A Decision Support Framework for Sustainable Land and Water Management in a Floodplain

by

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In partial fulfillment of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

Land and water are essential deltaic floodplain resources and their interdependence necessitates an integrated approach for sustainable land and water resources management. Since 1980s, sustainable development has become the key development planning objective. However, detail procedure to achieve sustainable land and water use as part of sustainable development in a deltaic floodplain has been lacking.

In this study, there are two competing objectives: socio economic improvement and maintaining floodplain environment. However, there are two constraints in attaining these two objectives. Socio economic improvement must ensure equitable distribution of land and water resources. To maintain floodplain functions, the ecosystem in the deltaic floodplain should be safeguarded. The decision support framework has been developed for sustainable land and water use, incorporating three objectives, maintaining floodplain functions, improving socio economic condition and compliance to constraints. Further, this research developed the concept of "Inverted Pyramid", whereby, the present generation is treated not only as users, but also as custodian of deltaic floodplain resources for future generations.

In this study, floodplain functions have been defined for deltaic floodplain. To characterize the functions, a set of indicators (e.g. flooded area, condition of wetland habitat, change of monsoon/dry season flow, change in infiltration area, etc.) have been developed. In addition to functions and physical indicators, to improve socio economic condition, a set of social indicators have also been developed, including the availability of foodgrain, employment opportunity, gross income, safe drinking water, etc. Therefore, for sustainable land and water management framework, eight sub-objectives, twenty-two criteria and thirty six indicators have been developed.

The developed decision support framework has been tested in the Jamalpur district, part of the Old Brahmaputra and Jamuna floodplain. The constraints and opportunities have been calculated for four types of land and water use based on physical suitability, social preferences, government policies and strategies in the study area. RS, GIS, hydrodynamic and hydrological models were used to generate data for assessment of indicator values and objective criteria. For the study area, three land and water use options have been developed to test the sustainable land and water use framework. These options are, option A: autonomous development based on existing development trends, option B: implementation of regional water management plan in FAP 3.1, and option C: Balanced land and water use activities developed in this study based on policies and strategies assuming protecting floodplain environment as socio economic improvement without degrading the ecosystem and continuing floodplain function for the future generation. These options have been evaluated through multi criteria analysis (MCA). Option B scored the highest in achieving the objective of socio economic improvement. On the other hand, option C scored much higher than option B in protecting floodplain environment through maintaining floodplain functions. To comply with constraints, Option C scored the highest.

Finally, the suggested decision framework will be helpful to understand the interdependence of socio-economic, ecological and environmental resources in developing an integrated management plan for sustainable land and water management in a deltaic floodplain.

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ABBREVIATIONS

AHP	Analytical Hierarchical Process
BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BIDS	Bangladesh Institute of Development Studies
BMD	Bangladesh Meteorological Department
BSCIC	Bangladesh Small and Cottage Industries Corporation
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
CPD	Centre for Policy Dialogue
DAE	Department of Agricultural Extension
DEM	Digital Elevation Model
DN	Digital Number
DTM	Digital Terrain Model
DTW	Deep tube-well
EIA	Environmental Impact Assessment
EIP	Early Implementation Project
EMG	Embankment Maintenance Group
EPWAPDA	East Pakistan Water and Power Development Authority
FAO	Food and Agriculture Organization of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control, Drainage and Irrigation
FGD	Focus Group Discussion
FPCO	Flood Plan Coordination Organization

GDP	Gross Domestic Product
GIS	Geographic Information System
GNI	Gross National Income
GO	Government Organization
GoB	Government of Bangladesh
GPS	Global Positioning System
HIL	High Inundation Level
HTW	Hand tube-well
HYV	High Yielding Veritics
IBRD	International Bank of Reconstruction and Development
IPCC	Inter-governmental Panel for Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
KII	Key Informants Interview
LCS	Landless contracting Society
LGED	Local Government Engineering Department
LLP	Low Lift Pump
MDG	Millennium Development Goal
MoL	Ministry of Land
MPO	Master Plan Organization
NCA	Net Cultivable Area
NCR	North Central region
NGO	Non Government Organization
NLUP	National Land Use Policy
NWDA	National Water Development Agency, India
NWMP	National Water Management Plan

NWP	National Water Plan
NWPo	National Water Policy
NWRD	National Water Resources Database
O&M	Operation and Maintenance
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PRSP	Poverty Reduction Strategy Paper
PSR	Pressure-State-Response
WHO	World Health Organization
PWD	Public Works Department
RHD	Roads and Highway Department
RS	Remote Sensing
SRDI	Soil Research and Development Institute
SSWRDSP	Small-Scale Water Resource Development Sector Project
STW	Shallow tube-well
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
WARPO	Water Resources Planning Organisation
WCED	World Commission on Environment and Development
DSS	Decision Support System
MCA	Multi Criteria Analysis
MCDM	Multi Criteria Decision Making
DPSIR	Driving forces-Pressure-State-Impact-Response
OECD	Organisation for Economic Co-operation and Development
VRDC	Virtual Research and Development Centre
HDM	Hydro Dynamic Model

Chapter 1

INTRODUCTION

1.1 Background

The world's largest delta, Bangladesh, is formed by three mighty rivers: Ganges, Brahmaputra and Meghna. About 80% of the country is made out of rivers and floodplains (Brammer, 2002). In most parts, during the holocene period, huge sediment load, tectonic subsidence, major seismic events and a near shore canyon system have led to widespread sediment dispersal and formation of this delta (Goodbred et al., 2000). Land and water are the essential natural resources for the livelihood in the floodplain. Both these resources coexist and are interdependent. As a result, they should be considered jointly for their utilization (Navalgund, 2002) to ensure economic development, social wellbeing and a sustainable environment. The present pressure on water, food and health facilities will further intensify with future population growth in third world countries; a coordinated and integrated water resource management can address these problems (Bouwer, 2002).

