial distribution patterns in maximum and minimum surface air temperatures and rainfall over Burhi-Gandak basin of Bihar state were developed using above-mentioned climate simulation models data in GIS platform (ArcGIS 9.3). These analyses provide the likely shifts in spatial changes of temperature, and rainfall during 2040s (2030-2059) and 2080s (2070-2099) with respect to baseline time period (1961-1990). The key findings from these should be used to assess the implications of projected climate change on various meteorological and hydro-meteorological hazards (e.g., drought, flood, and heat wave etc.) over the selected river basin in Bihar State.

The possible impacts of changes in climate variability and the frequency of extreme events on droughts / floods in a river basin, requires analysis that tentatively links increases in climate variability with increasing flood severity in the future. The bias-corrected daily rainfall data series for the future time slices are used for inferring a number of rainfall indices to understand the nature of future changes in rainfall variability and extremes at various temporal scales. The rainfall indices are helpful in a better understanding of the nature of likely changes in rainfall and in assessment of the future flood scenarios in the selected river basin and subsequently in the development of integrated flood management options. These inferred changes in indices were also applied in the hydrological modeling exercise to assess the future flood intensity potentials during different time horizons. Our target in this analysis was aimed at the disaster management authorities who need to deal with climate variability and extremes and develop appropriate responses with actionable answers as to how they may adapt to prevent or minimize losses in the future. Given that the key knowledge on the full range of impacts of climate change on hydrological systems remains a critical gap on being able to address effectively the effects of climate variability and extreme events on human vulnerability, particularly in agriculturally based developing countries facing the challenge of having to feed rapidly growing populations in the coming decades. Our approach on developing the hydro-meteorological indices is an attempt to address this gap for the integrated flood management in the identified river basins in India.

3.2.5 Future climate change scenarios for Bihar

The projected rise in maximum (day-time) and minimum (night-time) surface air temperatures over Burhi-Gandak basin of Bihar State at two time slices namely, 2040s and 2080s are illustrated in Figure 14 and Figure 15, respectively. The plausible changes in annual mean and monsoon season rainfall over Burhi-Gandak basin of Bihar for two time slices namely, 2040s and 2080s are depicted in Figure 16 and Figure 17 respectively. The results shown here for the purpose is for GFDL-CM3 model only as a representative one.

It is evident from Figure 14 that the mean maximum annual day-time surface air temperatures in Burhi-Gandak basin of Bihar State is likely to rise on an average by about 2.0°C around the middle of this century while the rise in mean annual night-time minimum surface air temperature could exceed 2.2°C by the middle of this century. This suggests that the diurnal temperature range would become lesser in future in the Burhi-Gandak basin of Bihar State. During 2080s, annual maximum day-time and minimum night-time surface air temperatures in Burhi-Gandak basin are expected to rise in excess of 3.5°C and 4.0°C respectively (Figure 15). These projections of rise in surface air temperatures in future suggest that the intensity of heat waves in and around Burhi-Gandak river basin should become stronger with time during peak summer months and record high temperatures could be experienced here more often in future.

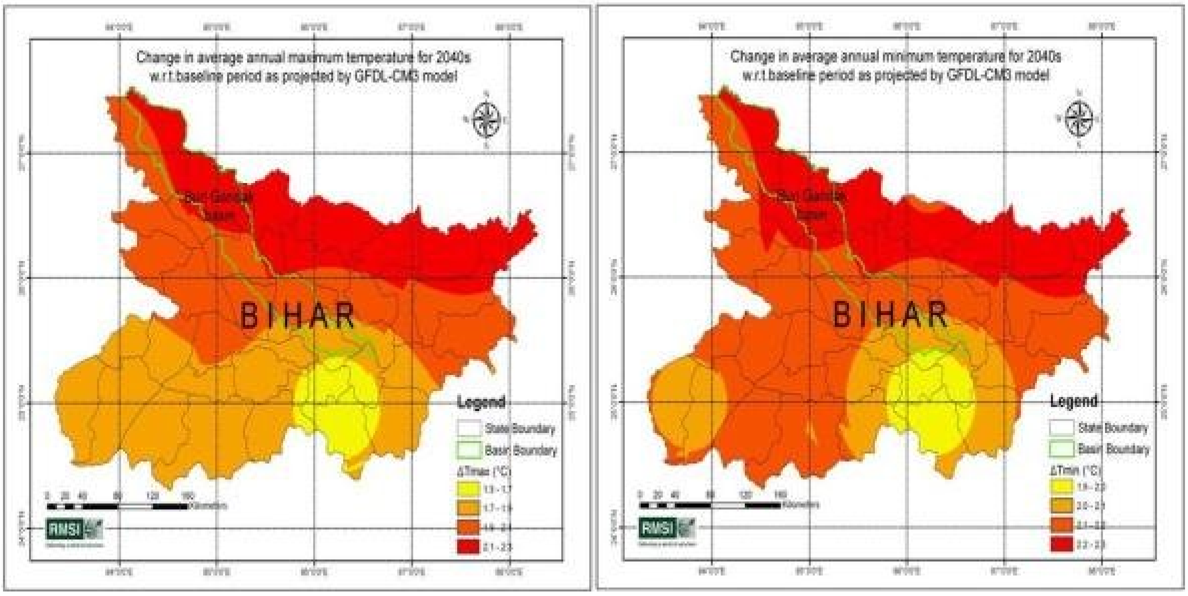

Figure 14: Projected rise in annual mean maximum and minimum surface air temperatures during for 2040s in Bihar (Burhi-Gandak basin is marked with green colour boundary)

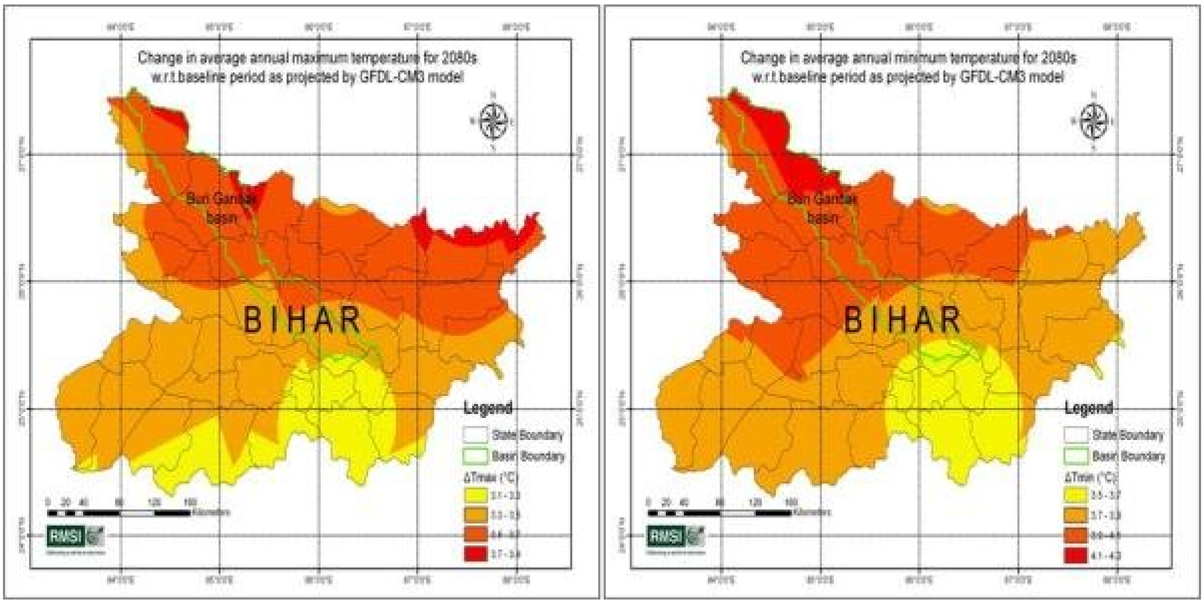

Figure 15: Projected rise in annual mean maximum and minimum surface air temperatures during for 2080s in Bihar (Burhi-Gandak basin is marked with green colour boundary)

The spatial change in annual mean and monsoon season rainfall patterns (simulated by GFDL CM3 model) over the Bihar State by the middle of this century is depicted in Figure 16. Figure 17 depicts the annual mean and monsoon season rainfall over the Bihar State by the end of this century. More detailed examination of the rainfall change over the Burhi-Gandak river basin as inferred from an ensemble of three models considered here suggests (Figure 18) that the total rainfall during the monsoon season is projected to increase by about 80 mm in a year over the Burhi-Gandak basin by the middle of this century. The total rainfall increase during monsoon by the end of this century over the Burhi-Gandak basin would by about 200 mm. On an average, the Burhi-Gandak basin is likely to experience an increase in rainfall by the mid 21st century and beyond. On annual basis, the rainfall could increase over the Burhi-Gandak basin by about 20% by the end of this century. It is interesting to note that, broadly speaking, both the monsoon as well as annual rainfall change projected by multi-model ensemble is marginally lower than those inferred by HadGEM2 model (Table 7).

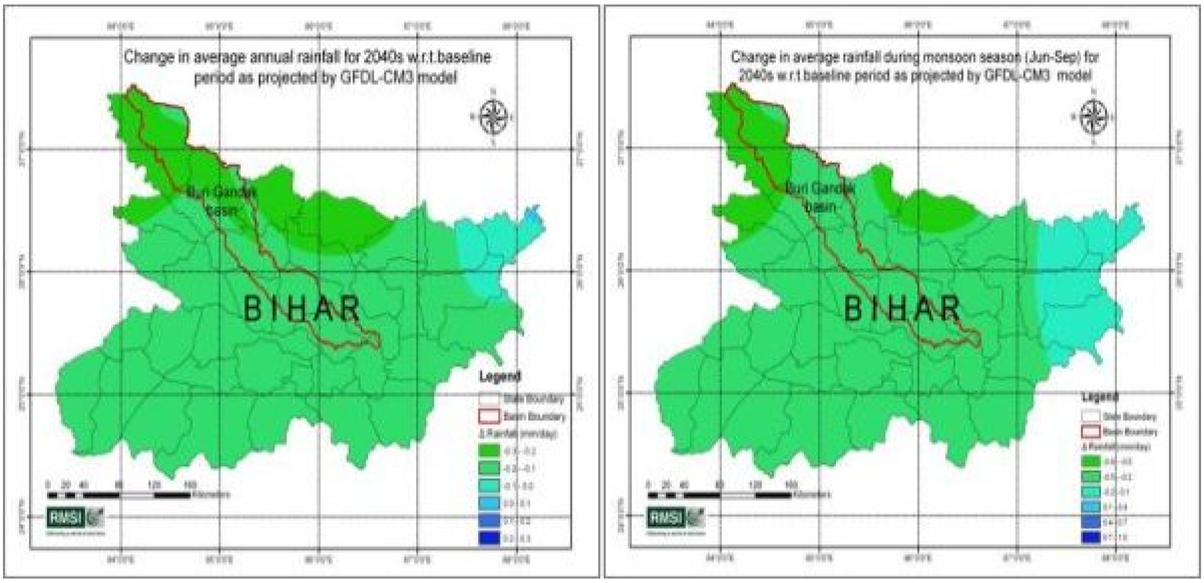

Figure 16: Projected change in annual and monsoon season rainfall (mm/day) for 2040s in Bihar (Burhi-Gandak basin is marked with red colour boundary)

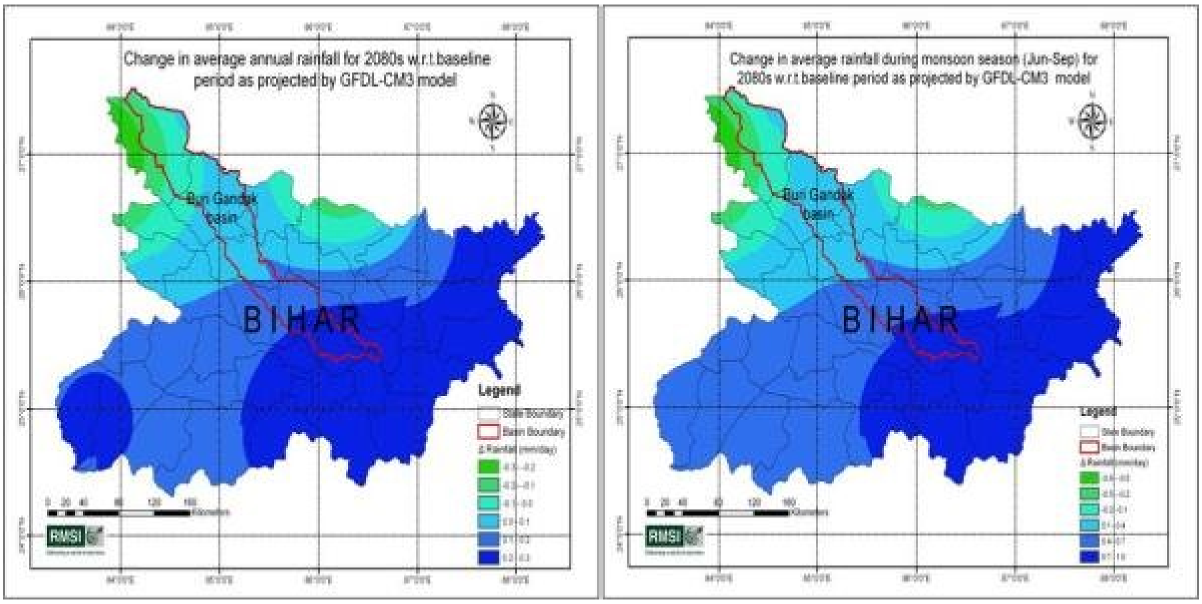

Figure 17: Projected change in annual and monsoon season rainfall (mm/day) for 2080s in Bihar (Burhi-Gandak basin is marked with red colour boundary)

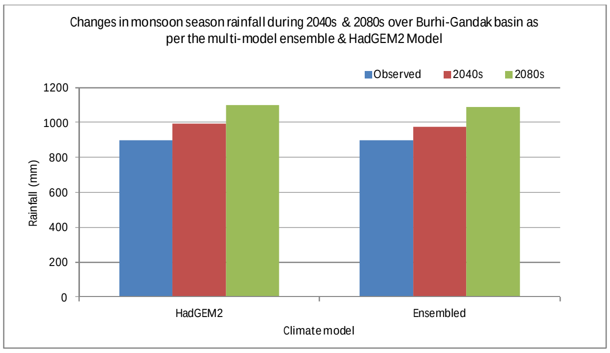

Figure 18: Changes in monsoon season rainfall during 2040s & 2080s w.r.t. baseline period (1961-90) over Bhuri-Ghandak basin as per the multi-model ensemble & HadGEM2 Model

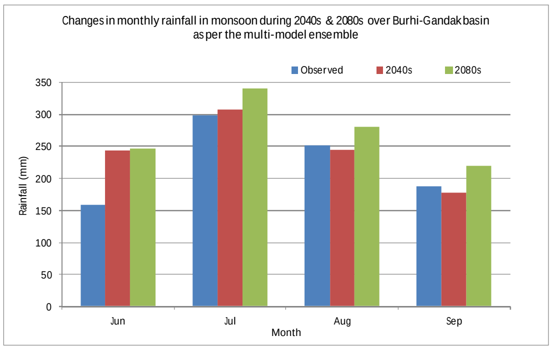

Figure 19: Changes in monthly rainfall in monsoon during 2040s & 2080s w.r.t. baseline period (1961-90) over Bhuri-Ghandak basin as per the multi-model ensemble

We have also analyzed the intra-seasonal behavior of monsoon rainfall during the four months from June to September each year. Our findings on likely behavior of monthly rainfall in each of these four months as illustrated in Figure 19 and Figure 20 for multi-model ensemble and for HadGEM2 model respectively suggest that over Bihar the nature of rainfall change in June (onset of monsoon) and in September (withdrawal phase of the monsoon) is different in the two illustrations (also evident in Table 7). This highlights the complexity in non-uniform behavior of the GCMs in simulating the rainfall and its change at the time of onset and withdrawal of monsoon over India.

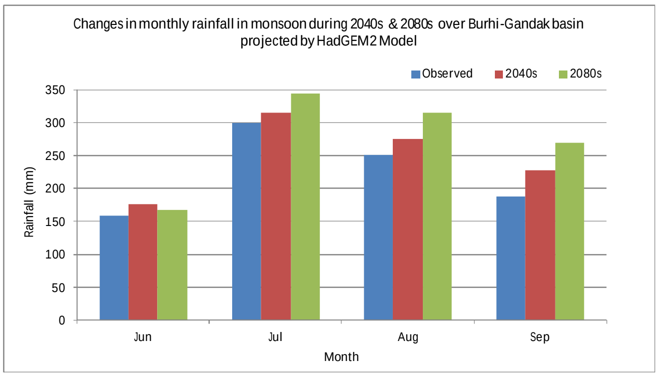

Figure 20: Changes in monthly rainfall in monsoon during 2040s & 2080s w.r.t. baseline period (1961-90) over Burhi-Gandak basin projected by HadGEM2 Model

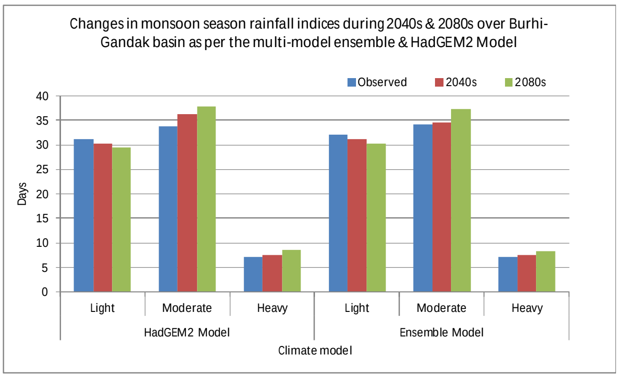

Figure 21: Changes in rainfall indices during monsoon season of 2040s & 2080s w.r.t. baseline period (1961-90) over Bhuri-Gandak basin as per the multi-model ensemble (HadGEM2, GFDL, & MIROC) & HadGEM2 Model

From the point of view of riverine flood in Bihar, the likely changes in the nature intensity of rainfall over the entire catchment area is equally important as this modulates the stream flow downstream of the river. Our analysis on the nature of rainfall intensity over the Burhi-Gandak basin suggests that each of the climate models simulate a decline in the frequency of light rain days and an increase in moderate and heavy rainfall episodes in future decades (Figure 21).

Table 7: Percent deviation of rainfall during 2040s & 2080s w.r.t. baseline (1961-90) over Burhi-Gandak basin as simulated by the HadGEM2 Model and multi-model ensemble

Month	**Observed rainfall (mm)**	**% deviation of RF during 2040s & 2080s w.r.t. BL period (1961-90) projected by HadGEM2 model**		**% deviation of RF during 2040s & 2080s w.r.t. BL period (1961-90) as per the multi-model ensemble**	
		2040s	**2080s**	**2040s**	**2080s**
Jan	10.66	-14.24	-16.84	11.64	-21.67
Feb	10.59	0.52	-26.10	80.81	20.19
Mar	10.16	12.03	-15.96	-1.76	23.48
Apr	18.95	0.12	7.16	43.94	0.49
May	48.69	5.47	13.99	65.62	16.63
Jun	152.69	15.85	9.87	59.54	61.05
Jul	307.64	2.53	11.76	0.20	10.62
Aug	251.63	9.38	25.01	-2.68	11.14
Sep	182.56	24.72	48.01	-2.59	20.22
Oct	58.12	38.26	187.01	14.05	76.87
Nov	5.31	-24.59	-25.69	-13.86	3.69
Dec	6.29	-26.15	-45.99	-27.82	-32.56
Annual RF (mm)	**1063**	11.52	28.99	12.76	22.95
Monsoon season RF (mm)	**895**	11.26	22.56	8.95	21.33

Maximum daily rainfall intensity during baseline period, 2040s, and 2080s over Burhi-Gandak basin as inferred from observed data, HadGEM2 model, and the multi-model ensemble are given in Table 8. No consistent behavior in the projected change in daily rainfall intensity is observed over the Burhi-Gandak basin as a whole in each of the months during monsoon season in the future. However, during the latter part of the monsoon season (August and September) the findings suggest an increase in the daily maximum intensity of rainfall over Burhi-Gandak basin. Interestingly, the projected increase in the daily maximum intensity of rainfall over Burhi-Gandak basin is also projected in October which is indicative of the likely occurrences of more flash floods in and around the basin during September-October months in later part of the century.

It is thus evident from our analysis that as the total seasonal rainfall as well as the episodes of heavy rainfall incidences is projected to increase over the Burhi-Gandak basin of Bihar State, the river catchment is likely to face more widespread flooding by the end of 21st century. The projected rise in maximum surface air temperature over the basin and the Bihar State during future further suggests that warmer air would have higher water holding capacity and stronger convective activity can lead to more intense spells of rainfall associated with thunderstorm activity which may contribute to faster stream flow and result in flash floods in parts of the catchment area.

Table 8: Maximum daily rainfall intensity during baseline period, 2040s, and 2080s over Burhi-Gandak basin as inferred from observed data, HadGEM2 model, and as per the multi-model ensemble

Month	**Maximum daily rainfall intensity (mm)**				
	Observed	**2040s projected by HadGEM2**	**2080s projected by HadGEM2**	**2040s as per the multi-model ensemble**	**2080s as per the multi-model ensemble**
Jan	31.2	28.0	29.2	54.0	29.2
Feb	22.9	26.5	18.3	83.5	53.7
Mar	25.6	22.4	18.8	22.4	28.1
Apr	35.9	37.9	41.4	50.6	41.4
May	38.1	41.5	48.5	158.6	68.8
Jun	116.5	193.0	167.8	366.1	295.6
Jul	147.0	120.7	139.4	121.6	139.4
Aug	135.9	131.0	156.1	154.5	198.7
Sep	211.2	218.4	308.8	218.4	308.8
Oct	206.9	471.7	886.4	471.7	886.4
Nov	30.9	28.0	28.1	36.1	45.2
Dec	34.4	20.2	11.8	44.5	44.3

Bihar, which is normally stated as a water rich state, has come to have water availability of only 1273 cum per capita in 2011. This is much below the 1700 cum per capita standard, thereby placing Bihar under Water Stressed Zone. Bihar faces severe onslaught of floods in every monsoon season starting in June and continuing until October. In the absence of integrated storage structures, most of this water flows away without even recharging properly the groundwater level. Therefore, it is imperative that flood water should not drained wastefully when it could be effectively used for ground water recharge, agriculture and industrial use. The present cropping intensity of 151% is proposed to be raised to 180% by 2017 and 200% by 2022. This entails increasing the irrigation intensity from 83% at present to 158% by 2017 by 209% by 2022. The future climate scenarios indicate an overall increase in the intensity of mean monsoon season floods in Bihar. The analysis of 30 years of daily rainfall data further indicates that most intense spells of rainfall during monsoon season and hence the floods incidences could increase in future. Therefore, Bihar will have increasing requirement of water for agriculture. It is therefore recommended to resolve inter-state issues on dam and reservoirs with Jharkhand and Uttar Pradesh and to coordinate scientific planning of land and water resources in order to mitigate the impacts of climate change.

3.3 Impact of climate change on flood hazards

The projections on change in rainfall within the river basin and associated statistics on indices were used as forcing for the hydrological model SOBEK in order to infer the future climate induced changes in surface runoff and flood characteristics for time slices of 2040s and 2080s in this study. The results of the modelling are tabulated in Table 9. It shows that for the Burhi-Gandak an increase of 5% in flooding extent could be expected in 2040 and even 22% in 2080 for floods with a return period of 25 yrs.

Table 9 Impact of climate change on flood extent

Basin	Baseline (current)		2040		2080	
	Maximum flooding extent (km^2)	Max. flood volume (Mm^3)	Max. flood volume (Mm^3)	Max. flood volume (Mm^3)	Max. flood volume (Mm^3)	Max. flood volume (Mm^3)
1:25 year	1571	2590	1644 (+5%)	2650 (+2%)	1911 (+22%)	2972 (+15 %)

Chapter 4 Evaluation of flood risks

4.1 Recommended safety levels (return periods)

The present HFL followed is based on Flood Frequency analysis, but with inadequate data. The methodology adopted in the past, as per GFCC Master Plan of the basin. The GFCC has estimated this return period floods based on a compilation titled 'Workshop on Flood Frequency Analysis by the National Institute of Hydrology-Roorkee-1987-88'. As per this procedure they have carried out Flood Frequency analysis, considering the time series of annual maximum instantaneous gauges available at that time. For the flood frequency analysis they have adopted both the Gumbel's Extreme Value distribution (Type I Extreme value) and the Log Pearson Type III distributions. The results arrived at by the Log Pearson Type III distribution have been recommended. The gauge heights thus arrived at for 25, 50 and 100-year return periods are then converted to corresponding discharges using the Rating Curve at respective site. The gauges arrived at for 25 year return period are followed as HFL.

However, at present there is longer data time series of annual maximum flood discharges for about 30 to 40 years varying from station to station according to the starting of gauge-discharge observation in these stations. This data need to be analysed by Flood Frequency Analysis to re-establish the Return Period Floods for 25 year and 100 year. If the results give a higher discharge for these return periods (and as such higher HFL), the embankments need to be raised and strengthened accordingly.

Meanwhile, under this present study, CWC is running Hydrological/Hydraulic Modelling for the basin with Climate Change effects. The Consultants provide advice to CWC officers in running these Models. The Consultants are not directly involved in running these models, the basin being a classified basin. Because of climate change, the increased flood producing rainfall intensity has been predicted by a set of three Global Models for the scenario years of 2040 and 2080 (see Section 3.2). The model runs take these increased rainfall intensities for these two scenario years and result in the discharge rates at different locations of the river. Obviously, these discharges will be higher for a particular return period (25 and 100 years), calling for a higher HFL and consequent increase in the heights of the embankment in these scenario years. Then the HFL estimated even with the up to date data at present might correspond to a lower return period (say only 15 years). So in the future scenario years either the embankments need to be raised further and strengthened, if the present criteria is to be followed or else, the criteria need to be reviewed.

However, on the other hand, the projects under proposal in the basin could play a flood moderation effect. This will be discussed in the next Chapter.

4.2 Benefits (avoided damage) for different return periods

The model results (section 3.1) have calculated the potential damages for different return periods. For the evaluation of the desired safety level it is important to calculate Average Annual Damages (AAD). To better understand this concept, take for instance a damage for a specific event, say one in 75 years. This damage does not occur every year, but has a chance of 1/75 to occur. So to derive the AAD we have to divide the damage of the event with the probability. This would give a potential damage for that specific event of 0.01333 x 533,440 = INR 7112 Lakh. In order to include all possible events we have to integrate the area under the damage curve. In our case we have 5 different points on this curve. The AAD can then be approximated by using the following formula:

$$AAD = \int_0^1 D_F dp \approx \sum_{i=1}^{N} (D_{i+1} + D_i) \times (p_{i+1} - p_i) / 2$$

Where

D_F = Flood Damage

D_i = Damage of a flood event i

P_i = probability of a flood event i

For the four intervals we can calculate the annual interval damage. This has been done in the next table. The total flood risk for the Brahmani-Baitarani river floodplains can now be estimated by adding up all annual interval damages, resulting in a AAD of 1747.23 crores. With this table or formula it is also possible to evaluate the benefits of safety levels. For instance, providing a safety level of 1:25 years would mean that the damage for the 1:2 and 1:25 year flood will be zero. The AAD then is reduced to INR 108.22 crores. It shows that providing a safety of 1:25 years reduces the risk with 94%. Of course it is assumed that this flood protection is ideal and without failures.

Table 10 Calculation of Average Annual Damages using different return periods

Return period (per year)	Probability	Damage (Lakh INR)	P interval	mean damage (Lakh INR)	Annual interval damage (Lakh INR)
150	0.006667	579,426			
			0.003333	567,962	1,893
100	0.01	556,497			
			0.003333	544,969	1,817
75	0.013333	533,440			
			0.026667	494,302	13,181
25	0.04	455,163			
			0.46	343,113	157,832
2	0.5	231,062			
AAD					174,723

Table 11 Calculating the remaining AAD with a flood protection of 1:25 years.

Return period (per year)	Probability	Damage (Lakh INR)	P interval	mean damage (Lakh INR)	Annual interval damage (Lakh INR)
150	0.006667	579,426			
			0.003333	567,962	1,893
100	0.01	556,497			
			0.003333	544,969	1,817
75	0.013333	533,440			
			0.026667	266,720	7,113
25	0.04	0			
			0.46	0	0
2	0.5	0			
AAD					10,822

Chapter 5 Flood mitigation measures and strategies

5.1 Flood mitigation measures

The Ganga Flood Control Commission (GFCC) has brought out a detailed and comprehensive Master Plan of flood control for the Ganga basin(part II/11), in which exhaustive details are covered for the Burhi-Gandak basin. This Master Plan was updated in 1992 and has analysed the Burhi-Gandak basin in various perspectives like:

- Introductory description of the Burhi-Gandak River basin
- The hydrology and relevant analysis
- River Morphology and River behavior
- Past floods and damages
- Past efforts for flood management and the future approach
- Flood Forecasting and warning
- A set of recommendations after critical analysis of the basin parameters in Short term and Long-term measures.

The last item is very relevant to this study focusing the recommendations with respect to flood control embankments, which at present are the only major structural flood control measure in the Burhi-Gandak basin. The gist of these short-term and long-term measures are given below. These need to be appreciated and followed in a phased manner. The present study findings discussed in the paragraphs hereunder also lead to appreciation of these improvement measures.

Short-term Recommendations of GFCC

The remaining portion of the un-banked reach of the upper reaches should be provided with embankments to check floods in the region (see also figure 6). The on-going flood embankments should be completed and the gaps existing in the completed embankments should be closed after necessary investigations. The embankments should be properly maintained and the various anti-erosion measures should be continued to safeguard the embankments from bank erosion. On-going drainage improvement schemes should be completed and the proposed schemes should be taken up at the earliest after their due prioritization.

Long-term Recommendations of GFCC

A hydraulic model should be developed for the River system to study (i) The flood management measures to be undertaken in the upper reaches; (ii) Assessing the efficiency and appropriateness of alignments of the existing embankments, and improve these as per criteria; (iii) To improve the flood situation and drainage congestion in the catchment, inter-basin schemes to divert flood waters of the Sub-basin to Ganga. Increasing width of waterways under rail/road bridges have also been suggested, which may be taken up for execution after due study/investigations.

A suitable legislation on flood plain zoning to control and regulate the use of land for various purposes may be enacted after preparing flood risk maps for various flood frequencies so that in the event of flood the damages could be kept at a minimum level, soil conservation measures need to be taken up especially in the upper reaches. The possibility of opening a few flood forecasting sites should be examined.

5.1.1 Embankments

No major flood management scheme has been taken up till the middle of fifties, though the river witnessed many severe floods after the great earthquake of 1934 in Bihar. The successive floods of 1952, 1953, 1954, coming in a row, crystalized the idea of protecting the affected areas by making continuous embankments along both the banks of the river. Accordingly, constructions of embankments were taken up in 1955 and practically completed in 1957 in all the reaches starting from downstream of Motihari town to the end (GFCC, 1992).

Still, there are several gaps in the embankments of Burhi-Gandak as can be seen in the schematic diagram (Figure 22)[2]. The existing embankments should be maintained adequately as at places the top and slopes have faced deterioration. Also various anti-erosion measures should be continued to safeguard the embankments from bank erosion. Besides, many rail bridges have inadequate water way. GFCC Patna had asked for comprehensive proposals for raising and strengthening of existing embankments along Burhi-Gandak and construction of new embankments along Sikarahana river (as a short term flood control measures of Burhi-Gandak river system) vide its letter no. G.F.C.C./P/Tech/338/2007/2614 dated-11/4/2008 to Water Resources Department.

With respect to the issue of designing river embankments, reference is made to Section 4.4.6.2 "Suggestions for improved design of embankments" of the Main Report. These suggestions could be followed depending on the site specific needs. The parameters on the degree of protection to be provided, spacing of the embankments, side slopes and free board are to be reviewed as per the suggestions provided in the above mentioned Section.

[2] For instance, the gap of 10.50 km length in the existing embankment near Muzaffarpur should be closed after thorough examination and finding ways to remove the adverse effects on the Bagmati floods, if any (GFCC Master Plan for Flood Mitigation Burhi Ganga, 2008)

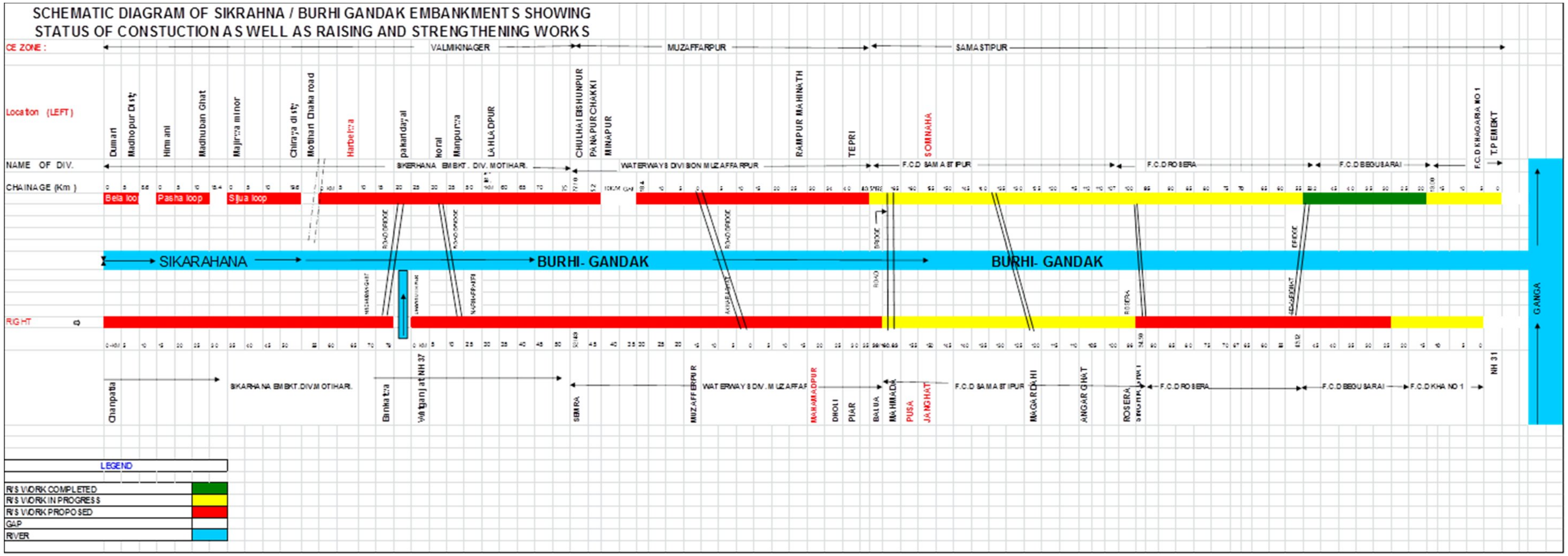

Figure 22 Schematic diagram of embankments Burhi-Gandak

5.1.2 Outlined IFM plans for new structural measures

There is an old proposal from the year 1981 to build a storage dam across the Masan river. The Masan river is a tributary of the Burhi-Gandak river in its upper catchment. There is also a Detailed Project Report prepared very recently by the NWDA for interlinking Burhi-Gandak with its western tributary Noon and further linking it with the river Baya, a river to the west, which outfalls in to Ganga. NWDA has termed this project as “Burhi-Gandak-Noon-Baya- Ganga link”. In addition, some draft proposals for diverting water from Burhi-Gandak basin in the upper and middle reaches of the basin have been identified by the First Irrigation Commission of Bihar as early as in the 1970s. Hence, in this section we will study the following structural measures (see Table 12):

- Masan dam
- Burhi-Gandak-Noon-Baya- Ganga link
- Akharaghat barrage proposal
- Meiur Irrigation scheme
- Bapsa irrigation scheme

Table 12 Characteristics of (potential / planned) projects in Burhi-Gandak

SL. No.	Characteristics	Masan Dam	Burhi-Gandak-Noon-Baya- Ganga link	Akharaghat barrage
1	Dam Site Location	near the village Behwari in the Ramnagar block of the West Champaran district	near the village Muriaro	5 Km downstream of Akhrahaghat bridge
2	Latitude	27^{0} 18’ 30’’ N	25^{0}49’ 15’’ N	26^{0} 08’ 18’’ N
3	Longitude	84^{0} 13’ 20’’ E	85^{0} 53’ 45 ‘’ E	85^{0} 23’ 25 ‘’ E
4	River	Masan river	Burhi-Gandak	Burhi-Gandak
5	Catchment area	350 Km^2	12,500 Km^2	5,044 Km^2
6	Mean Monsoon Rainfall		1300 mm	
7	Annual 75% dependable rainfall	143.35 Mcum		
8	Design Flood Discharge	3851 m^3/s (to be checked)	4920 m^3/s (1:50 year)	2089.08 m^3/s
9	Gross Storage capacity at FRL	178.34 Mcum		
10	Main Dam Type	earthen dam		
11	Type of Spillway	chute spillway		
12	Gross Command Area	30,062 ha	125,000 ha	80,981 ha
13	Cultivable Command Area	21,600 ha		64,777.32 ha
14	Left main canal discharge	11.60 m^3/s	492 m^3/s (only one canal)	36.25 m^3/s
15	Right main canal discharge	7.93 m^3/s		
16	Total cost of the project	347.293 million (1981)	43,137.50 million (2013)	33.51 million (1970)
17	Benefit Cost Ratio at 10% interest	1.54 : 1 (1981)	1.54 : 1	
18	Internal Rate of Return		16% (8% interest)	

5.1.2.1 Masan Dam

This is a proposal made by the State Government of Bihar as early as in 1981. This was to construct a dam across the Masan river; Masan river is a tributary of the Burhi-Gandak river, rolling down from Nepal in the North-Western part of the upper catchment portion of Burhi-Gandak. This proposal was approved by CWC in 1981 and sanctioned; however, there are some problems with respect to the clearance from the Environment and Forest department;

The location of the dam is at East Longitude 84° 13’20’’ and at North Latitude 27° 18’30’’ (see Figure 23 for location). Though a number of tributaries roll down in the upper catchment with good water resources, they do not have sites for creating storages or diversions due to unfavourable topography. As such in the upper part of the catchment of Burhi-Gandak, Masan river only offers water resources as well as favourable topography to form a dam. The catchment area at the proposed Masan dam site is 350 Km^2 near the village Behwari in the Ramnagar block of the West Champaran district. The annual water resources estimated at the site is 143.35 Mcum (at 75 % exceedance probability level), which has been considered for project planning. The proposal envisaged an earthen dam with a chute spillway arrangement. The project aims to provide irrigation benefit for an extent of 27, 062 ha with the composition of gross and cultivable command areas of 30,062 and 21,600 ha respectively. The irrigation will be provided by two canals, one being the left irrigation canal with a discharging capacity of 11.60 m^3/s and the other, right canal, with a discharging capacity of 7.93 m^3/s. Thus a constant discharge of 19.53 m^3/s will be going out of the dam.

Figure 23 Location of projects in Burhi-Gandak basin

The cost estimate and the benefit –cost-ratio, both assessed in 1981 are INR 34.7 crores and 1.54:1, respectively. The gross capacity of the storage behind the dam is 178.34 Mcum. The chute spillway outflow maximum is stated to be 3851 m3/s, which seems to be disproportionally high for a small catchment area of 350 km^2 (even at Probable Maximum flood level).