Sustainable development has become the objective of the world community for every development sector in the United Nation's Millennium Development Goals (MDGs). Sustainable development requires an integrated approach in planning of resource management, but there is no indication about the detail procedure to achieve sustainability. As a result, these resources are over utilized without considering their sustainability. At the same time, contaminants are continuously released to the environment from different development activity. Society is also generating different contaminants that are being released to the environment as shown in Figure 1.1. On the other hand, environment is supplying different goods and services for the betterment of the society. Sustainable development cannot be achieved without considering the relationship between natural and human system and the interdependency of resources. Thus harmonization in the use of resources is essential for sustainable resource management.

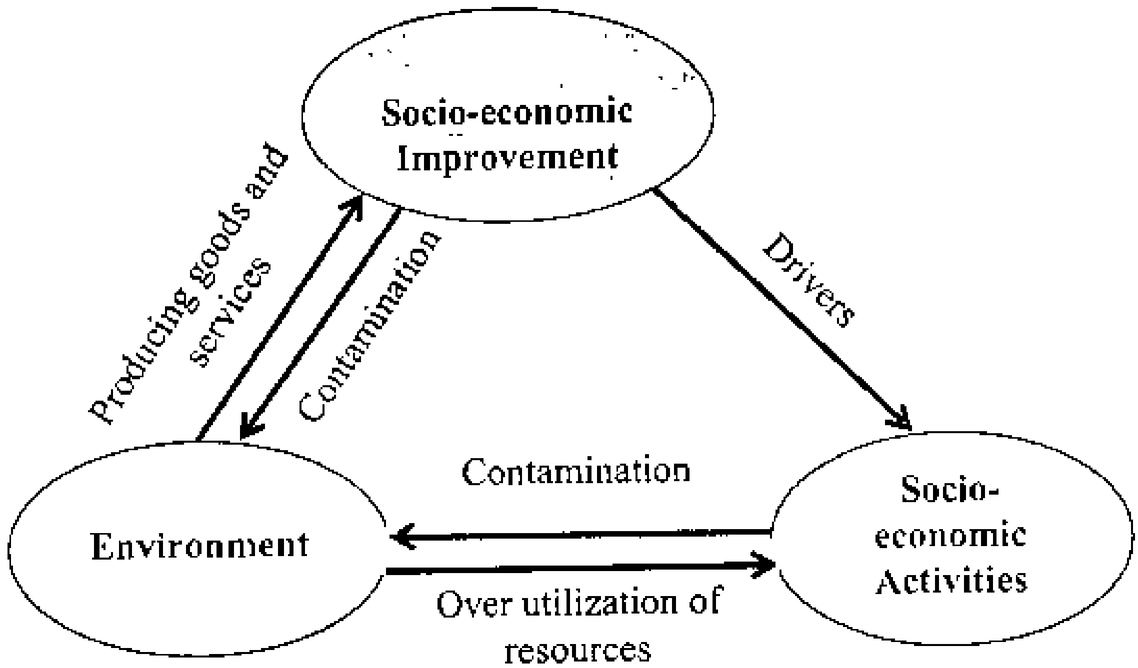


Figure 1.1: Interaction between natural and human system

Sustainable resource management means not only to produce goods and services for the society but also to maintain functionality of the environment. Risk and uncertainty, which mainly depend on climate, demographic and other factors have influence on sustainability (Howard, 2002). The development and utilization of water resources must be in harmony with economic development and environmental protection (Xuequan et al, 2002). The economic benefits provided to human society from maintaining healthy aquatic and riparian ecosystems, coupled with the high cost and difficulty of restoring degraded ecosystems (Bernhardt et al. 2005) have fueled the growing awareness that principles of ecosystem need to be more fully integrated into water resource planning and management (Poff, 2009). Further, for sustainable resource management, equity principle is the criterion for distributive fairness and impartiality in decision making for resource use (Matheson et al., 1997 and Chowdhury, 2009).

In Bangladesh, large and medium Flood Control and Drainage (FCD) projects were implemented by Bangladesh Water Development Board (BWDB), while Local Government Engineering Department (LGED) implemented the small water management projects (less than 1000 ha). Following the devastating flood of 1974, the Early Implementation Projects (EIP, 1975-1995) were started by BWDB. From the mid 1990s, LGED implemented Small-Scale Water Resource Development Sector Project (SSWRDSP) in two phases. The major objectives of these projects was to increase agricultural production, protection of environment and ultimately to reduce poverty. All these projects were implemented with an integrated resource management approach and the goal was to improve quality of life of the people. However, equity was not considered in this process and also safeguarding ecosystem and maintaining floodplain functions (natural process) were not adequately addressed. Wellbeing cannot be sustained without ensuring equity. Impact evaluation of these projects (Datta, 1999; BUET et al., 2003 and BIDS, 2008) concluded that these projects were implemented on an isolated basis with no assessment of overall effect on the floodplain. Due to the lack of following a holistic approach, the projects contributed in increasing food productivity by reducing damage from floods, but did not safeguard the ecosystem and floodplain functions.