5.1.2.2 Link Burhi-Gandak-Noon-Baya-Ganga

The National Water Development Agency (NWDA), has prepared the Detailed Project Report. The structure across Burhi-Gandak is a barrage of 611 meters long; the total cost of the project has been estimated at INR 4,314 crores rupees.

From the barrage, waters will be first diverted towards west to the river Noon, a tributary of Burhi-Gandak; at Noon, another regulating structure, will divert these waters to further West to Baya river, a small tributary of Ganga. The location of the Burhi-Gandak Barrage (see Figure 23) is at East Longitude 85^{o} 53' 45'' and at North Latitude 25^{o} 49' 15'', near the village Muriaro. The objectives of the Link Project are to divert flood waters of River Burhi-Gandak to river Baya and ultimately to Ganga through the tributary of Burhi-Gandak Noon (Figure 24) for flood moderation and irrigation to an area of 0.125 million hectares. The irrigation area is situated in the districts of Begusarai, Samastipur and Khagaria.

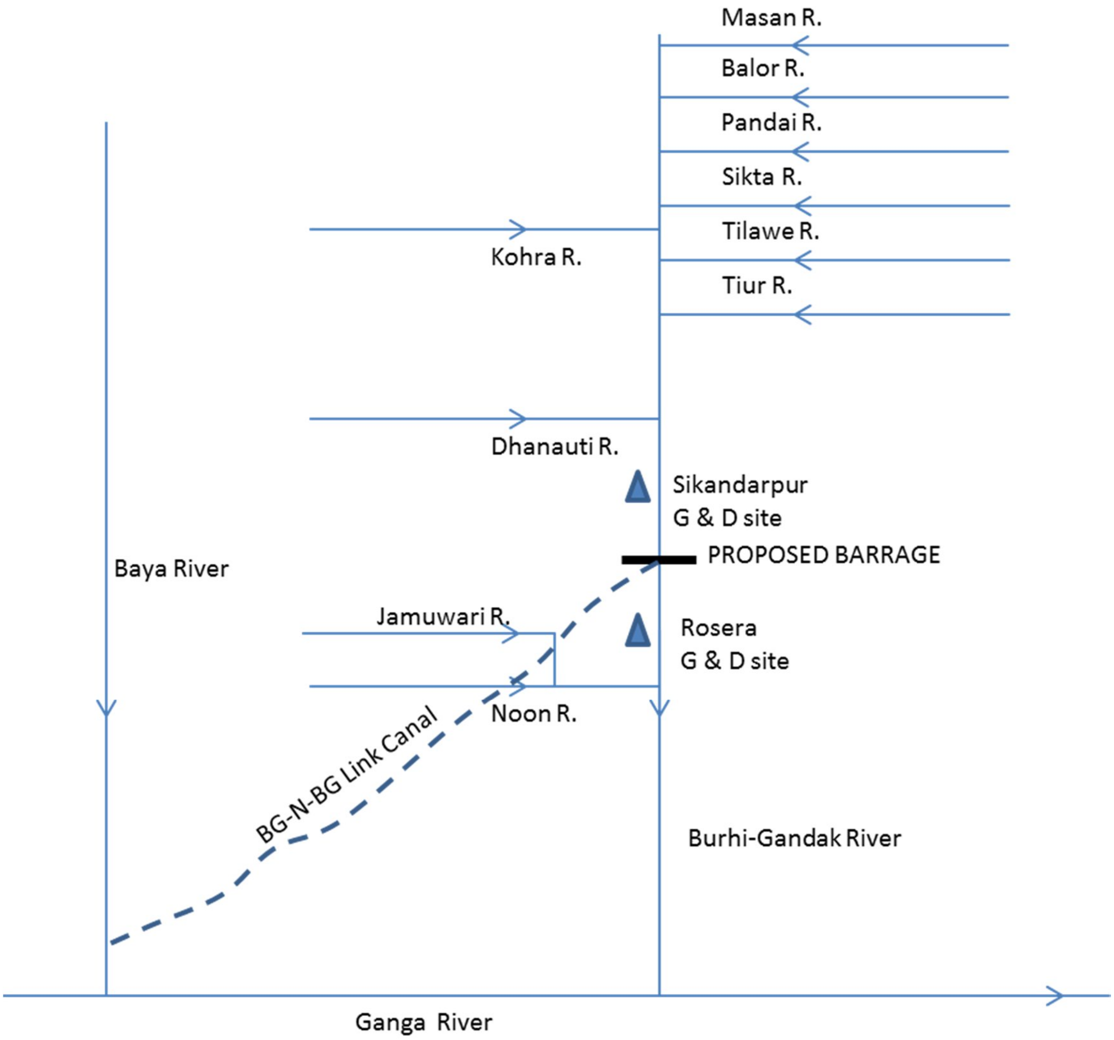

Figure 24 Schematic overview of BG-N-BG Link Canal

The catchment area of Burhi-Gandak at the proposed barrage site is 12,500 Km^2.The annual mean rainfall over the catchment is 1300 mm. The maximum observed flood discharge at the barrage site is 3787 m^3/s. The barrage design discharge however is fixed at 4920 m^3/s, corresponding to 50-year return period level at the site.

The Detailed Project Report has been prepared by the National Water Development Agency (NWDA), after analysing various aspects as below before fixing up the continuous diversion of 492 m^3/s, from Burhi-Gandak for irrigation in its Western track.

The project study has been finalised in the year 2013 after the approval of CWC. A continuous diversion of 492 m^3/s, of water will be diverted from the River Burhi-Gandak. This will reduce the flood realised at Burhi-Gandak at the head regulator site by this amount and only the remaining incoming flood will pass the regulator and will go downstream in Burhi-Gandak. Details on the economic costs and benefits are reviewed in Section 5.3.1.

5.1.2.3 Akharaghat Barrage Project.

This was a proposal identified by the First Irrigation Commission of Bihar as early as in 1970s. A proposal was submitted to CWC by Bihar Government and it seems that no further initiatives were taken up by all concerned. It became known that the Government of Bihar has entrusted the work of preparing the Detailed Project Report for this project to NWDA.

The old Bagmati river channel in the Eastern side of Burhi-Gandak basin pushes its flood flows almost every year into the Burhi-Gandak basin. This flow takes place through some parts of a gap of 10 km that exists in the left embankment of Burhi-Gandak, about 18 Km upstream of Muzaffarpur (see Figure 22). This worsens the flood scenario in the middle and lower reaches of the Burhi-Gandak basin. The valuable lands falling on the left side of Burhi-Gandak river, in Muzaffarpur, Sitamarhi and Deohar districts, remain inundated with resulting waterlogging. It affects the cultivation of crops in these fertile lands, hindering the economic growth of the region.

Drawing the flood waters of old Bagmati channel in a regulated manner (instead of presently unregulated/random) into Burhi-Gandak and release it in a regulated manner to the left side would free the valuable lands from waterlogging. For making this possible a canal of 60 Km length is proposed to link the old Bagmati channel with Burhi-Gandak, passing through the gap in the left embankment of Burhi-Gandak, about 18 Km upstream of Muzaffarpur. Downstream, a barrage is proposed across Burhi-Gandak, 5 Km downstream of Akhrahaghat bridge (East Longitude 85 ^{0} 23' 25'' and North Latitude 26^0 08' 18''), just upstream of Muzaffarpur. From the barrage, a left bank canal is proposed to irrigate a gross command area of 80,981 ha with an aggregate irrigated area of 64,777 ha. The barrage will continuously divert 36.25 m^3/s, to irrigate the area on the left side for crops like Aghany paddy, Bhadai paddy, Jute, Sugar-cane and some Rabi crops. The water to be diverted from the old Bagmati channel into the Burhi-Gandak through the link canal is assessed to be 500 m^3/s. The catchment area at the barrage proposed across Burhi-Gandak is 5,044 Km^2. The observed per day mean discharge is 313.53 m^3/s and the barrage has been designed to pass a maximum discharge of 2089 m^3/s, however it is not known from the past records to which criteria this discharge belongs to.

The cost as estimated in 1970 is INR 3.35 crores. The farmers having lands in the present waterlogged area in the left side of Burhi-Gandak aspired for this scheme during our community consultations.

5.1.2.4 Two small irrigation projects identified by First Irrigation Commission.

The First Irrigation Commission identified two small irrigation schemes in the upper portion of the Burhi-Gandak catchment in West Champaran district (1970). These so-called Meiur and Bhapsa Irrigation schemes are planned to divert small discharges of 1.28 m^3/s and 1.42 m^3/s respectively. The Meiur Irrigation scheme is planned near the village Gamauli and the Bhapsa scheme is in the vicinity of village Harmatar. The irrigation extents planned for each of these small schemes and the associated cost at 1970 level are as below:

Meiur Irrigation Scheme

- Khariff Irrigation: 1576.51 ha
- Rabi Irrigation: 161.94 ha
- Cost of the scheme (1970 level) INR 8.9 lakh

Bhapsa Irrigation Scheme

- Khariff Irrigation: 1619.44 ha
- Rabi Irrigation: 404.84 ha
- Cost of the scheme (1970 level)INR 5.1 lakh

However, both these schemes are going to divert together only 2.70 m^3/s, which is not significant with respect to flood reduction.

5.1.2.5 Discussions and Recommendations

Out of the 4 planned projects as above, for the Masan dam, Akhrahaghat barrage and the group of two small irrigation projects, the records are very old and up to now, no systematic feasibility studies have been undertaken, either by the State Government or by the NWDA. Perhaps these studies could be taken up and as per techno-economic viability, could be implemented as a long-term measure for flood reduction and expanded irrigation.

Whereas at present the full DPR for the Burhi-Gandak-Noon-Baya-Ganga link has been prepared and approved based on detailed studies and stands ready for implementation, the Akhrahaghat scheme is in only a proposal stage without detailed studies. It is now learnt that the Government of Bihar is about to request NWDA to take up the study for Akhrahaghat barrage.

Considering all these,

I. The Burhi Gandak-Noon-Baya-Ganga link project is to be implemented, since the DPR is ready with approval of CWC. The benefit of irrigation is for 0.125 million hectares; the flood diversion of about 500 m^3/s to the West. This is a continuous diversion during the entire monsoon season when floods occur, there by relieving the area downstream of Burhi Gandak with a reduction of the same amount from the incoming floods of any magnitude/any return period.

II. Next in a medium term (about a decade) the Akhrahaghat barrage project could be studied and implemented to work in synchronization with the Burhi Gandak-Noon-Baya-Ganga link in the downstream, to arrest waterlogging and promoting irrigation over an extent of 65, 000 hectares, for spurt in economic development of the region.

III. The Masan dam, and the group of two small irrigation dams could be studied and implemented as a long-term measure (within 20-years), which will serve better for irrigation development than flood control. Perhaps the Masan dam could reserve 15% of the gross storage for flood cushion to control the flooding in the upper portion of the Burhi Gandak to certain extent.

5.1.3 Non-structural measures

5.1.3.1 Watershed management

As discussed in Section 2.1.3 the watershed of the Burhi-Gandak is characterised by soil erosion leading to high sediment loads in the river, with serious flood hazard consequences. In order to reduce soil erosion sound watershed management is required. Watershed management involves management of soil and water, agriculture and forestry and consists of a wide range of measures to be implemented in a participatory manner with the local population. Examples of such measures include: re-vegetation/afforestation, slope protection and drainage structures, contour terracing, and check-dams.

Conservation practices can be divided into two main categories: 1) *in-situ* and 2) *ex-situ* management. Land and water conservation practices within agricultural fields, such as contour bunds, graded bunds, field bunds, terraces building, broad bed and furrow practice and other soil-moisture conservation practices, are known as in-situ management. These practices protect land degradation, improve soil health and increase soil-moisture availability and groundwater recharge. Construction of check dams, farm ponds, gully control structures, pits excavation across the stream channel is known as *ex-situ* management. *Ex-situ* watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds (Wani & Garg, n.d.).

It must be stated that these technical remedies will only succeed if they can function within and address local socio-economic constraints (FAO 1999). Farmers rarely adopt recommended technologies by the experts (Vishnudas et al., 2005). This has been recognised also in the Indian experience. In 2005 the *Neeranchal Committee* evaluated the entire government-sponsored, NGO and donor implemented watershed development programs in India and suggested a shift in focus “away from a purely engineering and structural focus to a deeper concern with livelihood issues” (Raju et al. 2008).

By considering the traditional practices and experiences of the farmers, experts and scientists could co-develop appropriate technology jointly with the people. For instance, instead of providing engineering structures, semi-permeable vegetative barriers using local materials and local labour can be used. These barriers will filter out sediments, reduce the velocity of runoff and also retain runoff water. This will be less costly compared with constructing engineering structures. Soil conservation measures that produce the most rapid return on investment are the most favoured. These include bunds that require relatively small initial investment, provide fodder or fuel, and conserve soil moisture (Vishnudas et al., 2005).

Problem with many rivers in North-Bihar including BG river is that (part of) their watershed is located in Nepal, and the measures need to be taken up by that country. Deforestation rates in Nepal are estimated at 1.7% per annum based on forest assessment studies conducted in 1978/79 to 1994 (REDDdesk, 2015). FAO gives 1.8 % per year over the period 1990-2000 (FAO, 2015). As per the FSI statistics the forest cover in Bihar state in showing an increasing trend during the last 15 years. The percentage coverage of forest to the State is not in par with the national coverage and Bihar Govt. is envisioning to increase the extend of forest cover in the state from 7% to 14% by 2017.

Specific land use measures for the Burhi-Gandak to reduce flooding and sediment transport should include proper watershed management both upstream and in the plains as well as anti-erosion programmes for river banks. Although siltation and deforestation are mentioned among the main factors affecting floods (Govt. of Bihar, 2007), there is no scientific study found for Bihar to quantify its impact. The State of the Environment Report for Bihar suggests building of several types of structures in the watershed for the specific purpose of reducing sediment yield in the floodplain. These include such structures as sedimentation basins to trap sediment below eroding areas, and erosion control structures to halt the production of sediment.

5.1.3.2 Flood warning

There are seven flood forecasting sites (Ahirwalia, Champatia, Lalbegia Ghat, Sikanderpur, Samastipur, Rosera and Khagharia) in the Sub-basin. All of them are maintained by CWC (Middle Ganga Division-IV Patna). These stations are well connected to the base stations, Divisional and Sub-divisional headquarters of CWC. The CWC uses these stations for providing flood forecast bulletins to district administrations via the Flood Control Cell of the WRD.

As regards Burhi-Gandak (sub) basin, which has a total drainage basin area of 12,500 sq. km, there are 19 rain gauging stations, and there are four gauge discharge stations and three gauge stations in the basin maintained by CWC. The estimates of flood discharge for different return periods are available for the four discharge gauging stations from two sources. One is from GFCC and the other is from Sinha and Jain (1998). However, there isn’t much tallying of the figures arrived from these two sources. Sediment flow measurement is done for two of the downstream discharge gauging stations in the river.

Over the years, CWC had increased the number of hydrological observation stations in lower Ganga basin area. To manage the hydrological observations, flood forecasting and other functions of mandated by the CWC, the LGBO has Circles headed by Director/Superintending Engineer; two divisions headed by Executive Engineer/Deputy Director (viz., Lower Ganga Division 1 and Lower Ganga Division 2. The Lower Ganga Division (LGD)-1 looks after north Bihar, including Burhi-Gandak basin. There are four sub-divisions under LGD-1, each headed by an Asst Engineer/Asst Director and one of them looks after the flood forecasting work of Burhi-Gandak sub-basin.

The regional office, the two circle offices, the two divisions and the four sub-divisions put together have a total of 132 sanctioned technical positions starting from the post of Chief Engineer to the post of Junior Engineer. However, out of these 132 posts, there are 49 posts are remaining vacant. Many of them are at the lowest level, i.e., at the level of Junior Engineer. Out of the 13 positions at the level of Junior Engineer (Communications), eight were found to be vacant. But, this is a very critical position when it comes to hydrological observations and data transmission, and therefore crucial for performing the job of flood forecasting.

A major issue is the reducing strength of field staff, especially of field surveyors. For accurate ‘flood forecasting’, getting exact profile of the river cross section at the gauge sites is very crucial. Field visits indicate that the river bed levels keep changing due to heavy siltation during flood, and therefore, ‘resurvey’ and re-calibration of the ‘stage curve’ based on these data every year is extremely important. However, due to shortage of staff, such resurvey is done once in 4-5 years.

5.1.3.3 Preparedness

Before the onset of the flood period, WRD creates different zones for flood fighting. For every zone a Senior Retired Chief Engineer is notified to head as Chairman of the Flood Fighting Force. The force is manned with one serving Executive Engineer and one Asst. Engineer to help the chairman in suggesting, supervision and monitoring the flood fighting works being executed. The Burhi-Gandak river flood fighting works in recent past has been covered by Flood Fighting Force stationed at Muzaffarpur up to Samastipur District Border near Mohamda (Pusa) and downstream of this is supervised and monitored by a Flood Fighting Force stationed at Khagaria.

After the end of each monsoon period the Chairman of the Flood Fighting Force (who has supervised flood fighting works on the river from 15 June to 15 October) and the Chairman of the Anti-erosion Committee visit the river sites which had faced onslaught of heavy floods, erosion points, where flood fighting took place to save public, property and agriculture crops. The joint committee identifies vulnerable sites and proposes anti-erosion schemes. On the basis of the committee report, field Executive Engineers measure the damages and frame a scheme with required design. Through a number of administrative steps the scheme is sent to the State Flood Control Board, headed by State Chief Minister. This board has to finally approve the agenda and makes funds available for the anti-erosion scheme.

5.1.4 Pilot projects at community level

During the field investigation two key issues related to flood identified in the BG basin are i) waterlogging conditions leading to loss of livelihood and ii) lack of community level preparedness to "live with the flood". There are several initiatives in the State towards handling these two issues. However, this was not effectiveness or didn't last long due to various reasons. As part of this assignment, the team has investigated among various institutions and communities to understand community based flood management initiatives which are potential pilot projects to improve the community flood resilience. This exercise was carried out in the back drop of the key issues and needs of the community and through analysing the causes of failures and success of several community initiatives particularly in the State.

Water logging is one of the key problems in the mid and downstream of the BG basin which is mainly caused due to the heavy siltation. Farmers have to abandon their agriculture land due to this. Nav Jagriti, a Bihar based NGOs has mobilised the farmers affected due to water logging problems to develop drainage channels to drain the excess water. The NGO has carried out this kind of work in Sonpur village along the Gandak River, and Saraiya village of Muzaffarpur along Burhi-Gandak River. In Sonpur village, the NGO organised farmers who owns contiguous agriculture land which are affected by waterlogging and carried out levelling survey to construct channels to drain out the excess water. The channel was constructed for 3-4 km to drain the water from the agriculture land to lower side of the river. The NGO got financial support from international funding sources. There is a potential for local administration (Panchayats) to take up similar work in water logged areas of the basin.

Under the GoI - UNDP Disaster Risk Management Programme (2002-2007), UNDP has supported the state in preparing village level disaster management plan for all the villages of Bihar. UNDP has engaged NGOs to mobilise the communities to formulate DM committees, carry out awareness activities including mock drill, rescue operations, etc. However, after the exit of UNDP, the DM committees in most of the villages became non-existent. Some NGOs including Nav Jagriti are working with the communities to revive and keep these DM committees active with support of international funding agencies like UNICEF and IUCN. Nav Jagiriti revive the community DM team and continuously work with them to provide training to identify the vulnerable pockets of the village, mobilise community to formulate DM task force, training in preparedness and planning. The task force is constituted by village head, women's group (Self Help Groups) and farmers. Women are trained to carry out first aid like tying bandage, first aid for drowned victim, first aid for snake bite, etc. Before the rainy season, villagers will carry out lot of preparedness activities in terms of food, fodder, medicine, drinking water, dry woods etc. The villagers shared that they used to prepare and stock dry food like *Sattu* (baked channa made into flour which can be mixed with water and take as food without cooking - traditional nutritional rich drink), *Chuda* (beaten rice which also can be eaten without cooking or cook with less fuel) for three months before the rainy season. As the village is very much prone to flood and each and every year the villagers face the flood, they used to follow the preparedness activities meticulously.

These two initiatives – river training (developing drainage channels) and community preparedness are very critical for improve the resilience of the communities in the basin. It needs institutional mechanisms beyond government departments to reach communities in the village and make these community level intervention effective. NGOs working among communities are the best means to carry out these activities.

5.1.5 Detailed agricultural systems review

Agricultural sectors play a key role in the overall Bihar economic and social well-being. Contribution of agriculture to GDP (Gross Domestic Product) is 21.30% in Bihar (UNDP, 2012). However, the share of agriculture in both the employment sector and the GDP has declined over time in India as well in Bihar. The share of agriculture in GDP is observed to decline from 39% in 1980-81 to 17% in 2009–10 while at the same time the corresponding decline in the employment sector was observed to fall from 63% to 60% at the national level. One of the primary factors for such decline in food production in recent years is enhanced severity of climatic hazards such as drought, flood, and heat wave. This is attributed to the fact that climatic hazard affects the two most important direct agricultural production inputs, precipitation and temperature. Climatic hazard also indirectly affects agriculture by influencing emergence and distribution of crop pests and diseases, exacerbating the frequency and distribution of adverse weather conditions, reducing water supplies and irrigation, and enhancing severity of soil erosion. The potential impacts of extreme weather events such as drought and flood are varied and can affect a wide range of economic, environmental and social activities. Drought causes direct and indirect impacts. Those include acute water shortage and over exploitation of groundwater, soil degradation, loss of crop, spread of pest and disease, migration of people, increased unemployment, strain on financial institutions, malnutrition of human beings, etc. On the contrary, flood causes huge surplus of water in a very short span leading to infrastructural damage, agricultural and livelihood losses. For this study our focus only will be on the flood hazard and associated impacts on the cropping systems.

Review of agricultural systems in Burhi-Gandak basin

Historical agricultural data (from 2000 to 2009) has been collected for 10 districts of Bihar (Begusarai, Khagaria, Munger, Muzaffarpur, East Champaran, West Champaran, Samastipur, Sheohar, Sitamarhi, and Vaishali) in the Burhi-Ghandak. Based on the analysis of available crop data, cultivable area, major crops cultivated, acreage, yield in each district falling in the Burhi-Ghandak basin were identified (Table 13).

Table 13: Agricultural profile in the districts of Bihar falls in Burhi-Ghandak basin

District and cultivable area ('000 ha)	Major crops during Kharif season	Kharif season cropped area (%)*	Crop yield (t/ha) *	Major crops during Rabi season	Rabi season cropped area (%)*	Crop yield (t/ha) *
Begusarai 160	Maize	67.98	1.02	Wheat	67.09	2.01
	Rice	17.4	1.43	Maize	20.57	2.8
	Pulses (pigeonpea, black gram, horse gram, green gram)	9.64	0.92	Oil seed (rapeseed, mustard, sesame, linseed, sunflower, safflower)	6.99	0.96
Khagaria 104	Maize	35.54	0.99	Wheat	49.4	1.61
	Rice	23.66	0.97	Maize	37.73	4.35
	Pulses (pigeonpea, black gram, horse gram, green gram)	22.96	0.86	Oil seed (rapeseed, mustard, sesame, linseed, sunflower, safflower)	5.18	1
Munger 60	Maize	75.7	1.28	Wheat	78.92	1.7
	Pulses (pigeonpea, black gram, horse gram, green gram)	10.02	0.89	Maize	5.86	2.42
	Rice	2.12	1.67	Chickpea	4.9	0.83
Muzaffarpur 219	Rice	72.76	1.26	Wheat	63.65	1.94
	Maize	11.64	1.08	Green Gram	16.38	0.49
	Pulses (pigeonpea, black gram, green gram)	7.01	0.97	Maize	8.42	2.5
East Champaran 266	Rice	85.74	1.55	Wheat	78.36	1.95
	Pulses (pigeonpea, black gram, green gram)	4.45	0.82	Lentil	6.03	0.81
	Maize	4.4	1.27	Maize	5.3	3.13
West Champaran 271	Rice	78.85	2.13	Wheat	63.4	2.26
	Pulses (pigeonpea, black gram, green gram)	10.91	1	Oil seed (rapeseed, mustard, sesame, linseed, sunflower, safflower)	14.33	0.87
	Maize	2.43	1.07	Lentil	10.38	0.58
Samastipur 184	Rice	54.04	1.21	Wheat	47.04	2.07
	Maize	24.89	1.33	Maize	22.02	3.32

	Pulses (pigeonpea, black gram, horse gram, green gram)	8.12	0.76	Green Gram	10.43	0.43
Sheohar 31	Rice	78.99	1.5	Wheat	77.45	1.65
	Mesta	5.25	6.12	Maize	5.13	2.83
	Pulses (pigeonpea, green gram)	4.66	0.82	Lentil	4.3	0.65
Sitamarhi 123	Rice	77.25	1.56	Wheat	76.35	1.73
	Pulses (pigeonpea, black gram, horse gram, green gram)	4.98	0.83	Lentil	5.76	0.75
	Maize	4.64	1.14	Green Gram	3.73	0.86
Vaishali 150	Rice	36.15	1.59	Wheat	57.67	2.24
	Maize	32.99	1.16	Green Gram	21.25	0.55
	Pulses (pigeonpea, black gram, horse gram, green gram)	9.83	0.87	Maize	8.14	2.72

Source: Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India (http://apy.dacnet.nic.in/crop_fryr_toyr.aspx)

During Kharif season in the Burhi-Ghandak basin, rice and maize are the staple cereal crops which occupy about 85% of the total cropped area. Pulses, which serve as staple as well as cash crop in this basin, occupies almost 10% of cropped area and stands second in terms of acreage (Table 13). Based on the field survey, it has been noted that during Kharif season rice is the only crop cultivated in some parts of the study area due to water stagnation problem.

During Rabi season in this basin, wheat and maize are the staple cereal crops and occupy about 80% of total cropped area (Table 13). Pulses, which serve as staple as well as cash crop in this basin, occupies about 10% of cropped area and stands second in terms of acreage. Oilseed, which is mostly grown as a cash crop, stands third (about 8%) in terms of cropped area (Table 13). It has been observed from the field survey that during Rabi season, very limited area is used for the cultivation in some parts of the study area due to waterlogging problem. From the survey it has also been noted that in some parts of the study area during Rabi season, wheat occupies about 70% of total cultivated area and remaining area is used for the cultivation of potato and maize.

Some more key facts about the flood hazard, acquired from the field survey observations, in Burhi-Ghandak basin have been summarized in Box 1.

Box 1: Summary of some key facts about the flood hazard acquired from the field survey in Burhi-Ghandak basin

- There has been crop loss and yield reduction as well due to flood.
- There has been damage to the soil as well (e.g., erosion, debris and litter deposit, contamination, etc.)
- There has been damage on stocks (e.g., inputs and products including loss of conserved grass)
- There has been damage of machinery and equipment during severe flooding.
- Over the last couple of years onset date of monsoon rainfall has been shifted from mid-June to end-June (i.e., by about 15 days).
- Rainfall distribution pattern has been changed over the last decade. Sometimes it rains so heavily causing severe damage to crops, house, and road, and sometimes there is complete dry spell causing drought like situation.
- Over the last decade rainfall amount has been increased.
- Embankments use to breach frequently due to heavy water flows in the river.
- Over the last decade carrying capacity of river has been decreased due to heavy siltation in the river causing

water overflows the embankment.

- Some study areas experiences flood due to heavy rain as well water flows from the river. Besides, poor drainage system also aggravates the flood situation as it takes long time to recede the water from the land. As major occupation of the villagers is agriculture, the stagnant water damages the crops.
- In some study areas rice is the only crop which is cultivated during Kharif season.
- During Rabi season, wheat occupies about 70% of total cultivated area and remaining area is used for the cultivation of potato, maize, other crops.
- Farmers do not get any benefit from the crop insurance scheme due to manipulation of the crop yield in favour of insurer.
- Communities in this area do not get any flood warning or advisory from the government authority or from NGO to protect their assets and lives.
- In most of the villages in the study areas, there is no community shelter nearer to the village which makes them more vulnerable.
- Though there is a hospital nearby the village but during the flood, it is not accessible as most of the villages remains surrounded by the flood water.
- The communities want a proper drainage system so that flood water would recede quickly.
- The communities want a structured training to protect themselves from the flood risk.
- Overall according to the field survey, it has been observed that large numbers of farmers in the study area are engaged in subsistence farming only due to very small operational land holding size at their disposal. Furthermore, small holdings also face new challenges on integration of value chains, liberalization and globalization effects, market volatility and other risks and vulnerability, adaptation of climate change etc. (Thapa and Gaiha, 2011).

Figure 25 shows the cropping pattern over the years in the Burhi-Ghandak basin. This figure shows that there has been increasing trend in high value crop acreage (e.g., green gram) in this basin. Whereas, there has not been any significant changes in the acreage of principle crops such as rice and maize in this basin.

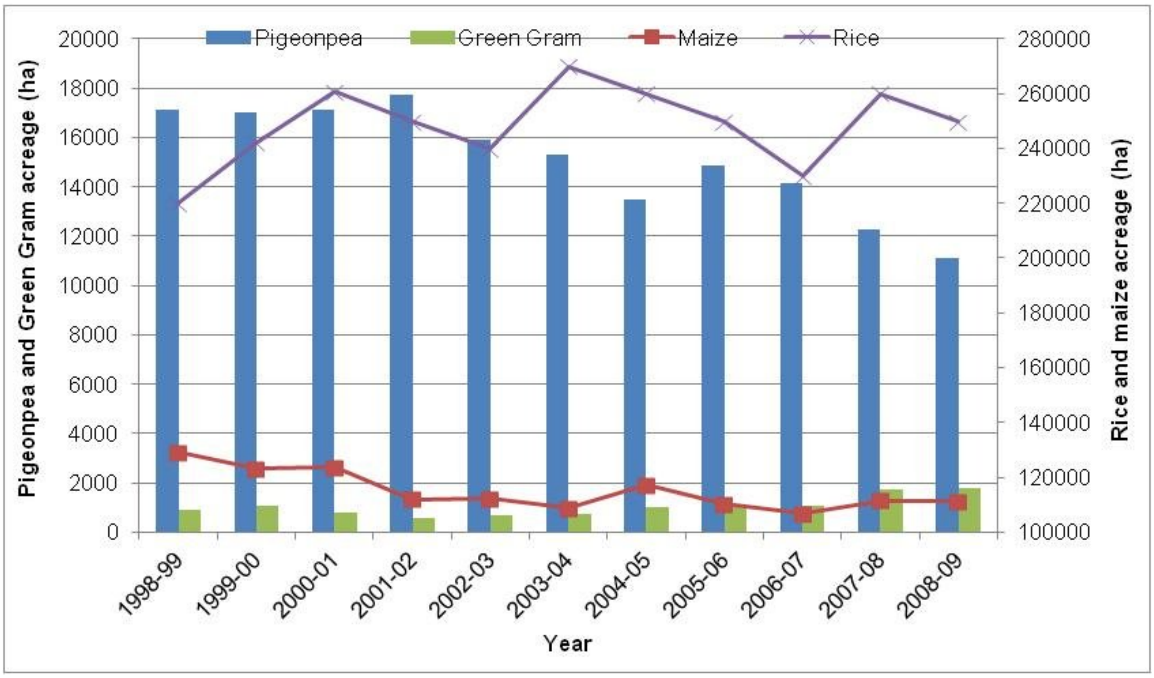

Figure 25: Kharif season crop acreage trend analysis over the years in the Burhi-Ghandak basin

Assessment of flood induced impact on agriculture in Burhi-Gandak basin

Districts prone to the various hazards in the Burhi-Ghandak basin have been summarized in Table 14. The table shows that all districts in the Burhi-Ghandak basin are prone to the flood hazard and it is causing huge damage to the crops in these districts leading to a reduction in the crop productivity. The severity of damage on the crop production depends on the flood intensity (flow/depth) and season. Aerobic crops (e.g., maize, pulses, and groundnut) cannot survive under standing water and submergence. Anaerobic crop (e.g., rice) can resist standing water due to supply of oxygen to root through aerial parts but cannot tolerate submergence for continuous 7 days. Deep water rice can resist flood up to 15 days when at rapid growth stages. But at early stage of crop growth, sudden rise of water level, speed and muddiness of water are the factors which make most of the varieties vulnerable. Since rice is the main crop in rainy season in Burhi-Ghandak basin, the extent of damage varies according to days of submergence. The flood can be classified as Early Cropping Season Flood, Mid Cropping Season Flood, and Late Cropping Season Flood.

Table 14: Districts prone to the various hazards in the Brahmani-Baitarni basin

	District prone to the hazards						
	Drought	Flood	Hail storm	Heat wave	Cold wave	Frost	Pests & disease outbreak
Begusarai	√	√		√	√	√	√
Khagaria	√	√	√	√	√	√	√
Munger	√	√		√	√	√	√
Muzaffarpur	√	√		√	√	√	√
East Champaran	√	√		√	√		√
West Champaran	√	√		√	√		√
Samastipur	√	√		√	√	√	√
Sheohar	√	√		√	√	√	√
Sitamarhi	√	√	√	√	√	√	√
Vaishali	√	√		√	√		√

(Source: District Agriculture Contingency Plan, Ministry of Agriculture, Government of India)

Early cropping season flood (June-July): For all major crops, June is the beginning of planting season in this basin. Normally before the onset of monsoon, farmers sow the lowland and some medium land rice which germinates after onset of Monsoon and grows to a certain height to resist standing water during the month of July and August. After onset of Monsoon, pulses, oilseeds, and upland rice are sown along with raising nursery for transplanted rice for medium land. Normally early season flood causes following damages:

- Damage of rice in nursery, standing crop of vegetables, pulses, and oilseeds.
- Early-transplanted and standing direct sown rice are also affected by flood.

Mid cropping season flood (August-September): When flood comes during this period the extent of loss in most of the times is severe and irreparable as the crops are in active growth stage and the farmers have already spent enough money on management of crops. Besides, farmers loose the season of cultivation and the land cannot be used to cultivate immediately. Normally mid season flood causes following damages:

- Incidence of pest and diseases to standing crop that escaped or resisted flood.
- Damage of upland crops like vegetables, pulses and oilseeds at fruiting stage.
- Damage of short duration rice at maturity stage and medium and late duration rice at growth stage.

Late cropping season flood (October-November): The flood causes severe damage to medium and long duration rice at maturity and grain filling stage. Farmers bear complete loss of money invested to grow the crops. The winter vegetables, oilseeds, and pulses sown in uplands are also seriously affected at growth stages. Normally late season flood causes following damages:

- Lodging and germination of grains in the field.
- Incidence of disease and pest in crops that escaped or resisted water logging.
- High value vegetables are also affected.

Table 15 shows the extent of crop land affected area due to flood in Bihar state.

Table 15: Crop damage due to flood in Bihar

Year	Crop damage (in million Rupees)
1998	3,669.67
1999	3,669.67
2000	830.37
2001	2672.179
2002	5114.961
2004	5220.564
2007	Heavy losses of crops

(source: Bihar Flood Management Information System)

Suggested flood mitigation measures and strategies to protect the crops in Burhi-Ghandak basin
Damage to crops and livelihood is highly significant in terms of cost to the government as well as the farmers themselves. Although the floodplain is ideal for agriculture, measures should be taken to prevent losses. These can include a shift in timing for the planting and harvesting of crops, change in the cropping system, etc. This can be adopted to avoid seasonal floods and subsequent crop losses. Feasible remedial measures, which can be taken to minimize the flood induced risks during Vegetative, Flowering, Crop maturity, and at Harvest have been given in Table 16.

There is acute shortage of seed for re-sowing and replanting operation in early season flood. Availability of seeds (both rice and non-rice crops) should be ensured by intervention of Government and NGOs. Further while recommending the crop management options under recurrent and/or severe flood conditions, possible shifts in the cropping calendar or cropping system, or uptake of new crop can be considered so that farmers can sustain their livelihood under the extreme weather conditions. For example, if flood has become a recurrent phenomenon then farming communities can switch from less water intensive crop (e.g., green gram) to more water intensive crop such as rice and sugarcane. However, before switching over from the conventional crop to new crop, market analysis would be required so that new crop can be sold in the market.

Table 16: Suggested feasible mitigation measures and strategies to protect the crops in Burhi-Ghandak basin

Crop	Vegetative stage	Flowering stage	Crop maturity stage	At harvest
Rice	Drainage management Gap filling, if required Re-sowing through drum seeder Re-transplanting through Dapog nursery if needed Seedling treatment with granular insecticide (i.e., Cartap hydrochloride or phorate 10G or carbofuran 3G) in the event of outbreak of pests & diseases	Drainage management Subsequent crop like rapeseed may be taken if present crop is substantially damaged Pesticides spray	Drainage management Harvest at physiological maturity	Proper drying Safer storage and transportation
Maize	Drainage management Gap filling, if needed Re-sowing, if sequentially affected	Drainage management Alternative Rabi maize or other rabi crop if substantially damaged Pesticides spray	Drainage management Harvest at physiological maturity	Proper drying Safer storage and transportation
Pigeonpea	Drainage management Gap filling if needed September sowing of pigeonpea if Kharif pigeonpea is completely affected	Drainage management		Proper drying Safer storage and transportation
Lentil	Plan for September sowing	Drainage, alternative crops if totally damaged	Quick harvest	Shifting of produce to safer place for drying

Furthermore, overall flood mitigation measures and strategies to protect the crops can be divided into two types of initiatives (short and long term initiatives) to adjust agriculture in the flood prone areas details of which has been elaborated in the following sub-sections.

Short term initiatives

Under this initiative, before the floods, farmers should make high soil beds in the flood free areas to sow seeds of rice, vegetables, and other crops. Furthermore, farmers should use following strategies to reduce damages of crops from floods:

Precaution before floods: Farmers should make seedlings of flood prone crops at flood-free highlands, while cultivate short duration water loving crops in lowlands of severe flood vulnerable areas. In this regard, farmers should wipe out weeds, grasses, and use medicine to control pest. Sometimes, they should cultivate sapling of long stem paddy and hard straw paddy in flash flood areas to resist the power of flood waters.

Action during floods: Farmers should harvest 60 to 80% of mature crops before submerging floodwater. At this time, they should prepare seedlings in flood-free highland and floating seedlings in raft or fence covered with soil in flood-free land. After recession of floodwater, farmers should transplant sapling onto lands.

Initiatives after flood: Farmers should prepare lands as soon as water drains away and sow seeds, such as molasses, lentils, coriander, maize, mustard, and khesari without cultivating lands after the recession of floodwater. In addition to recovering plants, farmers should make a systematic drainage system in lands to remove water that are still stagnant in the root of plants. In this regard, farmers should take special care of medicinal plants and fruit trees. However, they should pile fresh soil around roots of plants, and steady saplings and trees with bamboo sticks.

Migration to safer place: Farmers should migrate to safer place and select high land to cultivate some crops.

Long term initiatives
Under this initiative, farmers should use the following strategies for long-term initiatives to adjust the agricultural activities:

Diversity of crops: Based on flood intensity, farmers should change the cropping system.

Land levels: It normally consists of a succession of broad ridges and depressions varying in size and shape. The cultivation of crops on each of the various levels determines the frequency of floods, effectiveness of drainage, and the amount of silts deposited by floods.

Selection of appropriate crops types: Farmers should grow short duration crops with high yield varieties (HYV) to reduce the crop damage due to flood. The length of the growing period is very important towards the adjustment of agriculture in flood-prone areas.

Crops diversification: Farmers should cultivate various types of crops based on the climatic conditions and trends of flood.

Use of flood tolerant crop variety: Government would provide flood tolerant varieties to the farmers so that in the event of flood farmers can use this variety to get better yield.