Land, water and ecosystem resources of Bangladesh are subjected to degradation because of extensive use in conjunction with the lack of consideration of the interdependence of land, water, eco-system and socio-economic development. In order to take into account the interdependencies, integrated management of land and water use is essential part of a nation's economic plan. A holistic approach requires balancing the competing demands on the resource – domestic, agricultural, industrial, and environmental (GWP, 2000). The National Water Policy (MoWR, 1999) emphasizes the need of combining water use and land use planning and consideration of equity criteria and ecosystem needs. It indicates that water and land use planning should be integrated but the process and procedure are not clearly mentioned.

With an increasing population pressure, both land and water are quickly becoming critical and limiting resources to maintain economic sustenance for present as well as future generational needs. Thus resource planning, especially, land and water resource needs careful planning through an integrated management approach. Land and water has become critical elements in strategic resource planning and it's spatial and temporal control has become a decision criterion in the trade-off between socio-economic improvement and environment. For sustainable land and water resource, Decision Support System (DSS) is able to address strategies and scenarios, water resource system simulation, user's demand and impact and assessment and evaluation of management options/strategies for planning (EGIS, 2001b). This research will develop a framework to address these needs by using DSS.

1.2 Objectives with Specific Aims and Outcomes

The specific objectives of this study are

- Develop indicators to characterize the functions of deltaic floodplain in order to assess the opportunities for land and water use activities.
- Formulate constraints based on equity criteria for distributive fairness in the management of land, water and ecological resources in the rural area of deltaic floodplain.
- Develop a decision support framework for integrated management of land and water use in deltaic floodplain based on the principles of sustainable development.

The expected outcome is a decision making framework for land and water use management that takes into consideration the sustainability criteria. It will be useful in planning an integrated management of land and water resources in the deltaic floodplain.

1.3 Limitations of the Study

The ecosystem and environmental conditions include quantity and quality parameters and both are important for the assessment of the conditions. But this research only include the quantity aspect. Equity is an essential element for sustaining any socio-economic improvement. Social, economic and physical environmental components are major pieces for equity. The present study only focuses on the physical availability and opportunity towards equitable resource distribution.

All the physical, social and economic parameters are changing constantly and the interactions between them are also dynamic. In order to simulate the future conditions perfectly, this dynamic nature needs to be considered. But this research followed a simplistic approach which did not incorporate all the dynamic interactions.

The available models to simulate the floodplain environment include MIKE by DHI and SOBEK by WL | Delft Hydraulics. The rainfall runoff components of these models (rainfall-runoff model of SOBEK, NAM model of DHI MIKE) have limitations in properly simulating floodplain hydrology and interaction between surface water and groundwater in situations like rural areas of Bangladesh. As a result, base flow estimation has not been done and the potential recharge has been calculated using empirical formula. The flooding simulations for the research have been done with fixed cross section data, which are highly dynamic in a floodplain and their hydro-geomorphic conditions are also constantly changing. In addition, variation in floodplain sedimentation (Goodbred et al., 2000), inconsistent distribution and constant natural process as well as human activities will change the landscape and topography with time. But in this research, the land elevation data has been assumed constant.

1.4 Structure of the Thesis

This thesis comprises of six chapters starting with ***Introduction*** in ***Chapter 1***. The ***Literature Review*** in ***Chapter 2*** describes the concept, definitions, the key factors in achieving sustainable development and sustainable resource management, existing models of sustainable development and the pressure-state-response system. This chapter also describes floodplain characteristics and functions, models and tools used in decision support framework, decision support framework in resource management and multi criteria analysis in decision making. ***Chapter 3: Development of Decision Support Framework for Sustainable Management of Land and Water Use*** highlights the research methodology where indicators and criteria for sustainable land and water use and decision support framework has been developed. This chapter also describes data collection and data generation by models for sustainable management of water use. ***Chapter 4: Description of Study Area*** gives a detail of the study area which includes physical characteristics, socio-economic profile and environmental settings in the study area. Further this chapter discusses the problems and issues and also present land and water use in the study area. ***Chapter 5: Applications and Testing of Decision Support framework*** explains the driving factors, opportunities and the three options this thesis developed for 2050, to evaluate sustainable land and water use. This chapter also explains the evaluation results of the constraints and indicators. Further, this chapter explains the computational tool used for multi criteria analysis (MCA) and the results of the multi criteria analysis. Lastly, ***Chapter 8*** covers the ***Conclusions*** and the ***Recommendations*** for future research.

Chapter 2
LITERATURE REVIEW

2.1 Sustainable Resource Management

2.1.1 Sustainable Development

The concept of sustainability was first used to define the physical limits of exploiting individual resources, especially forests and fish stocks (Braat, 1992). This concept of sustainable development was put on the international agenda by the World Commission on Environment and Development (WCED) in 1987, and confirmed by governments as an international priority at UNCED in 1992 (UNCED, 1992).

There are several definitions of sustainable development. The WCED definition of sustainable development (Brundtland Commission's report, WCED, 1987) is widely used. Other definitions and rules for sustainable development elaborate this definition in various ways. Some of these definitions are presented as follows.

- WCED (Brundtland Commission's report) defines sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs".
- Sustainable development ensures a harmonious process of social and economic betterment that satisfies the needs and values of all interest groups while maintaining future opportunities and conserving natural resources and biological diversity. But physical sustainability cannot be secured unless development policies pay attention to such considerations as changes in access to resources and in the distribution of costs and benefits. Even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation (WCED, 1987). Equity, or fairness, is a measure of the distribution of impacts associated with development in both time and space. Equity is generally measured on two scales, within the same generation (intra-generational) and between different generations (inter-generational) (Simonovic, 2001).
- According to FAO Council (1988), sustainable development is the management and conservation of natural resources and orientation of technological and

institutional change to ensure the continued satisfaction of human needs for present and future generations.

Pearce et al. (1990) and Serageldin (1994), define sustainable development as "to attend long term optimum of societal interest, economic welfare and a healthy environment".

According to IUCN, sustainable development is "improving the quality of human life while living within the carrying capacity of supporting ecosystems" (IUCN, UNEP, WWF, 1991).

Government of Australia, defines ecologically sustainable development as "using, conserving, and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased" (Government of Australia, 1992).

Flint (2003) defined sustainable development as progressive socio-economic betterment without growing beyond ecological carrying capacity: achieving human wellbeing without exceeding the Earth's twin capacities for natural resource regeneration and waste absorption.

A study published by the World Bank (Serageldin & Steer, 1994) defines sustainability in the context of capital theory. This study operationalised the concept of sustainable development as "the total amount of capital in a society should be non-declining at any time". According to capital theory, there are four types of capital:

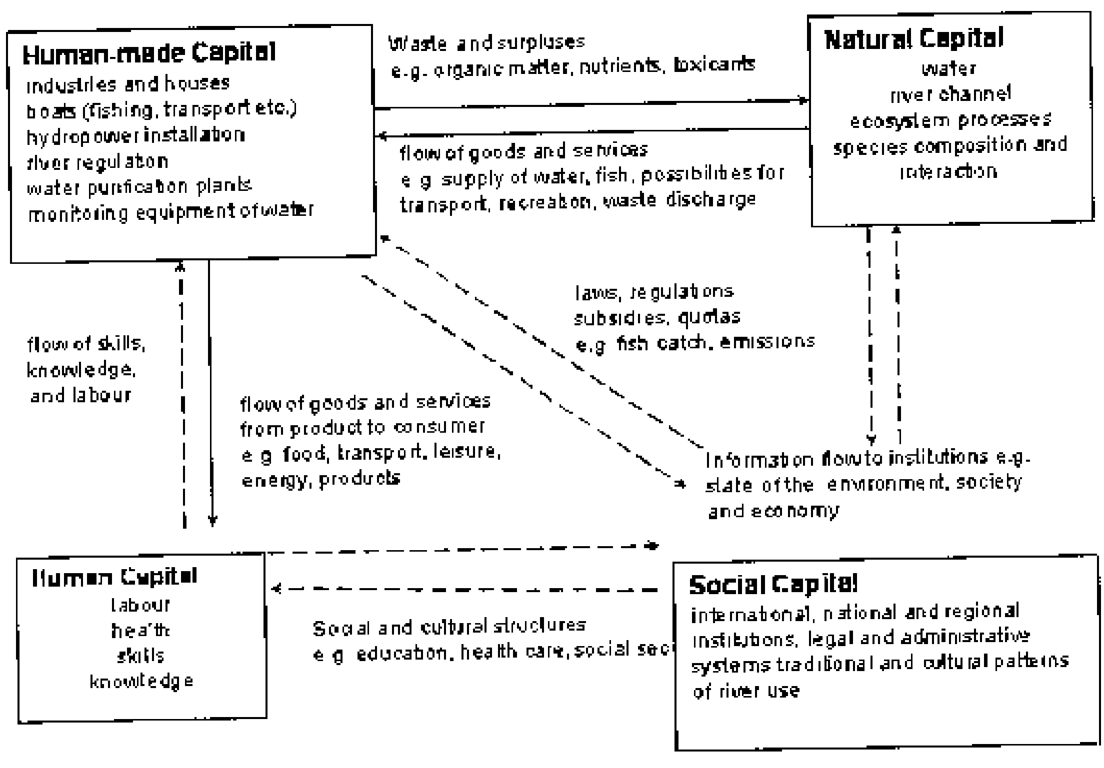
(1) Natural capital: stock of environmental assets providing a flow of goods and services.

(2) Human-made capital fabricated capital such as machines, factories, and buildings.

(3) Human-capital: labour, skills, and other products of investments in education, health, etc.

(4) Social capital: the institutional and cultural basis of a society. Most of the social capital assets can not be valued in monetary terms, as is the case of social and professional networks or social norms (Hatfield Dodds and Pearson, 2005.)

The four types of capital and flows between them are illustrated according to Lorenz (1999) for a river context in Figure 2.1. Here, the capital flows should be made for the development but total capital should not be declined. For example, the production of economic goods from non-renewable natural resources will increase human made capital and decrease natural capital. That means, the natural capital is substituted by human-made capital. This type of substitution among capitals results in a spectrum of possible sustainable states comprising weak and strong sustainability as two extremes. According to Lorenz (1999), for weak sustainability, substitution of any capital specifically natural capital has no constraints whereas for strong sustainability, substitution of natural capital is either not possible or at least severely constrained. However, there is criticism to the approach regarding the percentage of natural capital that could be substituted by other capitals (Lorenz, 1999).



Note. Solid lines are physical flows and broken lines are information flows

Figure 2.1: An example of flows between different capitals in the context of a river (Source: Lorenz, 1999)

Capra (2002); and Costanza et al. (1993); and Costanza (2001) define an ecological economics view of sustainability which is inevitably based in systems thinking. They present a systems conceptualization of sustainable development where natural, human, intellectual and manufactured capitals are transformed continuously one into another.

Bossel and Peet (2000) propose a framework that analyses sustainability from a systems science perspective. They argue that all systems have a number of fundamental properties (or needs) determined by the environment the system evolved in. These fundamental properties are expressed as a set of basic needs that are constant, few and classifiable, and all systems have these same needs and the thing that changes in their path they are met. The framework views the sustainability of a system as a function of the degree to which the basic needs for that system are met. Therefore, developing a set of sustainability indicators involve measuring the level of the satisfiers of a particular system against those required for sustainable development.