Introduction of Early Warning System (EWS): Government would introduce EWS to inform farmers well ahead of time about the chances of flood so that farmers can protect their crops accordingly.

Construction of embankments to control flood: Government would construct embankment to control the floods.

5.2 Analysis of promising measures

5.2.1 New reservoirs and diversions

The flood mitigation of the proposed Masan Dam in the upstream part of the Burhi-Gandak is expected to be in the order of 16 % (Table 17). In other words, a one in 25 year flood event would have 16% less area inundated and damage would reduce with INR 271 crores. (from INR 4663 to 4392 crores). The effect of the link project would even be substantially higher: a reduction in flood extent of nearly 30% and reduced damages in the order of INR 366 crores (from INR 4663 to 4297 crores).

Table 17 Flood mitigation effectiveness of dams and reservoirs

1:25 year flood events	Baseline (current) flood extent (km^2)	With project situation flood extent (km^2)	Difference (%)
Burhi-Gandak:			
Masan Dam (B-G)	1774	1489	-16%
Burhi-Gandak-Noon-Baya-Ganga link	1774	1261	-29%

5.2.2 Embankments

The details of the existing embankments serving as flood control measure have been discussed in the paragraph 5.1.1. Up to now, the embankments have been constructed for a length of about 700 Km. For planning, design, implementation, well established criteria have been evolved by GFCC (Ganga Flood Control Commission-Compendium of Guidelines-2004).These criteria with respect to the components of Embankments are similar to the Guidelines of the Central Water Commission referred to in the paragraph 5. 2.3 of the volume 2.

As such, well established criteria are existing to decide the important parameters of embankments like the free board, degree of protection in terms of the statistical return periods, slopes on the River as well as in the country side and spacing of the embankments. These criteria have been well framed and as such there is no need to update these Guidelines.

The embankments design have been followed the criteria in almost all aspects except for the spacing between and alignment of the embankments. The embankments exist very close to the river bank at many places, infringing the required minimum distance of one Lacey's width between the embankments. This deficiency is the one of the root cause for the erosion of embankment material in some vulnerable locations, especially during receding time of a flood wave. This requires a lot of time, energy and money for constructing anti-erosion works. Further, such erosion affects other parts of the body of the embankments leading to breaches even in normal/routine floods, for which the embankments are expected to give full protection.

In addition, during the site visits by the consultants it was understood from various departments of the government of Bihar that during the construction, the compaction is not being carried out adequately (see also section 2.5 of Main Report).

Though the degree of protection has been decided based on the criteria (25-year Return period for Agricultural areas and 100-year Return Period for townships and industrial establishments), the data used as available up to 1987-88 for determining the Return Period discharges in a flood frequency sense, was short and inadequate. Because of this, the actual degree of flood protection estimated earlier on the basis of such inadequate data might not represent the degree of protection to be provided as per the criteria. So it becomes imperative to review the return periods with the up to date data of annual maximum flood time series in the Statistical Flood Frequency analysis. The present HFL followed is not the representative HFL according to the return period to be adopted. Probably, the present HFL could be lower than the representative HFL and perhaps, that is why frequent breaches occur leading to inundation, water logging leading to frequent disturbance to the safety and well-being of the community.

In the upstream river reaches above Motihari town, where Burhi-Gandak goes by the name of Sikrana River, no embankment has been constructed. In the already existing embankments, there are gaps on both side embankments. This could be appreciated from Figure 22. Obviously, spills from the river banks are common in the un-embanked upper reaches and through the gaps in the existing embankments in even routine small magnitude floods. Once such spills occur, the problems associated with erosion, scouring, inundation and water logging take place affecting normal life of the community.

These combined effects of the deficiencies ultimately make the embankments weaker with degradations in the heights, slopes on both the sides leading to loss of original shapes, resulting in a loss of the envisaged slope stability. The present performance of the embankments can be increased by removing all these deficiencies. The WRD is doing all possible maintenance including executing the anti-erosion works with the available budgets. But it seems that the root causes are not effectively taken up. Therefore, it is recommended to do some applied research in order to scientifically assess the root causes of the frequent breaches in the BG and other rivers in Bihar and design measures that fundamentally address the problem.

The following Flood Control embankments were under the proposal of WRD as short term flood control measures mostly connected with the raising and strengthening of the embankments (river strengthening), These were as per Figure 22. Subsequently, after completing some of the proposals, the remaining reaches planned to be taken up are:

I. In different patches in the reach between Km 25.00 to Km 94.50 of the right embankment of Burhi-Gandak
II. Between Km 0.00 to Km 39.00 (downstream of Akrahaghat) and from Km 0.00 to Km 49.00 (upstream of Akhrahaghat) of right embankment of Burhi-Gandak.
III. Between Km 0.00 to Km 43.50 (downstream of Akhrahaghat) and between Km 0.00 to Km 49.00 (upstream of Akhrahaghat) of the left embankment of Burhi-Gandak
IV. Km 0.00 (Chilai Bishunpur-East Chaparan Muzaffarpur border) to KM 5.20 (Minapur near panapur chakki junction point of highway between Muzaffarpur and Shohar) of the left embankment of Burhi-Gandak.
V. Between Km 0.00 to Km 6.00 of the right embankment of Sikrana River
VI. Between Km 0.00 to Km 15.40 (Pashala-Tier) of the left embankment of the Sikrana River
VII. Between km 0.00 to Km 19.6 (SijuaSikrana-Tier loop) of the left embankment of River Sikrana
VIII. Construction of Tilaway right marginal embankments from railway track near Ramgarhwa to Chichuahia (21.42 Km)

5.2.3 Urban and rural drainage

Conventional drainage systems are designed to achieve a single objective — flood control during large and infrequent storms. This objective is met by conveying and/or detaining peak runoff from large and infrequent storms. There are several forms of drainage, such as natural drainage systems, deep open drains, pipe drains etc. Simply put, when the drainage is sufficient, water will be removed quickly. If drainage capacity is less than the inflowing or precipitating water, flooding will occur. Today's drainage systems must cost-effectively manage flooding, control stream bank erosion, and protect water quality.

There is a need to develop effective drainage systems that balance the objectives of maximizing drainage efficiency and minimizing adverse environmental impacts. The development of agriculture and transportation networks has resulted in modifications to the natural drainage system. These modifications to land use and drainage patterns can be the source of drainage problems in rural systems.

Urban and Rural Drainage

Rural and urban drainage are interrelated since both may contribute to the overall hydrology of a watershed. The objectives of an urban water drainage design are to provide a drainage system that will collect and convey storm water from a catchment to its receiving waters with minimal nuisance, danger or damage at a financial and environmental cost that is acceptable to the community as a whole to provide limited flooding of public and private property. This system will provide convenience and safety for pedestrians and traffic in frequent storm water flows by controlling those flows within prescribed velocity/depth limits.

Further, because of the impermeable surfaces in urban areas, flooding occurs very often as a human-made event. Runoff from such surfaces has a high velocity, which adds to stormwater drainage systems. This increases peak flow and overland flow volume and decreases natural groundwater flow (as no is percolation possible) and evapotranspiration. Furthermore, urban runoff has an increased pollution load, which leads to water pollution.

In rural areas, the cumulative impact of countryside living subdivisions, roads and buildings causes an increase in peak flow rates, and the volume of water that is discharged after storm events. This leads to two key effects: flooding and stream erosion. The main problem in rural areas is impermeable surfaces (e.g. caused by roads and buildings) and overstrained sewer systems. In rural areas and agricultural land it can lead to erosion.

Basic design principles of drainage

An open channel or drain system generally consists of a secondary drainage system, with a network of small drains attached (micro-drainage). Each serves a small catchment area that ranges from a single property to several blocks of houses. These small drains bring the water to a primary drainage system, composed of main drains (also called interceptor drains), which serve large areas of the city. Thereafter these drains are generally connected with natural drainage channels such as rivers or streams. Not all water precipitating as rain needs to be removed by the drainage system. Some will be directly absorbed by naturally infiltrating into the ground, while some may stand in puddles and other depressions and will eventually evaporate.

The part that drains off the ground surface (runoff) into the drainage system is known as the runoff coefficient. There is little chance for evaporation during a rainstorm, so that the runoff coefficient used to calculate the size of the drains required should be based on the infiltration capacity of the ground. The latter mainly depends on soil condition (if the drainage system is not lined, as is often the case in rural areas, chances of percolation are high); the slope of the terrain (steep slope or flat area); land use in the catchment area (roofs and pavement prevent infiltration) and the intensity of rainfall (e.g. design for a 5-year storm return period).

In flat low-lying areas subject to flooding, a major problem often results from the relatively high level of the receiving water body. Because of the limited slope to which drains can be laid when water flows along them it is quite slow and inefficient. Together with the difficulty of digging deep drainage channels especially where the groundwater level is high, results in drains having to be proportionally wider in order to have sufficient water passage. There is also a risk of puddle building in which pests such as mosquitoes can breed. Building a drainage channel with sloping sides and a narrow bottom helps to maintain a steady flow speed whatever the water level in the channel. A refinement of this principle is to build a channel with a composite section.

Box 2 Indian standards for drainage

Drainage in India is based on gravity flow. Drainage systems comprise of three components:

- Main drains along main roads and nalas
- Area where drainage problems have been identified
- Branches and lateral drains

Even in areas where the slope is flat, pumping is avoided. Drainage by pumping is an expensive proposal to construct and is equally expensive to operate and maintain.

The design of drainage system should generally follow the guidelines recommended in Central Public Health & Environmental Engineering Organisation (CPHEEO), Ministry of Urban Development, Government of India, Manual on Sewerage and Sewage Treatment or other relevant codes with proper justification for deviation or modification. The design of the drainage system requires the following:

- Calculating the total discharge that the system require to drain off
- Fixing the slope & dimensions of the drain to have adequate capacity to carry the discharge and afford proper maintenance

The discharge is dependent upon intensity and duration of precipitation, characteristics of the area and time required for such flow to reach the drain. The storm water flow for the purpose may be determined by using the rational method, hydrograph method, rainfall runoff correlation studies and empirical formulae. The rational method is most commonly used and serves the purpose for design of drain satisfactorily.

A fraction of the storm water would flow to the Storm Water Drainage (SWD), which depends on the imperviousness, topography, shape of the drainage basin and duration of the storm. This imperviousness is quantified by a coefficient of runoff, which needs to be determined for each sub-catchment of the drain. The peak runoff at any given point is calculated using the following rational formula:

$Q_p = C_s\, CIA/360$

In which:

Q_p = peak flow in m^3 /sec
C = Runoff coefficient
I = design rainfall intensity mm/hr
A = Contributory area in hectares
C_s = storage coefficient

Pilot study of Muzaffarpur

Muzaffarpur is located on the Southern bank of the Burhi Gandak River. The topography of the city is lower than the outer area. The water levels of the river during the peak monsoon period remains higher than the ground level of Muzaffarpur City. This makes discharging by gravity difficult during the monsoon period. Table 18 shows some water logged areas near to the study area. Figure 1 shows the map of the study area along with embankments.

Table 18: District wise waterlogged area nearby study area

Sl. No.	District	Total area in Ha
1	Samastipur	18074
2	Begusarai	2908
3	Khagaria	2070

Proposals made in the Storm Water Drainage Scheme for Muzaffarpur City

- Fall out drains of 39.325 kms have been proposed in Burdhi Gandak river, old course of Budhi Gandak River, Furdoo Nallah and low lying areas of Dighra Chour
- Pumping of flood /storm water to Brahmaputra Lake
- Three more pumping stations at existing sluice gates
- One pumping station at Kalyani Chowk
- DG sets to be provided at pumping station due to intermittent power supply

Drain sections: Rectangular and trapezoidal drain sections have been proposed. For RCC drains for flow upto 4.5 cum/sec are proposed and for greater flows trapezoidal sections have been proposed. Cement concrete M25 mix is recommended. Table 19 shows the types of drain recommended and their respective lengths.

Table 19 Types of drain recommended and lengths

Type of drain	Length in km
Outfall drain	39.325
Main and internal drains	125

The City Development Plan of Muzaffarpur by Urban Development and Housing Department, Government of Bihar envisages year-wise projects to control the floods in the lower reaches of Burhi Gandak. Table 20 illustrates the year wise projects to control flooding in the lower reaches of Burhi Gandak.

Table 20 Year wise projects to control flooding in lower reaches of Burhi Gandak

Projects	1st Year (11-12)	2nd Year (12-13)	3rd Year (13-14)	4th Year (14-15)	2016-2020	2021-2030
De-silting of existing drains	3.15	9.45				
Repair & covering open pucca drains	582.75	1748.20				
Construction of pucca drain over existing kuchha drain	70.38	211.13				
Lining of main drains outfall in Furdoo and Budhi Gandak River	62.50	187.50				
Construction of new drains	3000.00	4500.00	4500.00			
Preparation of Comprehensive Drainage Master Plan						
SUB TOTAL DRAINAGE	3748.80	6656.30	4500.00			
Grand Total	INR 14905.10 Lakhs					

All figures in Rupees Lakhs
Source: City Development Plan Muzaffarpur (2010-30)

Status of urban drainage system of Burhi Gandak in Muzaffarpur

Muzaffarpur lies between the Burhi Gandak River and Furdoo River. The Burhi Gandak is a perennial river and is an important tributary of the river Ganges. The Burhi Gandak River has a very flat slope near Muzaffarpur (0.06 m/km) which allows water to penetrate into the soil and increase lag times. It is waterlogged during monsoon periods each year and hence, it was decided that Muzaffarpur be studied for urban drainage. Inundation depths are 0.5m or more, and the duration of water stagnation is more than 5 days.

The drainage system in the city was constructed in 1895 to address its flood proneness. Taking advantage of the topography, the drains were constructed to discharge into the River Burhi Gandak. The capacity of the trunk drains has reduced on account of encroachment and faces blockage on account of dumping of wastes.

Encroachments are also a major problem in Muzaffarpur. Habitations started growing into cities alongside rivers and watercourses. As a result of this, the flow of water has increased in proportion to the urbanization of the watersheds. Ideally, the natural drains should have been widened (similar to road widening for increased traffic) to accommodate the higher flows of stormwater. But on the contrary, there have been large scale encroachments on the natural drains and the river flood plains. Consequently the capacity of the natural drains has decreased, resulting in flooding.

The city faces the threat of flood like situation every monsoon on account of the absence of storm water drains especially in Bela Industrial Area and northern part of the city. In course of time, the drainage structures in Muzaffarpur are used as both sewage and storm drains, functions for which they were never designed. As a result, the limited drainage system of Muzaffarpur has never functioned properly.

The study included a visit to Muzaffarpur Municipality and Water Resources Department (WRD) offices. A detailed walk through survey of congested water logged spots were also identified and recorded. The following paragraphs explain observations found at site.

Observations during Field visit to Muzaffarpur

The city does not have a sewerage system. The 36 MLD water is supplied to the city from ground water source through 13 functioning tube wells with 13 hours of operation per day. With supply coverage of around 30%, the per capita availability of water is 76 litre per day against the national average of 123 litre and required quantity of 135 litre for effective sewerage services.

There is no water treatment plant in the water supply system. The drainage system is inadequate covering about 59% of the city area with the capacity to drain the storm water of 22 cum/sec against a requirement of about 81 cum/sec.

Sewage flows through open drains and is discharged untreated into the River Burhi Gandak and Furdoo Nallah. The drainage structures in Muzaffarpur are currently used as sewage and storm water drains. The city area contour is very flat and the natural drainage is 3.5 feet to a mile. Central portion of Muzaffarpur is lower than the outer area. About 93% of drains within the corporation limits are open drains. Muzaffarpur is known to be an unplanned city and is rapidly growing with an unprecedented rate in the last decade. Figure 26 shows the map of Muzaffarpur showing Furdoo River.

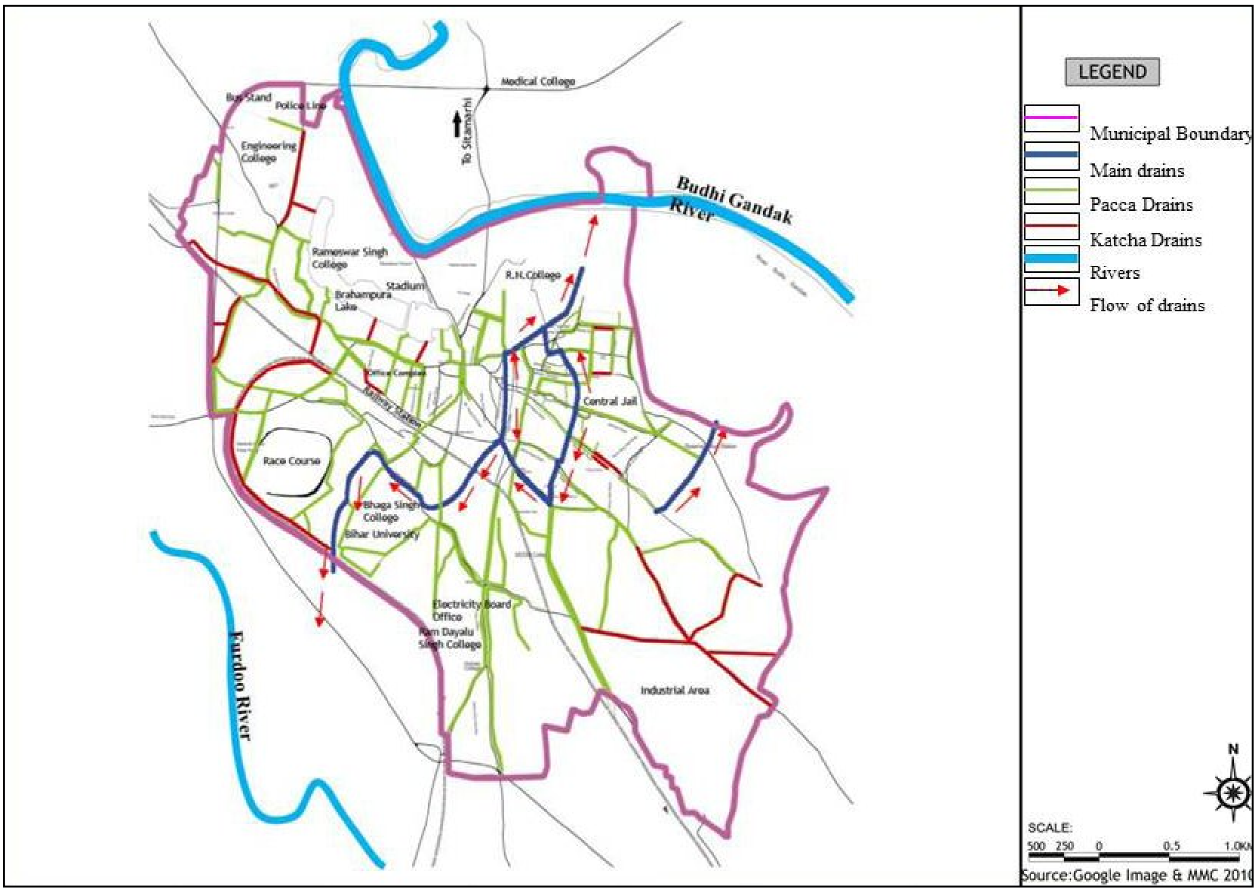

Figure 26 Map of Muzaffarpur showing Furdoo River
Source: Muzaffarpur Municipal Corporation

Outcomes of discussions with Government officials of Muzaffarpur

The visits to Water Resources Department (WRD), Patna, Flood Management Improvement Support Centre (FMISC) and Muzaffarpur Municipality were extremely fruitful. Detailed discussions with experts of Ganga Flood Control Commission (GFCC), Chief Engineer, WRD and members of Muzaffarpur Municipality provided very good inputs.

There is no systematic maintenance of drains – it is mostly 'reactive' with the common practice being to de-silt drains and dump the sludge at the edge. The capacity of the trunk drains has reduced on account of encroachment, blocking on account of dumping of wastes. The city faces the threat of flood like situation every monsoon on account of the absence of storm water drains especially in Bela Industrial Area and Northern part of the city.