Since the Brundtland report, sustainable development has become the focus of discussions and debates (Hufschmidt and Tejwani, 1993; Pearce and Warford, 1993; Serageldin et al., 1993). Through debates, one thing is clear that a more specific definition is needed to help those engaged in development work to evaluate their efforts with respect to sustainability. All of the above definitions recognize that sustainability of activities that provide for human wellbeing depends on the maintenance of environmental functions which themselves, directly and indirectly, contribute to human welfare. This refers to the capacity of natural processes and their components to provide goods and services to satisfy human needs.

In 2002, the world summit on sustainable development further marked the widely used three pillars of sustainable development: economic, social and environment. The Johannesburg Declaration created "a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development – economic development, social development and environmental protection – at local, national and regional and global levels" (UN, 2002). By acting under the principles of sustainable development, our economic desires/demands become accountable both to an ecological imperative to protect the ecosphere and to a social equity imperative to create equal access to resources and minimize human suffering.

SD Model

The concept of sustainable development can be represented by three circle model (principal elements) of sustainability (Flint, 2003) as shown in Figure 2.2. These three elements interact with each other continuously. As a result, we cannot make policies, decisions anything without considering the effects and costs upon all three simultaneously.

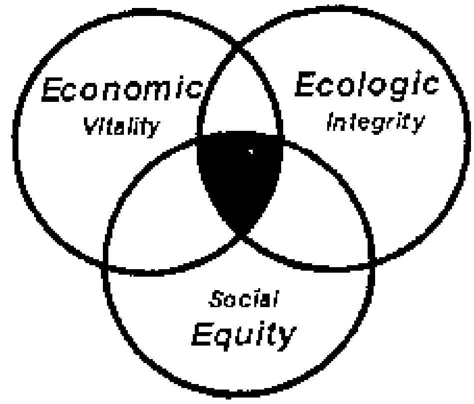


Figure 2.2: The Conceptual model of sustainable development (Source: Flint 2003)

According to Flint (2003) these three elements are described as follows.

- *Economic Vitality (Compatible with Nature)*

  Economic vitality is development that protects and/or enhances natural resource quantities through improvements in management practices/policies, technology. efficiency, and changes in life-style.

- *Ecologic Integrity (Natural Ecosystem Capacity)*

  Ecologic integrity is defined as understanding natural system processes of landscapes and watersheds to guide design of sound economic development strategies that preserve these natural systems.

- *Social Equity (Balancing the Playing Field)*

Equity derives from a concept of social justice. It represents a belief that there are basic needs that should be fulfilled, that burdens and rewards should not be spread too divergently across the community, and that policy should be directed with impartiality, fairness and justice towards these ends (Falk J, et al 1993). Social Equity guarantees equal access to jobs (income), education, natural resources, and services resulting in total societal wellbeing. According to Flint, equity lies at the centre of sustainable development.

2.1.2 Concept of Sustainable Resource Management

Sustainable management is an essential prerequisite for any sustainable development (Steiner and Helmut, 1999). For sustainable resource management, the critical word is "sustainable" It means to develop, protect and manage natural resources in such a way, which enables people and communities to provide for their present social, economic and cultural well-being while simultaneously sustaining the potential of these natural resources to meet future generation needs. Sustainability always includes a consideration of the future and is ultimately related with the risk and uncertainty of the future. It is obvious that the future generation needs cannot be same as the present generation. But it is very difficult to exactly anticipate, what future generation will want or value. Therefore, sustainability concepts always argue that future generation will expect at least as much from these same resource base as the present generation do. However, over time as changes in demand becomes certain, plan and policies for sustainable resources management should adapt with future changes. For sustainable resource management, the use of the resources should be sustainable also. Sustainable resource use is defined as, the conservative use of a resource such that it may be used in the present and by future generations (Kentucky Division of Water, 1997). According to Daly (1990), the sustainable use of natural resources has three implications:

(i) Renewable resources should not be exploited at a greater rate than their regeneration level

(ii) Non-renewable resources should not be depleted at a greater rate than the development rate of renewable substitutes

(iii) The absorption and regeneration capacity of the natural environment should not be exceeded.

Land and water resources are two important natural resources of the floodplain. United Nations defines sustainability in terms of resource use, including water resource use (UN, 1991). So, management of these two resources are crucial in minimizing resource degradation, rehabilitating degraded resources and ensuring optimal use of these resources for the benefit of both present and future generations. Sustainable land resource management requires collaboration and partnership among land users, technical experts and policy-makers to ensure that the causes of degradation and corrective measures are properly identified, and that the policy and regulatory environment enables the adoption of the most appropriate management measures.

Both rapid population growth and the substantial uncertainty in projecting future water resource availability in the face of climate change (Vörösmarty et al. 2000; Milly et al. 2008) are encouraging expanded water resources planning and development. Falkenmark (1988) focuses on the role of water plays in sustainable development. She identifies various conditions of sustainability such as soil permeability and water retention capacity have to be secured to allow rainfall to infiltrate, fish and other aquatic biomass have to be preserved and remain edible etc. There are several definitions of sustainable water resources. UNESCO/WMO define water resources as the "water available or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand" (UNESCO/WMO, 1992). Whereas, sustainable water resource systems are those designed and managed to fully contribute to the objective of the society, now and in the future, while maintaining their ecological, environmental and hydrological integrity (Loucks, 1997; ASCE, 1998; UNESCO, 1999). Numerous sustainability criteria have been developed to assess the sustainability of water resources. Hashimoto *et al.* (1982). proposed a set of criteria for evaluating possible performance of water resource system based on risk criteria related to reliability, resiliency and vulnerability (R-R-V) Others like Matheson *et al.* (1997), proposed a criterion based on inter-and-intra generational equity. As sustainability is a function of various economic, environmental, ecological, social and physical goals and objectives, water resource management must involve multi-objective tradeoffs in a multi-disciplinary and multi-participatory decision making process (Loucks. 2000). To Move from vision to action, an important procedure is to make operational mid-to-long-term water resource planning according to real socio-economic development (Feng, 2001). To change the social and institutional components of water resource management system is often the most challenging because this involves changing the way individuals think and act. Individuals are primarily responsible for and adapting to changing political and social situations. Sustainability requires that public and private institutions also change over time in ways that are responsive to the demands of individuals (Viessman, 1998).

2.1.3 Key Factors in Achieving Sustainable Land and Water Use

There are some key factors for achieving sustainable development. The details about the factors are as follows:

Balancing environment and socio-economic improvement: Economic development must be achieved in an environmentally sustainable manner. The challenge is to strike a balance between socio-economic improvement and degradation of environment. These two areas are closely interrelated, and if either of them is neglected, the chances are that the repercussions will be felt on the other.

Integrating resource use activities: Natural resources should manage in a way so that opportunities for future resource uses are maximized and also ensure the maintenance of ecosystems. Land, water and biomass resources are currently under pressure in the context of highly competing and often conflicting demands from an ever increasing population. Integrating natural resource management activities inclusive of water, land, and biodiversity is crucial for sustainable land and water use.

Developing resiliency against natural hazards: Resilience is the ability of a system to maintain its most important processes and characteristics when it is subjected to disturbance. Resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behavior (Coller, 1997). Prolonged failure or disturbance event with a slower recovery procedure can cause serious implications to the system (Hashimoto et al., 1982). Usually resilient system does not collapse easily (Bruijn, 2004).

Natural hazard is the most common threat that will have a negative effect on people or the environment. To be hazard resilient, a society need a condition when the frequency and severity of threats decreases over time and in which our environment and ecosystems are being managed in a way that prepares people to handle stress when it occurs. Thus, the prevention, management and control of very extreme events have a high priority in the achievement of sustainability.

Ensure equitable resource distribution: Equity involves the degree of fairness and inclusiveness with which resources are distributed and opportunities afforded. It includes the provision of comparable opportunities of employment and social services, including education, health and justice. Significant issues related to the achievement of social equity include poverty alleviation; employment and income distribution including subsistence activity; gender, ethnic and age inclusiveness, access to financial and natural resources; and intergenerational opportunity.

Safeguarding ecosystem functions: Peterson et al. (1998) proposed a model that relates biological diversity, resilience and scale. The model states that the relationship between ecosystem stability and species richness varies with the degree of overlap that exists among the functional roles of different species and the amount of variation in the impact of the functional role of each species in the ecosystem. The resilience of ecosystems would depend upon the distribution of functional groups within and across scales.

In addition to the ecological interpretation of biological diversity there is also a societal interpretation, most often called biodiversity. Human interest in biodiversity relates to the life support function and the supply of goods and services, such as the provision of food, medicine, fuel etc.

Improving socio-economic condition: Human beings use natural resources for different activities for their livelihoods. Consequently, the natural system is being disturbed. The intervention of human being on natural system through development activities are considered as the prime cause of environmental degradation. To combat environmental degradation, 'Sustainable Resource Management' is the only way through which both environmental and human needs can be fulfilled.

The present development trends focuses mainly on improving socio-economic condition of people. According to Ellis and Allison (2004), protection of livelihoods depends on the availability/sustainability of: human capital (skills, education, health), physical capital (produced investment goods), financial capital (money, savings, loan access), natural capital (land, water, trees etc.), and social capital (networks and associations). However, these capitals/assets are interconnected and interchangeably affecting the socio-economic condition of the floodplain dwellers. Thus, floodplain resource management should be focused on these issues. For instance, livelihood diversification (i.e. meeting the needs of human using alternative assets based on risk and vulnerability) is a way of achieving livelihood sustainability through which resource overexploitation would be reduced. In Bangladesh, people are dependent on single crop (boro) to meet the increasing food demand. However, crop diversification can increase crop productivity as well as resilience of farmers.

2.2 Pressure State Response System for Sustainable Resource Management

The resources of floodplain areas are mainly land and water resources. These resources have various usages. Socio-economic pressure on floodplain resources have increased dramatically due to increase population, industrialization and economic growth. The over use of goods and services provided by land and water resources has negatively impacted the floodplain ecosystem and its resources through loss of natural wetlands, decline of water quality, species extinction etc. The pressure exerted on floodplain resources by humans and corresponding responses can be explained by frameworks for sustainable resource management indicators. The use of frameworks is essential as they assist in developing and reporting on indicators in a logical fashion so that key issues can be readily identified and summarized (Gouzee et al., 1995; Walmsley and Pretorius, 1996). There are two main types of frameworks, economic and physical environmental frameworks. Several physical environmental frameworks have been developed to measure the interaction between humans and the environment. The most commonly used frameworks are the Pressure-State-Response (PSR) framework and the Driving forces-Pressure-State-Impact-Response (DPSIR) framework.

The PSR framework follows a cause–effect societal-response logic (Walmsley, 2002). Figure 2.3 represents the PSR framework as illustrated by Walmsley and Pretorius (1996). According to Walmsley (2002), indicators are divided into three categories within the framework:

- Pressure indicators that measure the pressures that are exerted on resources and ecosystems from human activities (e.g., emissions, consumption, and utilization);
- State indicators that assess the condition of the resource or ecosystem as a result of the pressures, and
- Response indicators that relate to the societal responses via policies, laws, programmes, research etc.