The following were outcomes of discussions with the officials:

- Storm Water Drainage Plan for Muzaffarpur City has been proposed and will cost INR 12141.51 lacs. The plan is with the State Government of Orissa for evaluation and approval.
- The officials claim that the 11 km stretch of sewage clogged Furdoo Nallah is the main cause of water logging in Muzaffarpur City.
- The officials mentioned 26 chours (low lying areas causing water logging) which contribute to water logging in the area.

- Frequent floods aided by the terrain of the city has resulted in silting of drains, thereby restricting carrying capacity of the drainage system.
- Encroachment of drains obstructs rain water drainage, reducing efficiency of drains
- The innermost part of the city is lower in elevation than the surrounding area. This becomes a collection ground for rainwater. Further aggravation with flood discharge from Burhi Gandak makes it impossible to discharge city water through sluice gates.
- Close to 30% of the city is not covered by drainage network and 70% has sewage overflow and encroachment issues further reducing the design capacity
- High average annual rainfall during monsoon further puts pressure on the existing drainage system and overflow is a recurring phenomenon.

Photo exhibit of locations

The field visit was led by Muzaffarpur Muncipality draughtsman, Mr R Prasad. He explained that Muzaffarpur is a saucepan shaped depression which makes drainage of water a severe issue. A detailed pedestrian tour of vulnerable locations of water logging was proposed. The first location was at Kalyani, Chapra Nala (Figure 27). The open drain was located near a sweetshop and had a lot of sewage dumped into it. The space was also encroached by houses and shops hence reducing carrying capacity of the drain as can be seen in the figure.

Further examples of the same could be seen at the side of the fish market at Kalyani (Figure 28). The same observations of sewage dumping and encroachment were witnessed. A covered drain built on 1895 was the next location (Figure 29). This too had refuse dumping along with covered drain before Garibsthan (Figure 30). It illustrates the near zero capacity of urban drainage in the study area. A new pukka drain was a pleasant surprise. It was an open drain partially covered with bamboo sticks. It was much cleaner than other portions of the drain and was located near Mahila Silpakala School shown below. This is shown in Figure 31. Another open drain near Chandwara Chok was visited. These drains are servicing residential shanties by receiving garbage and sewage dumps. Shops also are constructed along the open drains. A bamboo platform helps the customers cross the drain to visit the shops. This was observed at Rambagh Road (Figure 32).


Figure 27 Location 1 near Kalyani sweet shop


Figure 28 Location 2, side of fish market at Kalyani


Figure 29 Covered drain built in the year 1895


Figure 30 Covered drain before Garibsthan area


Figure 31 New pukka drain near Mahila Silpakala School


Figure 32 Open drain infront of shop

Summary of existing situation

- All existing drains are choked with solid waste dumped in the drains. This prevents draining out of storm water.
- Cross section of existing drains are insufficient to discharge the rain water smoothly.
- Central part of city is at a lower level than outer surrounding area which prevents gravity flow of water
- Drains in North Eastern part have no escape channel into the old course of Burhi Gandak river, hence these areas face water logging

- The drains of South Eastern part i.e Bela Industrial area have no escape channel into nearby town, Dighra Chour. Hence these areas face water logging
- Furdoo River which is the main source of discharge of rainwater is completely silted. Therefore this does not help to drain out storm water from city.
- Absence of anti-flood device at the confluence of drains and Furdoo River causes backwaters to drain into city.
- The combination of kacha and pukka drains are not sufficient to drain the rainwater out of Muzaffarpur.

Recommendations

- The preparation and implementation of a Drainage Master Plan as a first step
- Fardoo Nalah which caters to three fall out drains requires remodeling, cleaning and strengthening of side slopes.
- Bund on right bank of Burhi Gandak River needs to be raised by more than 1.5 m
- Cleaning and desilting maintenance of Muzaffarpur should be performed on a regular basis.
- All encroachments at the alignments of existing and proposed drains to be removed.
- At state level there is thinking on 'Interlinking of Rivers for Prevention of Floods' to reduce the flood damages in the lower reaches of the River Burhi Gandak basin.
- Muzaffarpur city being in the flood prone zone needs to have comprehensive drainage strategies and goals with immediate extension and augmentation of existing network of drainage especially in the areas near to Industrial Area and Zero Mile.

Further recommendations for urban drainage design in Muzaffarpur can be found in Appendix A.

5.3 Economic and environmental considerations

5.3.1 Review of cost-effectiveness and CBA of flood management approaches

General

An economic analysis of flood management approaches is used for assessing if a project or measure has an added value for society. There are several methods to do so. Cost-effectiveness and Cost-Benefit Analysis (CBA) are two of the methods often used. A cost-effectiveness analysis can show whether a measure provides the maximum value in terms of goods or services for the money spent. We can use this for instance to compare two flood control strategies which both provide the same level of safety. The one which is cheapest has the highest cost-effectiveness. It is distinct from a CBA which assigns a monetary value to the effect itself and then compares it with the cost of the measure. The CWC stipulates in its 'Guidelines for preparation of detailed project reports of irrigation and multi-purpose projects' the use of CBA as part of the Detailed Project Report (DPR). Evidently, for a CBA more data is needed than for a cost-effectiveness approach.

For a cost-effectiveness analysis it is required to define the perceived goal or impact for a measure. In the case of flood management this could for instance be the safety level for embankment design of 1:25 years for agricultural areas and 1:100 years for urban and industrial areas as stipulated in the Guidelines for Planning and Design of River Embankments (levees), issued by the Bureau of Indian Standards (BIS, 2000). With a flood model several ways to reach this safety level (e.g. through reservoir dams) can be analysed after which a comparison can be made with respect to the differences in cost. But even a project with the best cost-effectiveness can have a low benefit/cost ratio so that is why CWC stipulates to use CBA.

Economic project evaluation

As described in Section 5.1.2 the following projects are considered as most effective for the flood risk reduction in the river basin:

1. Masan dam
2. Burhi-Gandak-Noon-Baya- Ganga link
3. Akharaghat barrage proposal and
4. Improvements of the embankments system

For the Akharaghat barrage and improving embankments no economic analysis was prepared by the State, and there is too little data available to do it in our study. For the Masan dam and the Link project there has been an analysis made by the State. Below an economic review of both projects is given based on available documents.

Masan Dam and Reservoir

Masan Reservoir Project was cleared by CWC and TAC of Planning Commission during November 1980 has been administratively approved by the Govt. of Bihar during July 1981 for providing flood control as well as irrigation north of the Don Branch Canal. The costs were estimated at INR 3,472 lakh (revised 1992) and a BC ratio was calculated of 1.54. A new calculation would be advisable because in the more than 20 years many costs and benefits are probably increased. The sources which were available to the team did not specify details of the calculations, so an update could not be made. However, it is quite probable that a new calculation would show a higher BC ratio because i) modern techniques would make construction more efficient and ii) the avoided damage through flood control are probably much higher because of the demographic and economic growth in the past 20 years have increased the value exposed to flooding.

Burhi Gandak Noon Baya Ganga link

This link is proposed recently in 2012 by the National Water Development Agency (NDWA). The link is to divert water for flood moderation and irrigation. The BC ratio has been worked out by the NDWA based on 'Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects-2010' issued by MoWR, Govt. of India. The results of the NDWA calculations are given below:

The gross value of the benefits of the project for the pre-project and post-project scenarios have been computed adopting the yields and prices of commodities collected from agricultural and marketing departments of Govt. of Bihar. The net benefit from irrigation works out to INR 47.00 lakh per 100 ha of cropped area. The total annual benefit from irrigation was calculated to be INR 587.10 crores. The overall damage (1:25 year flood) due to flood has been calculated on the basis of average annual flood damage of the three districts and is found to be INR 204.73 crores. As per the studies carried out by the NDWA, reduction in flood damages to houses, crops and public utilities would be of the order of about 70% of total flood damages. Thus, the annual benefits due to reduction in flood damages has been estimated to be INR 143.31 crores. In total (flood and agricultural benefits) this adds up to INR 730.41 crores. Together with the costs the BC ratio has been worked out as 1.54. The internal rate of return of the project considering 100 years life of the project has been worked out as 16% (NDWA, 2012).

Suggested Cost Benefit Analysis method for flood mitigation projects

1. Benefit categories

The main benefits of a flood mitigation project are the avoided damages and losses. These include:

- Damages to private properties and assets, such as houses and household assets
- Damages to crops, livestock and culture fisheries
- Damages to income generating assets, such as tractors and waterpumps
- Damages to public infrastructure and buildings
- Loss of industrial and service sector incomes in urban and tourism areas
- Loss of wages due to unemployment during flooding, increased time and cost of commuting as transportation routes get disrupted and damaged
- Relief expenditures

2. Calculating annual average damage

Instead of using average damages over the last ten years or so it is recommended to use a risk approach. This entails the estimation of the expected damage for a given flood event, by combining data on the characteristics of the event (hazard) with information on the assets that would be affected by it (exposure) and information about the susceptibility of those exposed assets to the particular hazard (vulnerability). This involves the use of a mathematical flood model, such as used in this study for determining the probability of various flood events. For the vulnerability so called damage curves are used, relating the percentage of damage to an asset with the flood depth.

The Average Annual Damage (AAD) is found by integrating the damages with each probability (see Figure 33) using the formula:

$$AAD = \int_0^1 D_F\,dp \approx \sum_{i=1}^{N} (D_{i+1} + D_i) \times (p_{i+1} - p_i) / 2$$

where D_F = flood damage, D_i = damage of a flood event I, and P_i = probability of a flood event i. Based on these damage calculations the AAD for different safety levels are calculated, as well as the benefits. These benefits occur every year in perpetuity. The present value (PV) of an annual benefit (perpetuity) can be calculated using the formula:

$$PV = AAD \times (1/((1+r)^n)$$

with r being the discount rate for government infrastructure investments. The AAD is an annuity; so the formula can be simplified to:

$$PV = AAD / r$$

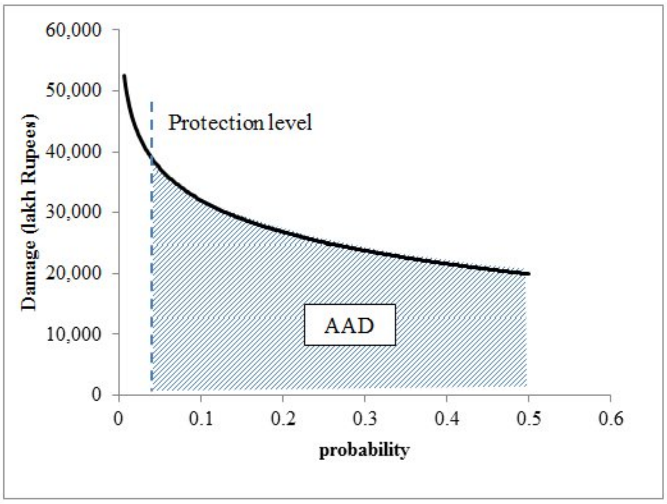

Figure 33 Damage-probability curve and Average Annual Damage

3. Adjustments to benefit calculations:

- Because it is very difficult to estimate losses as a function of flood depth, a percentage of the asset damage can be used (e.g. 10%).
- Improvements of the present conditions of flooding could tap an additional production potential. Such improved productivity could occur from the much less frequent incidence of natural hazards and the perception of farmers that it would be safe enough to deploy better agricultural practices. A more stable physical environment would encourage farmers to accelerate productivity or to diversify into high-yield varieties or more profitable crops. Therefore the benefits could be hiked with a certain percentage per year.
- Increased flood safety will attract more people in the protected area and lead to more economic prosperity. This will generally result in more assets (houses, cars, small and medium enterprises) and higher asset values. A certain percentage could be used, or a number of scenarios could be developed.

4. Costs

In estimating the economic costs, conversion factors to be applied to the financial cost estimates of the IFM. For investment costs, conversion factors for different types of civil works (comprising embankments, sluice gates) are to be estimated based on their composition of key expenditure items and applying the relevant conversion factors to them. For other cost items (project management, and consultants), a standard conversion factor of 0.90 to be applied for local cost items. Following the project design, physical contingencies accounting for 12.5% of the base costs for civil works and 10.0% for other expenditures should also be included in the analysis.

Regarding the recurrent costs, the analysis includes the annual maintenance costs of the project (such as head works and embankments), estimated at 1.0% and 2.0% of the capital investment costs for the first 15 years, and twice as much amount beyond the year 15. For nonstructural components, project wise personnel and operational costs should be included as annual recurrent costs for individual subprojects.

For adaptation of reservoir operation (flood cushioning) an analysis needs to be made for the impacts on other reservoir functions in case of a multi-purpose reservoir (e.g. losses in energy production or irrigation potential).

The costs should also take into account cost for land acquisition, resettlement cost of people (if any), opportunity costs, sluices for drainage, reduced preparedness of the people for larger floods, the loss in soil fertility and aquifer recharge, etc.

5. Benefit cost ratio
Based on the above estimation of the present value of costs and benefits of the project a ratio can be prepared. The assessment should assume that the project benefits associated with the avoidance of loss would be fully achieved after a certain period (e.g. by the end of the year 3). The analysis should be undertaken over a 50 year time period to reflect the economic life of the project assets/infrastructure. Furthermore, an assumption should be made that the residual value of the civil works amounts to 50% of the initial capital investments. The discount rate used for the calculation of present values is usually set by government rules.

6. Sensitivity analysis
A sensitivity analysis should be performed to test the economic viability of the proposed project works to various changes in the cost and benefit streams. At least the following items should be tested: i) a rise in investment costs; ii) a rise in O&M costs, iii) a delay in implementation, iv) lower crop prices.

Financing IFM project interventions
Government spending on IFM may be considered on two grounds: (a) humanitarian considerations helps save human life and resources which may not be economically viable in short term (b) economic considerations help grow GDP leading to enhanced or better livelihood of flood affected communities. The economic considerations of investments should be guided by positive cost benefit ratio, a positive NPV and EIRR.

There are also other contributors in growth of GDP besides IFM interventions. However, it will be interesting to make an assessment of IFM interventions as how it has improved the economic situation and contributed to creating an enabling environment for investment for GDP growth.

Flood management works are funded from different sources either from State Government or from the Government of India. Although the State governments are primarily responsible for the execution of projects, their financial resources may not always be adequate for undertaking major flood control works. Therefore the Central government provides both technical and financial assistance. But floods have never been considered as a priority sector in the planning process or in the process of funding in either the State Plan or Central Plan. Current levels of provisions under Five Year Plans and Finance Commission do not match desired capital investment in the IFM. This has resulted in projects getting stalled for quite a long time (even up to 30 or 40 years).

Thus we recommend that also alternative resources for IFM may be tapped from several programs and schemes. For instance from the Mahatma Gandhi National Employment Guarantee Program, which allows 'Flood control and protection works including drainage in water logged area' to be funded under the program. The resources under MGNREGA are useful for both capital investments in the above works and also to meet recurring / maintenance costs using community driven approach for caring O&M of flood control infrastructure.

Similarly there are several other programs meant for soil and water conservation on a watershed basis in the catchment area under the Ministry of Rural Development and implemented through District Rural Development Agency, and many other schemes and programs.

At present there is no arrangement to share the costs between different ministries when drainage congestion and flooding occurs due to the construction of railways and highways. Therefore it is recommended to arrange cost sharing between the Ministry of Surface Transport, Ministry of Railways and Ministry of Water Resources.

5.3.2 Review of environmental impacts of flood management strategies

Masan Dam

As per the estimates of the Planning Commission, 3700 people will be displaced due to submergence of their villages (S Singh, 1997). There are no major town or cities in the area where Masan Dam has been proposed.

On completion of the dam, it is expected that there will be extensive agriculture activities in an otherwise un-irrigated area of about 27,000 ha of 115 villages enclosed by Don Canal, the Kosil River and the Pandai River of North Bihar region. Masan Dam location is in close proximity of the Valmik Tiger Reserve that spreads between India and Nepal. It is hence likely that there will a major impact on the wildlife habitat in the area due to submergence of land in forming of the reservoir. Of the total area under submergence of 3520.84 ha, forestland is 1780.66 ha. Remaining submergence area is revenue land and village farmlands.

With extensive forest area in the upper reaches of the proposed Masan Dam proper watershed management in forest areas in the catchment can help in reducing the sediment load in the river. A Report of the Special Task Force on Bihar (GoI, 2008) has recommended that - "A holistic system based approach is needed to simultaneously enhance productivity, profitability, equity and environmental sustainability through synergistically integrating crop, cash crop, horticulture, livestock, fisheries, agro forestry, watershed-based soil and water management, social capital formation, agro-processing and marketing in an end-to-end mode", putting emphasis on watershed management.

Akharaghat Barrage

There will be minimal inundation of land due to the proposed Akharaghat Barrage, as most of the land under submergence is within the embankment and part of the river course.

There are six drainage outlets from Muzaffarpur that open into the Burhi Gandak River along the embankments. Of these six, five have sluice gates on them and one is an open drain. All this six outlets are on the upstream of the proposed Akharaghat Barrage. Since, the storm water drains and sewers are not separate, all the sewage is discharged in the river without being treated. There will be a negative impact on the water quality at the proposed barrage due to the untreated sewage. The remedial measures for this impact will be commissioning of a proper sewerage system for Muzaffarpur city along with a sewage treatment plant and an outfall of treated sewage on the downstream of Akharaghat Barrage.

It was observed that there is excessive growth of water weed in the stagnate waters on the outskirts of Muzaffarpur City near the Akharaghat Barrage site (Hirpur Pier). Common weeds observed were *Hydrilla verticillata*, *Eichhornia crassipes*, commonly known as (common) water hyacinth and Water Lettuce *Pistia stratiotes*. Post commissioning of the barrage care must be taken so as not to allow these weed growth to migrate to the canals.

There will be a positive impact of the proposed Akharaghat Barrage on fisheries in the upstream as currently all the water along with the fish flows downstream. With the ponding near the city, there will be an added advantage of developing fisheries in the reservoir. The river being perennial, natural fish will be in abundance.

Embankments

In Bihar, embankments also prevented the river water from flowing into the country side, which deprived the agricultural lands of nutrient laden silt that would have been brought by the flood waters (Mishra, 2008).

The impact of embankment in Muzaffarpur city is clearly visible during the site visit. The drainage system in the form of sluice gate on the outside of the left embankment was observed to be chocked and non-function. On inquiring with the local populace, it was informed that there was no maintenance of the gates done in the past few years. The channel leading to the sluice gate was silted and at places encroachment was also observed in the channel. Thus, aggravating the waterlogging problems in the peri-urban areas of Muzaffarpur.

Due to improper drainage stagnate rainwater mixed with sewage is the breeding ground for mosquitoes that lead to frequent malaria and dengue epidemics in the Muzaffarpur City and the surrounding area. If the sewerage system and sewage treatment plant is not commissioned prior to the building of the Akharaghat it will lead to a major health problem in the area, as the ponded water on the upstream of the barrage is in close proximity of the city.

Burhi Gandak Link Canal

The impact of silt that will be carried in the Burhi Gandak Link Canal will have some adverse impact. It has been identified in the EIA report that the meandering nature of Burhi Gandak River is the main reason of carrying silt loads and depositing it while changing the course. Some quantity of suspended silt is still likely to get deposited on the bed of link canal which has to be removed. Soil erosion is definitely a problem, mainly in high flood period. The soil is highly erodible due to less cohesiveness of the deep alluvial soils. The river linking project is likely to have a positive impact on this problem. The proposed link canal is fully lined so it will minimize the problem of soil erosion.

It is envisaged that the Burhi Gandak Link Canal will assist in releasing otherwise waterlogged area in the downstream of the Canal. This area is currently waterlogged and is inefficiently used for agriculture. With the Canal being commissioned the excessive flood water which otherwise would have inundated the vast track of land will be channelized into the link and this area will be freely available for agriculture round the year.