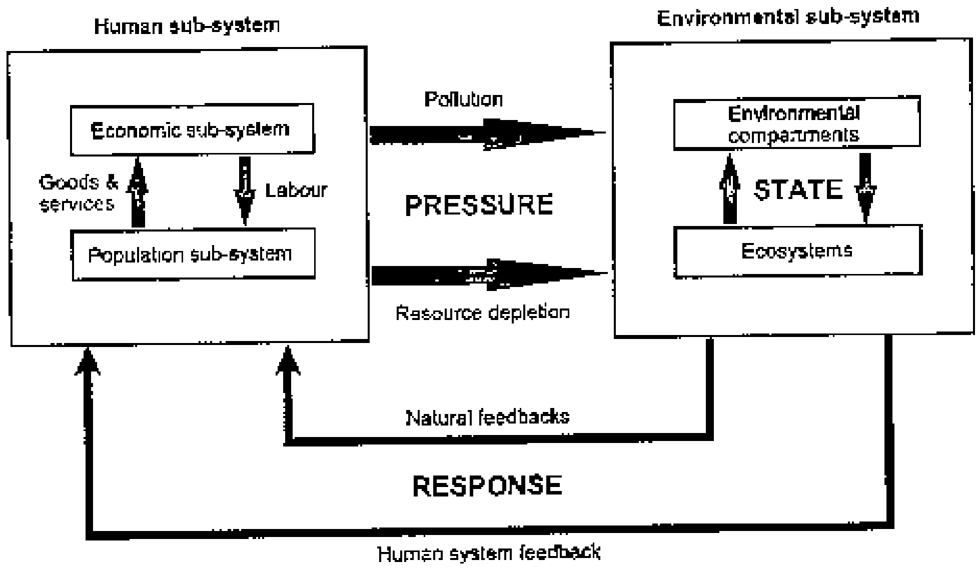


Figure 2.3: Pressure-State-Response framework (Source: Walmsley and Pretorius, 1996)

Figure 2.3 illustrates two separate sub-systems: human sub-system and environmental sub-system. The human sub-system comprises of economic and population sub-systems and they interact through labour, goods and services among them. While the environmental sub-systems, comprises of environmental compartments and ecosystems. The human activities and processes create pressures on the environment in the form of pollution and resource depletion. The pressures can result in changes to the state of the environment. Measures of how society responds to these changes include institutional, legal, or financial measures or changes in management strategies and policy (Walmsley and Pretorius, 1996).

The PSR framework was further developed into the DPSIR framework. This framework has five indicator categories (driving force, pressure, state, impact, and response). This same framework provides an overall mechanism for analyzing environmental problems. The two additional indicator categories can be explained from Walmsley (2002) as follows.

- Driving forces are the human influences and activities that, when combined with environmental conditions, underpin environmental change.
- Impacts are the results of pressures on the current state.

In DPSIR framework, the different indicator categories cover the various aspects of an environmental issue as illustrated in Figure 2.4 according to OECD (1999) and VRDC (2001).

From Figure 2.4, it can be seen that driving forces (industry and transport) produce pressure on the environment, such as pollution and emissions. As a result, environment gets degraded which affects human health and eco-systems, causing society to respond with various policy measures, such as regulations, information and taxes, which can be directed to any part of the system.

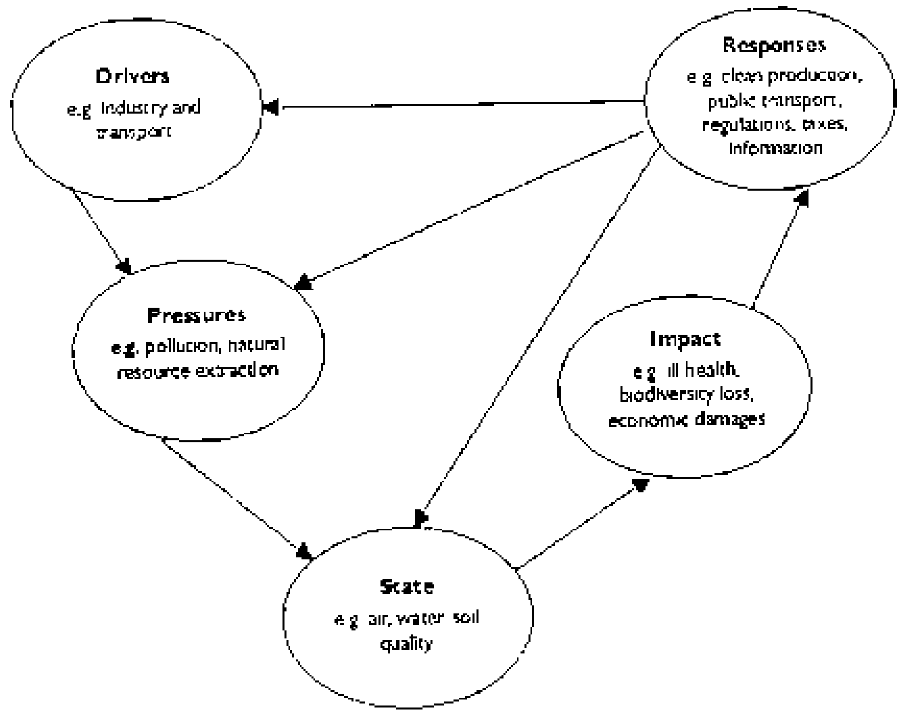


Figure 2.4. DPSIR framework (OECD. 1999 and VRDC, 2001)