There is no forest area or protected area in the study area or nearby the Burhi Gandak Link Canal project. The nearest protected area is Kanver Jheel which is more than 5 km from the study area. The EIA report states that, no rare or endangered plant or animal species are found in the area. No species of any economic significance, or of special interest to local population or tourists, flora or aquatic fauna of commercial/recreational value, migratory fish species, corridor or migratory path for wildlife, habitat including breeding ground and access corridor for food and shelter is noticed in the study area. Hence, it is concluded that there will be no adverse effect on biodiversity.

The water logging in the area downstream of the proposed Burhi Gandak Link project is caused due to flood waters of Burhi Gandak River. About 10% of this water i.e. 492 cumec will be carried through the link canal reducing the water logging in the area. Instead, the area which is currently water logged will be available for agriculture and other economic activities. Furthermore, a provision for a number of cross drainage structures/cross masonry structures in the proposed project is further expected to ease out the problem of water logging. Consequently, the salinization as a result of water logging is not anticipated. The water used for irrigation besides meeting the crop water requirements is helpful in recharging of the ground water in the command area for its utilization through tube-wells promoting conjunctive use of ground and surface water. Under these conditions also, no salinization is anticipated due to irrigation. Further the EIA report states that "The water bearing properties are the main guiding factors of the geological formations of study area. Mainly alluvial soil with ground water potentialities having considerable granulose zone with effective porosity are the characteristics of the river basin. Ground water is available right from the depth of 18 m to 49m. Since the proposed link canal shall be fully lined, it would not have any major impact on the ground water hydrology. The proposed project shall not have any negative effect on the drainage or ground water hydrology.

Chapter 6 Enabling institutional environment

6.1 Current institutional arrangements

The draft water policy of Bihar (GoB, 2010) included ‘flood and drought management’ under Priority 6, wherein issues of environmental etc. are dealt with. The Section 6.2 of the policy makes a reference to flood and drought management aspects, but without operational guidelines for flood management activities. There is a clear intention of prioritizing drought affected areas. The specific prescription on flood management is narrow and specifies only reactive, post-flood management tasks of developing suitable water and sanitation systems. Consequently, IFM is not specifically addressed by the policy.

The central government organization, Ganga Flood Control Commission, first prepared comprehensive flood management plans for the Burhi-Gandak in 1986. This plan has been updated several times. Much information for preparing the plans is obtained from the Water Resources Department and hence depends on availability and quality of the provided information.

A number of government organizations play different roles at different levels in relation to floods. Three tiers of state government are distinguished: state, district, and community levels.

Interestingly, there are both state level organizations and district level agencies which are engaged in executing structural and non-structural measures. Also, the same agency is performing different types of functions under flood management. For instance, the SWRD implements the State level water policy, irrigation schemes and programs, flood control programmes, assesses flood losses, does coordination with CWC, GFCC and other central agencies, does piloting of flood forecast, issuing flood warnings etc. Similarly, the State Disaster Management Agency is responsible for post-flood rehabilitation, construction of flood shelters, educating the communities on floods and community engagement.

The District Administration/Revenue Dept., the divisional offices of Irrigation Department, are responsible for flood monitoring, structural measures for flood protection, flood loss estimation, flood compensation and post-flood fodder distribution.

Central Water Commission

The Central Water Commission has a regional office in Patna. This office was the only office of Central Water Commission when it first started functioning in 1976, to develop institutional capabilities in flood forecasting. Flood forecasting work for various flood prone rivers of the country was taken up by this office of CWC for a long time. Later on the current office of CWC became the flood management cell of CWC, with two more offices, one in South India (Hyderabad) and one in Western India (Jaipur). Flood forecasting manual was developed by this office somewhere in 1980. This was also the hydrological observation and flood forecasting organization (HO & FF) of CWC.

After the re-organization of CWC in 1996, the Patna office was converted into the Eastern India Regional office, and rechristened as ‘Lower Ganga Basin Organization’ (LGBO), to look after the Commission’s work in all sub-basins falling in the lower Ganga basin area.

Institutional capability for flood management would depend to a great extent on the amount and accuracy of hydrological data that is available for flood predictions and flood forecasting. As regards

Burhi-Gandak (sub) basin, which has a total drainage basin area of 12,500 sq. km, there are 19 rain gauging stations, and there are four gauge discharge stations and three gauge stations in the basin maintained by CWC. The estimates of flood discharge for different return periods are available for the four discharge gauging stations from two sources. One is from GFCC and the other is from Sinha and Jain (1998). However, there isn't much tallying of the figures arrived from these two sources. Sediment flow measurement is done for two of the downstream discharge gauging stations in the river.

Over the years, CWC had increased the number of hydrological observation stations in lower Ganga basin area. To manage the hydrological observations, flood forecasting and other functions of mandated by the CWC, the LGBO has Circles headed by Director/Superintending Engineer; two divisions headed by Executive Engineer/Deputy Director (viz., Lower Ganga Division 1 and Lower Ganga Division 2. The Lower Ganga Division (LGD)-1 looks after north Bihar, including Burhi-Gandak basin. There are four sub-divisions under LGD-1, each headed by an Asst Engineer/Asst Director and one of them looks after the flood forecasting work of Burhi-Gandak sub-basin.

The regional office, the two circle offices, the two divisions and the four sub-divisions put together have a total of 132 sanctioned technical positions starting from the post of Chief Engineer to the post of Junior Engineer. However, out of these 132 posts, there are 49 posts are remaining vacant. Many of them are at the lowest level, i.e., at the level of Junior Engineer. Out of the 13 positions at the level of Junior Engineer (Communications), eight were found to be vacant. But, this is a very critical position when it comes to hydrological observations and data transmission, and therefore crucial for performing the job of flood forecasting.

A major issue is the reducing strength of field staff, especially of field surveyors. For accurate 'flood forecasting', getting exact profile of the river cross section at the gauge sites is very crucial. Field visits indicate that the river bed levels keep changing due to heavy siltation during flood, and therefore, 'resurvey' and re-calibration of the 'stage curve' based on these data every year is extremely important. However, due to shortage of staff, such resurvey is done once in 4-5 years.

Water Resources Department, Govt. of Bihar

The Water Resources Department of Bihar undertakes flood forecasting, execution of flood control measures, their repair and maintenance and issuing of flood warnings in the flood prone areas. During the flood season from mid-June to late October, the Water Resources Department operates flood control rooms that receive and disseminate water levels as well as trends and sometimes flood forecasts.

The WRD is organized geographically and the implication is that the Engineer in Chief North or South is responsible for both irrigation and structural flood management, under his territory. The department is headed by a Principal Secretary, under whom there are six bureaucrats. viz., Jt. Secretary (Management); Jt. Secretary (Engg); Director (Land acquisition); S.E. (Flying Squad); Jt. Secretary (Vigilance); Director (Purchase, Stores, Material Management); Law Officer, and PRO. There are two Engineer-in-Chiefs who report directly to the Principal Secretary, one for North Bihar and one for Middle region. The irrigation administration in the State is organized around districts, and each district, which has one Chief Engineer. Under each Chief Engineer, there are Executive Engineers, and under Executive Engineers, there are Asst Engineers. The organogram of the Water Resources Department of Bihar is given in Figure 34.

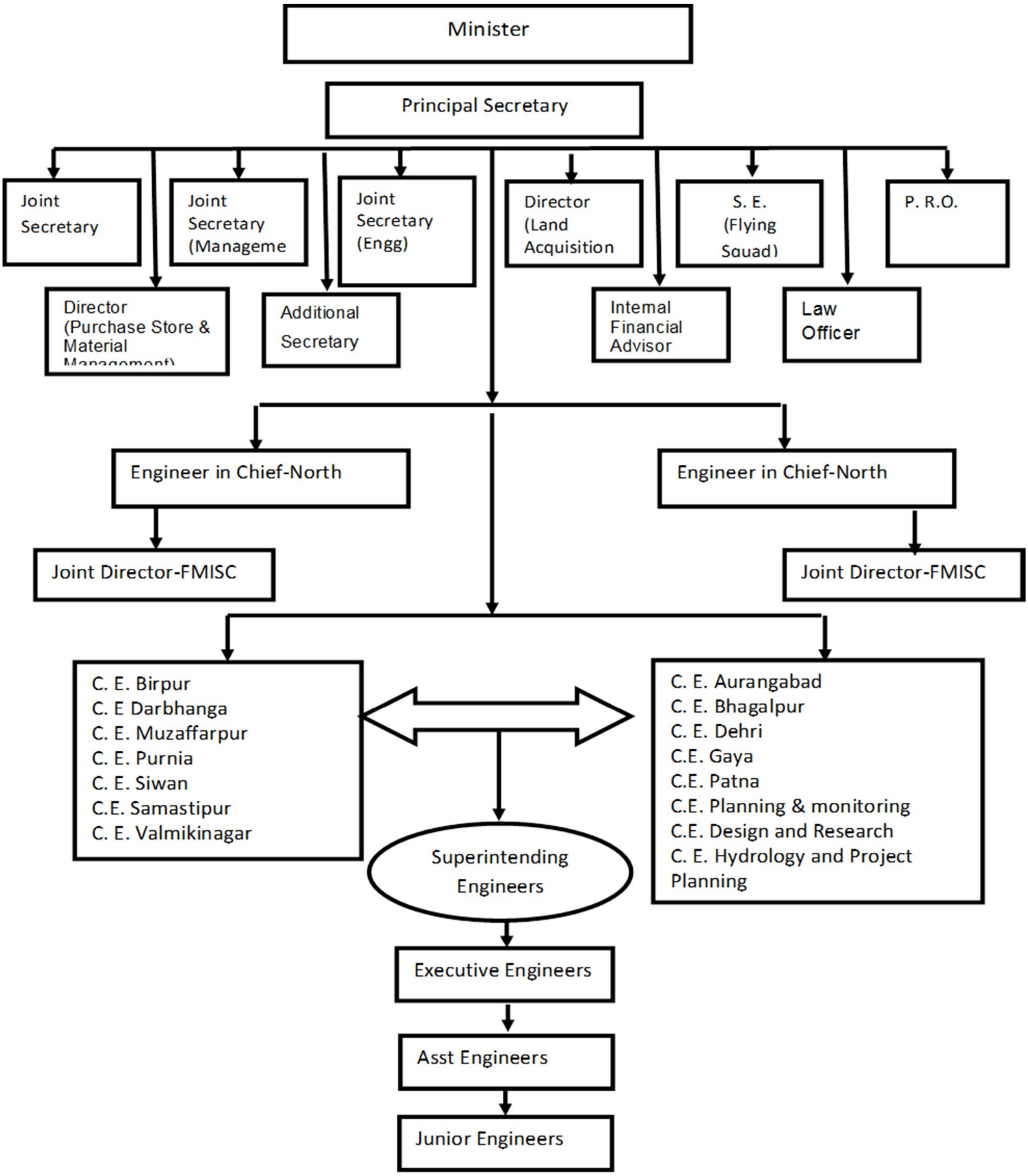

Figure 34 Organogram of Bihar State Water Resources Department

The WRD undertakes construction of embankment works for flood protection. The Ganges river and its 12 tributaries pass through the state for a total length of 2943 km. Embankments to protect from floods cover a length of nearly 56% (with a total embankment length of 3338 km). However, of the total flood prone area of 68,800 sq. km in the state, the area which is protected through embankments is 29,490 sq. km (Source: author's estimates based on Sinha *et al*. 2012). However, these data are not indicative of the quality of flood protection, as it would depend on the quality of construction of these embankments and the maintenance and repair works carried out.

Sinha *et al*. (2012) analyzed the institutional gaps in flood management in Bihar from the point of view of people gap; process gaps; technology gap; resource gap; support system services and ecosystem gap. The study found inadequate human resources, with many critical positions lying vacant in the WRD and the existing staff not having the necessary skills required for performing their duties. The number of staff to monitor flood risk areas was found to be inadequate. The need for more frequent training of all technical staff was observed. The promotion and transfer system was found to be unsatisfactory.

Also, problems of mismatch in priorities between various levels in the hierarchy; top-down decision making; lack of clarity in decision making; delays in approving proposals due to time spent in chasing them through multiple nodes; inadequate communication and flood warning systems, resulting in inadequate lead time in providing information on flood risk to the communities; lack of adequate resources (poor facilities and equipments for field staff) and inadequate training systems were observed. In fact very few officers had received advanced training in flood management systems (Sinha *et al*., 2012).

The study also found major gaps exist in coordination between field staff and senior officers were noticed. There was also lack of collaboration with partner agencies such as the State Disaster Management Authority. With the focus mainly on building and protecting flood management infrastructure, there was lack of community centered approach, with the community's concerns not being integrated into the WRD's decision making processes. As regards resources, funding shortage was found to be affecting the performance and quality of the institution. Insufficient funds for maintenance works, inadequate equipment and technological resources--lack of quality transport equipments, poor technical software and IT for communication and data collection at division levels, were found to be problems (Sinha *et al*., 2012).

When compared with the extent of flood damages in the state, the amount spent by the WRD on flood mitigation continues to remain very small. During the decade from 2000 to 2010, the cumulative expenditure on flood management was only 3% of the cumulative value of flood damages in the state (at constant 2004-05 prices). The State's relief budget is commonly a small percentage of the estimated flood damages. Even during the exceptional year of 2007/8 flood relief expenditure was INR 1004.39 crores, against the economic loss of INR 6,542.51 crores, or 15% of the occurred damages (MoWR, 2014). As seen in the earlier discussion on GFCC, the utilization of funds from GFCC for flood control in Bihar has also not been very commendable.

Flood Management Information Systems Centre (FMISC)

The Flood Management Information Systems Centre (FMISC) was established within the State Water Resources Department in 2007 to improve the technical and institutional capacity of the state in flood management, in particular the introduction of modern information technologies . The overall aim of the FMIS is to generate and disseminate timely and customized information in order to assist flood management agencies to move from disaster response to disaster preparedness and to effectively support flood control and management in the flood prone areas of Bihar. It was recognised that there was a compelling role and benefit for modern technology to improve decision-making processes before, during and after flood events.

The FMISC comprises a total of 23 staff currently in office against sanctioned posts of 34 officers. The Cell is comprised of one Joint Director, two Deputy Directors with an additional Director on deputation, six Assistant Directors and four Engineers on deputation, one JE on deputation, and seven contract staff that have technical specialization remote sensing, GIS, web and IT management, disaster management, among others.

The development of the FMISC was planned in four stages: i) Flood hazard characterization and emergency response; ii) improved flood preparedness and community preparedness; iii) Flood hazard mitigation; and, iv) integrated flood management.

The Phase I of the Flood Management Improvement Support Project (August 2006-June 2008) focussed on flood hazard characterization and operation of flood management products, supplemented by improved flood forecasts, a flood management website, updated flood control manuals, preparation of plans for upgrading hydrological measurements and telemetry and training of government agency personnel.

The FMISC has benefited flood management in North Bihar through: strengthening flood knowledge base; comprehensive analysis of hydrological data; dissemination and outreach of information on operational flood management; improvement in flood preparedness; and trainings. The FMIS-I covered a total area of 26 thousand sq. km from Burhi Gandak River in the west to Kosi River in the east. The area encompasses 11 most flood affected districts of North Bihar which include East Champaran, Sitamarhi, Sheohar, Muzaffarpur, Madhubani, Darbhanga, Samastipur, Begusarai, Khagaria, Saharsa and Supaul. Under the project, a website was also developed to provide easy access to flood related data and information. From July 2008 to May 2010, interventions under FMIS-I was continued by the State Water Resources Department (WRD) using their own funds.

Subsequent stages of FMIS development seek to encompass enhanced functions and products, supported by improved hydrologic observations and telemetry, more reliable and longer-term rainfall forecasts, enhanced flood forecasting and prediction of inundation using more powerful models, real-time inundation mapping during floods (using Synthetic Aperture Radar, ASAR surveys), real-time flood data dissemination, mapping of floodplain geomorphology using close-contour surveys, establishment of an embankment asset management database, enhanced information flow and communication links together with community outreach and participation programmes providing flood risk assessments and flood warning.

The World Bank supports FMISC staff and selected WRD personnel for training by the US Army Corps of Engineers on asset management plans for embankments, specialised training on flood forecasting and water resources management.

Once in a year the FMISC also hosts a training session for the WRD Technical Advisory Committee. Training is required for WRD engineers, particularly those working in the Flood Management Cell, in mathematical modelling, hydrology, meteorology and flood management. This training is provided by the Water and Land Management Institute (WALMI) and does not, surprisingly, involve staff of the FMISC who could cover the mathematical modelling and hydrological aspects. The FMISC website provides detailed daily hydro-meteorological data with water levels and danger levels in rivers, and flood bulletins; inundation maps; and 5-day rainfall forecasts for Bihar and Jharkhand.

Flood Management Implementation Support Project II (FMIS-II)

Based on the achievements made under FMIS-I, the Government of Bihar has submitted a proposal to Government of India for the second phase of the FMIS. The aim is to strengthen the interventions made under FMIS-I and also to scale up these interventions to other flood affected areas in the State.

The major objectives of FMIS-II are: to strengthen the basic institutional framework for improving flood management in the State; and to improve flood warning and preparedness for residents in targeted areas in Bagmati-Adhwara basin. For achieving the objectives, three major activities/components have been identified. They include: institutional strengthening for flood management; development of flood management information systems; and community-based flood risk management in targeted areas.

Under the component on institutional strengthening, major focus will be on: capacity building and strengthening of the FMIS Centre and Water Resources Department Flood Monitoring Cell and Hydrology Directorate by recruitment of specialist staff; and development of integrated flood management plan and strategy.

Under the component on FMIS, major focus will be on the development of a modern flood management information system for Bihar, with an initial demonstration in selected areas of the Bagmati-Adwara basin. It will also include support for improving the spatial knowledge base for flood management; developing and using models for forecasting flood flow and inundation; and the establishment of an Embankment Asset Management System.

Bihar State Disaster Management Authority

The Bihar State Disaster Management Authority (BSDMA) came into being in 2007, after the passing of the National Disaster Management Act in 2005 in Indian parliament. The BSDMA is a policy making body, and is concerned with promoting policies and programmes for disaster reduction; disaster management and disaster risk reduction. For this, it undertakes capacity building programmes for the same in the State.

Its main function is to create awareness about disasters; develop training materials on disaster preparedness; and design and implement training programmes for a wide range of stakeholders--from school children, local self-governing institutions, and agencies involved in emergency relief operations—fire services, police department, paramedical services--, to increase their preparedness to reduce risks when disaster strikes. The agency does not undertake disaster response work and therefore is not a field level agency.

The BSDMA is headed by an ex. bureaucrat, who is also the Vice Chairman of the Board of the State Disaster Management Authority, which is headed by the Chief Minister as its Chairman. There are seven members in its governing Body. It has four Senior Advisors, each one looking after one specific area, viz., Environment and Climate Change; Natural Disasters (floods, droughts and fire); Human Induced Disasters; and Technical Aspects of Disaster Reduction. It also has five project officers, under whom there are senior technical officers.

The agency had developed a State Disaster Management Plan and is currently involved in District wise Disaster Management Plans, which are specific to each problem—say for instance, floods, droughts, etc. The district disaster Management Authority, which is headed by the District Magistrate, is responsible for coordinating both the capacity building activities and rescue operations at the district level.

The BSDMA observes a 'Flood Safety Week' in the State every year, with special programmes for awareness on reducing the risks associated with flood disaster. The agency is planning to develop an early warning system for floods. The authority, though manages its activities with a very modest budget of around INR 5 crores per annum, has been able to reach out to a very large population, through schools and various government line agencies. Special training programmes are offered to officers of various government departments, who work at the state level and district level offices, on reducing disaster risks in their own offices.

The agency had developed a large body of training materials aimed at building community's capacity for disaster preparedness covering various types of disasters including floods and earthquakes, both in local language and English. The educational materials have plenty of illustrations for common men, women and school children to understand. These materials are available free of cost.

Bihar State Disaster Response Force (BSDRF)

The Bihar State government had established a State Disaster Response Force (SDRF) on the pattern of National Disaster Response Force (NDRF) for deployment in the event of flood, drought, epidemic and other natural and man-made disasters in 2010. It undertakes awareness programmes, community training for capacity building for their preparedness for 'first response', and rescue operations. The SDRF HQ and Training Centre is being set up in Patna district and civil construction work is in progress at a fast pace, and 95 SDRF officials had been appointed from 105 applicants belonging to ex-Servicemen, ex-paramilitary personnel and ex-BMP official's categories.

To strengthen the SDRF team, officials and constables are appointed on three-year contract. Renewal of their contracts would be done on the basis of their performance. Ability to swim is an important criterion for their selection. The SDRF officials and constables are trained on the pattern of National Disaster Response Force. They are also imparted training in health management and the service needed during epidemics. At present, NDRF officials and constables are being used for disaster management in the five districts of north Bihar, including Khagaria, Supaul, Saharsa and Muzaffarpur.

The department had organized training programmes for community preparedness for disaster management for 11,000 persons in the flood-prone districts of the state. As many as 1,890 master trainers had been already been given training, against a target of 11,000. Fund allocation for flood-related disaster management measures were made to every district in the month of May itself. Motor boats, fibre boats and local boats were arranged in all these districts before monsoon. The additional financial requirements of Bhagalpur, Vaishali, Khagaria, Darbhanga, Begusarai, Samastipur and Patna districts were met only the after receipt of utilization certificates of fund released earlier. Non-utilized fund would be surrendered to the department by the respective districts.

In addition to the SDRF, the state also has one battalion of the NDRF stationed in Patna, in view of the recurring floods in the state. During the Kosi floods of August 2008, the NDRF rescued around 105000 people from drowning.

6.2 Community needs to support IFM plan / Proposals to mainstream community needs into IFM

The institutional arrangements for DM activities at state level and its coordination with districts in the state is reasonably well structured with well-defined Standard Operating Procedures (SOPs). This is institutionalized through the national DM Act and policies developed since 2005. However, even though there are efforts taken to institutionalize DM activities at sub district level, the coordination for preparedness, response and relief is weak at sub district and below. This has led to the weak link to the last mile connectivity seriously affecting the effectiveness of flood preparedness.

Based on the community issues and needs identified and explained in section2.3.1, following are the proposals for mainstreaming community needs into IFM. A framework for strategy matrix for community involvement in IFM is provided in the volume 6 - community reports.

1. Consultation during flood management planning: Even though designing and implementing structural mitigation projects is more a mandate of the department and community can provide limited contributions, it is important to consult them to understand their needs, problems, concurrence, and ownership.
2. DM in local level planning: Leveraging the Panchayat Raj Act, Gram Sabha should consider DM activities while formulating development projects. Presently the state is developing district disaster management plan for all the districts of the state. It is important to inform the communities about the flood risk and provided advisory support for livelihood adaptation. It needs training and capacity building of local body administration to steer Gram Sabha meeting to integrate DM into development planning.
3. Flood mitigation: The cause of flood in the BG basin is due to heavy rain, and breach of embankment. It need a mechanism to maintain and proper surveillance of the embankment to avoid breaching.
4. O&M of irrigation channels and sluice gate: It is very important to utilise the full potential of the flood mitigation measure and this can only be possible if there is proper O&M in place to maintain the irrigation channels and sluice gate. The irrigation channels and sluice gates are not function due to choking of silt from the river.
5. Preparedness: Encourage Community Based Organisations (CBOs) and NGOs to work among the community on DM activities. This includes keeping the local DM plan and task force active and emphasize their roles and responsibilities during various phases of DM. Incentive mechanism and enforcement through local administrative bodies would be effective mechanism for this.
6. Response: Conduct mock drills in the communities, awareness development on dos and don'ts during flooding and post flood. Public announcement system and local sign board for flood warning and flood zones are required in flood prone villages.
7. Recovery: Training DM task force in rescue and relief operations, including first aid, hygiene and sanitation, safe drinking water, etc.
8. Knowledge dissemination of adaptation and mitigation measures: There are efforts at the community level as well as private sector support for developing adaptation and mitigation strategies to protect community livelihoods. These include promoting flood, drought, and saline tolerant crop varieties to ensure returns from agriculture even when there are disasters. Short duration crops need to be promoted and need to be cultivated monitoring the flood season.
9. Demonstrating pilot plots to encourage community to adopt adaptation strategies: Agriculture department should demonstrate (farm-based demonstration) introduction of crops suitable for adopting in water logged and saline soil conditions.
10. Farm advisories: The state lacks farm advisories, which can provide farmers to plan for the whole season. There should be farm advisories, which are accessible to rural farm communities. This should be reliable and should forecast rainfall and other critical weather parameters in advance so that farmers can plan their agriculture calendar.

Chapter 7 Conclusions

7.1 Structural measures

We saw in Section 4.2 that that providing a safety of 1:25 years reduces the risk by 89%. This underpins the current recommended safety level according to the Guidelines of the National Flood Commission of 1980. The question that remains is how to effectively reach this safety standard.

Considering the various measures discussed in this report, a River Basin Flood Management Plan should constitute a mix of these. Because the structural measures are most capital intensive, a thorough evaluation of their costs and benefits is required before a decision can be made. In the table below the key figures of current and future flood risk is provided for a 1:25 year rainfall event. It shows that the combination of structural measures would reduce maximum flood area with 35% and would reduce the subsequent damage with 25%. The Annual Average Damage (for this return period) would go down from INR 182.1 crores to 116.8 crores. This is the yearly benefit of these projects for flood mitigation alone. Using these data a cost-benefit analysis can be made for such projects.

Table 21 Overview of flood risks and impact of measures in Burhi-Gandak as computed

1:25 yr flood	Current	CC 2040	CC2080	Masan Dam	BG-NB-G link	Embankment improvement	Combined
Max. flood area (km2)	1571	1644	1911	1488.8	1466.8	1156.3	1015.3 (-35%)
People affected (Lakh)	81.0	81.4	86.1	77.2	77.2	65.9	59.7 (-18.6 %)
Damage (INR Crores)	4551.6	4571.8	4834.2	4392.0	4297.2	3402.8	2919.3 (-25.2%)
AAD (INR crores/yr)	182.1	182.9	193.4	175.7	171.9	136.1	116,8 (-36%)

7.2 Towards a River Basin Flood Management Plan

The analysis in the previous chapter discussed the features and feasibility of each of the flood risk measures separately. Because a River Basin Flood Management Plan should consist of a well balanced mix of all of these measures, the next step in preparing such Plan consist of a comparison between measures using a set of criteria. These criteria should be selected during the planning process by the responsible agencies (for instance a River Basin Organisation) in due consultation with all stakeholders. To illustrate how this evaluation can look like, the table below shows the scores of each type of measure on four different criteria: i) flood reduction effectiveness, ii) investment size, iii) BC Ratio and iv) time scale needed for implementation. Scores are given on a scale of 1 to 5, where 5 denotes a good score and 1 a bad score.

Table 22 Multi-criteria analysis for flood mitigation interventions in Burhi-Gandak

Intervention	Flood reduction effectiveness	Investment size	BC ratio	Time scale*	Overall rating
Flood warning	None 0	Low 5	Very high 5	Short term 5	15
Community Preparedness & Disaster Management	None 0	Low 5	Probably high 4	Short/medium 4	13
Embankments	Medium 3	High 2	High 4	Medium term 3	12
Crop protection	None 0	Low 5	? 2	Short/medium 4	11
Watershed management	Medium 3	Medium 3	? 2	Long term 2	10
Urban and rural drainage	Medium 3	High 2	? 2	Medium term 3	10
Dams and diversions	Medium 3	Very high 1	Medium 3	Long term 2	9

*: short term < 3 years; medium term 3-5 years; long term > 5 years

A first conclusion from the table is that none of the measures reaches the maximum score of 20, but neither of them have a very low score. Apparently all have strong and weak points, resulting in final scores between 9 and 15.

The multi-criteria analysis presented here shows highest scores for nonstructural measures Flood Warning and Community Preparedness & Disaster Management. Although they do not reduce the floods themselves, they score very good in terms of low investments and relatively quick results. Embankments, Crop protection, Watershed management and Urban & Rural Drainage have average scores between 10 and 12, but for different reasons. Embankments do reduce floods and often have good BC ratios, but they require substantial government funding and implementation takes many years. Crop protection does not reduce floods but requires little investment. On the other hand, its implementation requires appropriate market conditions which will take time to develop. Watershed management could significantly reduce floods, but its implementation will be a long term process. Urban & Rural Drainage is capable of substantially reducing inundations but requires high investments and results will be visible in medium term only. Dams and diversions have a lower score. Although they can significantly reduce floods, they require massive government funding and implementation will take many years.

Based on this preliminary multi-criteria analysis it is advisable to start flood warning and community DM activities as soon as possible as they can be considered as no regret measures (low investment and high results). Most of the other measures that require substantial (government) investments need to be prioritized further based on more detailed cost-benefit analysis and a collectively agreed set of evaluation criteria.

Because of the operational research character of this study, the above evaluation is indicative only but can be used as input to a formal planning process for the basin. Such planning process can use the information from this report, together with the available flood model, to create a sound knowledge base for all stakeholders. This knowledge base can then be enriched with more specific local knowledge through a joint fact finding phase. During this phase also the evaluation criteria need to be agreed upon by all stakeholders.

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Appendix A Prefeasibility design with costing for urban drainage system

Based on the site visit made to Muzaffapur a prefeasibility design is proposed along with costing. Tables A-1 to 7 display the costing and detailed breakup for each component. Further recommendations, which depend on available funding with State officials are mentioned in the following sections. They are important elements regarding efficient urban drainage and are included in this report considering their usefulness to abate the existing situation.

Control of Garbage

There is a significant amount of garbage accumulation in the drains of the study area. These accumulations are not only unsightly, but also restrict the hydraulic capacity of the drains and aggravate flooding. This menace cannot be avoided totally even if there is an organised system of solid waste management. However to restrict direct access to the main drains, they will be protected by a fence of MS BRC (IRC) fabric. The structural design will include the following:

- MS welded rectangular fabric mesh of 75mm X 25 mm.
- On two sides of drain the mesh will be placed vertically for a height of 2.5 m and then inclined outside for 0.75 m.
- This mesh will be stiffened by MS angles and flats.
- The span of each mesh panel will be 3 m c/c.
- On two sides the panel will be supported by 200 X 200 RCC posts which will be supported on drain top wall.
- The reinforcements will comprise of 4 nos-12mm Tor to be braced with 10 Tor transverse reinforcements @ 150 mm c/c
- The posts will be constructed monolithically from the drain wall.

Pump Station

Drainage pumping stations are necessary for the removal of storm water where gravity drainage is not possible or impractical. Therefore, the use of drainage pumping stations is recommended only where no other practicable alternative is available by gravity. The primary function of the pumping stations is to pump water out of the drains when gravity flow is not possible during the monsoon season when the rivers are high and the sluice gates are closed.

Inlet channel with sluice gate and trash rack

Since the pumping stations will be located off the main drains an inlet arrangement will be necessary. Such an arrangement will include a channel from the main drain to the wet well with a sluice gate at the transition from the main drain to the inlet channel and a trash rack at the entrance to the wet well.

The sluices gate will be automatically operated with a motor actuator and will normally be in the closed position. The gate will be opened when the water elevation in the main drain reaches a prescribed level. The sluice gate can also be used to isolate the pumping station for maintenance or repair purposes.

The inlet channel will be of reinforced cement concrete (RCC) construction and sized to carry the peak design flow at velocities less than 1.5 meters per second (m/s). Generally, the invert elevation of the entrance of the inlet channel will be 0.5 meters above from the bottom of the Drain.

At the end of the inlet channel a trash rack will be located to catch debris and protect the pumps. The trash rack will be inclined at 15 degrees from the vertical and have 20 mm flat steel bars spaced 25 mm on center. It will be manually cleaned.

Wet Wells

The wet wells for the drainage pumping stations need to be large enough to provide the necessary flow to the pumps so they do not start and stop too frequently and so there is adequate room for the pumps to operate and not create turbulent flow with cavitation. There will be adequate flow to the pumps since they will only operate when the main drain system is filled to a predetermined level.

Under these conditions the entire drainage system will act as an extended wet well and the pumps will function to prevent the water from rising to flood level. The wet well will have a common flow distribution chamber that will distribute the flow from the inlet channel to the individual pumps. Each pump will be in a separate chamber open to the distribution chamber and separated by baffle walls which will dampen turbulence in the suction zone when one of more pumps is running.

The following criteria apple to the Wet Wells:

- The distribution chamber will have velocities of less than 0.9 m/s at peak design flow
- The minimum wet well size will be the volume discharged at peak flow for 30 sec.
- The minimum horizontal clearance around the suction end of the pumps will be 1.2 m
- The minimum clearance below the suction end of the pumps will be 0.5 m
- The minimum water depth (head) above the suction point will be of 1.5 m

Pumps

Vertical axial flow propeller or vertical mixed flow impeller type pumps are suitable for flood control pumping stations. These pumps are high volume - low head types well suited for flood level control applications. These types of pumps can be equipped with diesel engines, electric motors or a combination of both for each pump. The engine or motor is mounted above the high water level with the pump installed in a wet well. The axial flow pump specifies a pitch or angle of the propeller blades while the mixed flow pump specifies an impeller diameter trimmed to match the design point.

Prime Mover

Electric-driven pumps are often installed with a single main electric service and stand-by generator(s) for back-up power. In the study area, the reliability of power during flood condition is uncertain. In addition, the service provider connection fees for the electrical service will be cost prohibitive for large capacity pumping stations that will only operate periodically during the monsoon season. For these reasons the more reliable diesel driven pumps are recommended for the drainage pumping stations.

Diesel fueled internal combustion engines will be used for the pump drives. Engine drives offer the advantage of variable speed as the engine can be throttled, which is a further benefit when compared with electric motors that operate at constant speed unless variable frequency drives are included.

Discharge System

The discharge line from each pump will enter a manifold which will combine the flow into one pipe. This pipe will be discharged through an energy dissipater to the Rivers or Canal at an elevation 1 m above high water. Gate valves and Air Valve will be located on each individual discharge line and Connected to the one discharge line from the manifold. The discharge line will be Ductile Iron (DI) material and energy dissipaters will be of RCC construction.

Recommendations for improvement of urban drainage efficiency

Improvement of urban drainage efficiency is another useful option and can be achieved through:

- Desilting, cleaning of road, bell mouth, gullies, removal of debris, solid waste materials from all drains of all depts. /civic bodies.
- Constructions of cunnette to provide sufficient velocity with aeration due to turbulence all along the drain for 100-150 cusec capacity flow.
- Comprehensive plan using STPs with covered drain.

Rain Water Harvesting

Rain Water Harvesting plays a key role in arresting urban flooding. It can be achieved through the following:

- On channel storage of rain water in storm drain
- Artificial recharge trenches
- Check dam in hilly reaches
- Providing retention basins to detain excess water

Creation and revival of water bodies

In urban areas the creation and revival of water bodies can help arrest flood situation and also increase water health. This can be achieved by:

- Surveying all water bodies to take rain water upto the catchment area
- To remove all encroachments entering the catchment area
- To provide drain if encroachment is not possible to remove
- To provide Sewage Treatment Plant (STP)s to treat solid and semi solid sewage that will otherwise enter sewage system and clog them.
- To deepen the water bodies upto the protecting/impervious layer
- To provide vegetation around and in catchment areas to reduce erosion

Prefeasibility design with costing for urban drainage system

Based on the site visit made to Muzaffarpur, we can propose a prefeasibility design along with costing. The costing is also supported by the document "Storm Water Design for Muzaffarpur City". Tables A-1 to A-7 display the costing and the detailed breakup for each component.

Table A-1: General abstract of cost for storm water urban drainage for Muzaffarpur

Description	Amount in lakhs of Indian Rupees
RCC Outfall drains	1,388.53

Trapezoidal drains and appurtenant works	2,309.49
Culverts	517.95
Covering of outfall drains with RCC slabs	1,395.94
Proposed internal drains	3,751
Renovation of existing internal drains	1,463.4
Hiring of godown	2.4
Land acquisition	200
Sub total	11,028.71

Table A-2: Abstract of cost of proposed RCC outfall drains

Description	Unit	Rate in INR
Excavation of earth including ramming of excavated earth into trenches		
0 to 1.50 mbgl	M^3	157
1.50 to 3 mbgl	M^3	178
Providing and laying cement concrete 1:4:8	M^3	2,144
RCC work with cement, approved coarse sand and 2cm guage. Including fixing and binding with wire.	M^3	5,181
RCC work in walls upto floor five level.	M^3	5,328
MS or iron in plane work	Quintal	6,760
Disposal of earth	M3	135
Cost of cutting trees	Lumpsum	75,000
Traffic diversion and signage	Lumpsum	1,50,000
Cutting road and making good the same		
Bituminous road	M^3	1,081
Cement concrete road	M^3	4,706

Table A-3: Abstract of cost of cost of outfall drains- (trapezoidal sections) and appurtenant works

Description	Unit	Rate in INR
Excavation of earth including ramming of excavated earth into trenches		
0 to 1.50 mbgl	M^3	157
1.50 to 3 mbgl	M^3	178
Providing and laying cement concrete 1:4:8	M^3	2,144
1st class half brick masonry with 1:4 cement mortar	M^2	319
Providing and laying cement concrete 1:2:4 in bed of drain	M^3	3,409
Brick work of class 75 inches foundation and plinth with cement mortar 1:6	M^3	2,516
12 mm cement plaster mix 1:4 on side and exposed surfaces including labour	M^3	83.3
Disposal of earth	M^3	135
Dismantling of existing culverts etc	Lumpsum	3,00000
Traffic diversion and signage	Lumpsum	3,00,000
Shifting of telephone and poles falling in the alignment of proposed drains	Lumpsum	3,00,000
Providing protection works like toe walls at various disposal points of drain to Furdoo Nala	Nos	75,000
Diversion of existing drains during construction at various intercepting points	M	750
Cutting road and making good the same		
Bituminous road	M^3	1,081
Cement concrete road	M^3	4,706
Filling dry brick ballast in existing drain bed		
3000mx2mx0.5m	M^3	869

Intercepting internal street drains and joining the main external storm water drain with necessary brick work and plaster. Including labour	Nos	4,000
Desilting Furdooh Nala of 11km length approx.		
Making temporary earthen bundha for pumping out water	Lumpsum	300000
Desilting of drain	M^3	178
Strengthening of side slopes	Lumpsum	1,650,000
Cross drainage works under existing railway track	Lumpsum	2,250,000
Cross drainage work under existing state/ national highway	Lumpsum	2,250,000
Special repairs of anti flood at existing sluice gates at various points of stormwater disposal in Burdhi Gandak river	Nos	1,50,000
Construction of pumping houses including supply of pumps. Boundary walls and generators for 100% power. Including labour	Nos	18,750,000

Table A-4: Estimate of proposed internal drains

Description	Unit	Rate in INR
Construction of internal drains including material and labour	Km	3,00,000
Shifting electrical/telephone lines	lumpsum	1,00,000

Table A-5: estimate of the renovation of existing internal drains

Description	Unit	Rate in INR
Cleaning works of the existing internal drains filled with plastic bags. Desilting solid/semisolid garbage and disposal of the	Km	40,000

same.		
Renovation works of existing drains to ensure proper flow of stormwater. Including labour and materials	Km	1,50,000

Table A-6: estimate of hiring godown

Description	Unit	Rate in INR
Hiring of godown for storing cement, steel and other items necessary for the period of execution of works	Month	10,000

Table A-7: estimate for land acquisition

Description	Unit	Rate in INR
Land for the construction of pumping station with appurtenant works at outfall locations	M^2	5,000