2.3 Floodplain Characteristics and Functions

2.3.1 Floodplain Formation

Floodplains can be defined from several different perspectives. As a topographic category it is quite flat and lies adjacent to a stream, geomorphologically, it is a landform composed primarily of unconsolidated depositional material derived from sediments being transported by the related stream; hydrologically, it is best defined as a landform subject to periodic flooding by a parent stream. A combination of these characteristics perhaps comprises the essential criteria for defining the floodplain (Schmudde, 1968). Simply, a floodplain is defined as "a strip of relatively smooth land bordering a stream and overflowed in times of high water" (Leopold et al, 1964)

Floodplains are extremely complex bionetwork, which are continuously transforming in response to physical and social influences. Floodplains form in response to a range of processes including climatic and erosion forces arising from floods and the deposition of sediment transported from catchments. Floodplains may undergo a variety of geomorphological changes and its shape largely depends on the deposition and erosion during floods. The size of floodplain is determined by the frequency and amount of water flowing through it. The two fundamental types of deposits that make up a floodplain are the point bar and the overbank deposit as described in various literatures (Fenneman, 1906; Melton, 1936; Mackin, 1937; Happ, Rittenhouse and Dobson, 1940; Challinor. 1946; Fisk, 1947; Jahns, 1947). These two types may respectively be described as deposits of lateral and vertical accretion of the river system (Wolman and Leopold, 1957). The lateral and vertical accretion processes are shown schematically in Figure 2.5.

Lateral accretion: Deposition *within* a channel, as it migrates	Vertical accretion: Sediment deposition from *overbank flow*

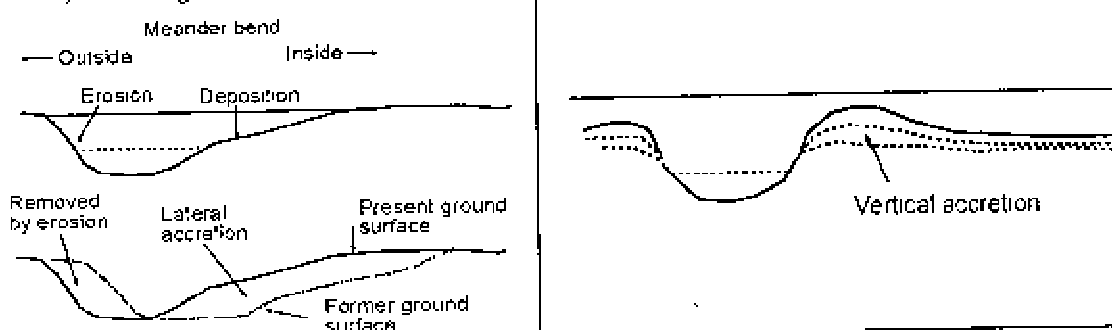


Figure 2 5: Floodplain formation processes of lateral and vertical accretion

The lateral accretion is the deposition within a channel as it migrates due to meander scrolls of the meandering river but can also occur as braided channels shift location as shown in Figure 2.6.

The vertical accretion may occur in three major forms: deposition on natural levees. in splays and in flood basins. The natural levees are the low ridges bordering stream channels and are often coarser grained than rest of the floodplain. Splays are fan-shaped deposit, which are formed by deep, fast flowing water spilling out of channel and generally occur at breaks in natural or artificial levees. The sediment in splays is predominantly bed load. The flood basin is the low area, far from channel where water is ponded during and after floods and the deposit comprises fine-grained suspended load (clay and silt) that slowly drops out of still water. Miller (2010), illustrated the vertical accretion process as presented in Figure 2.7.

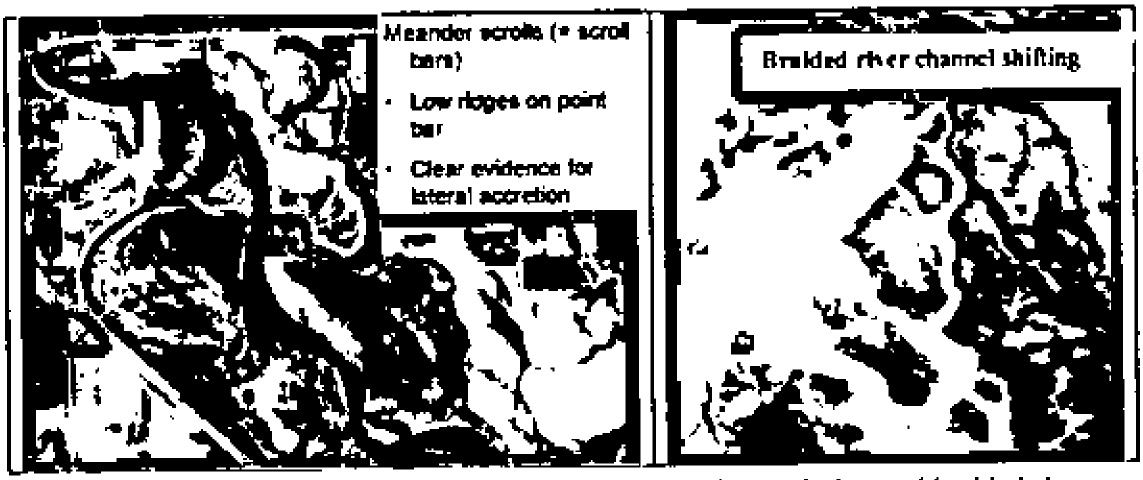


Figure 2.6: Lateral accretion due to channel migration of meandering and braided rivers

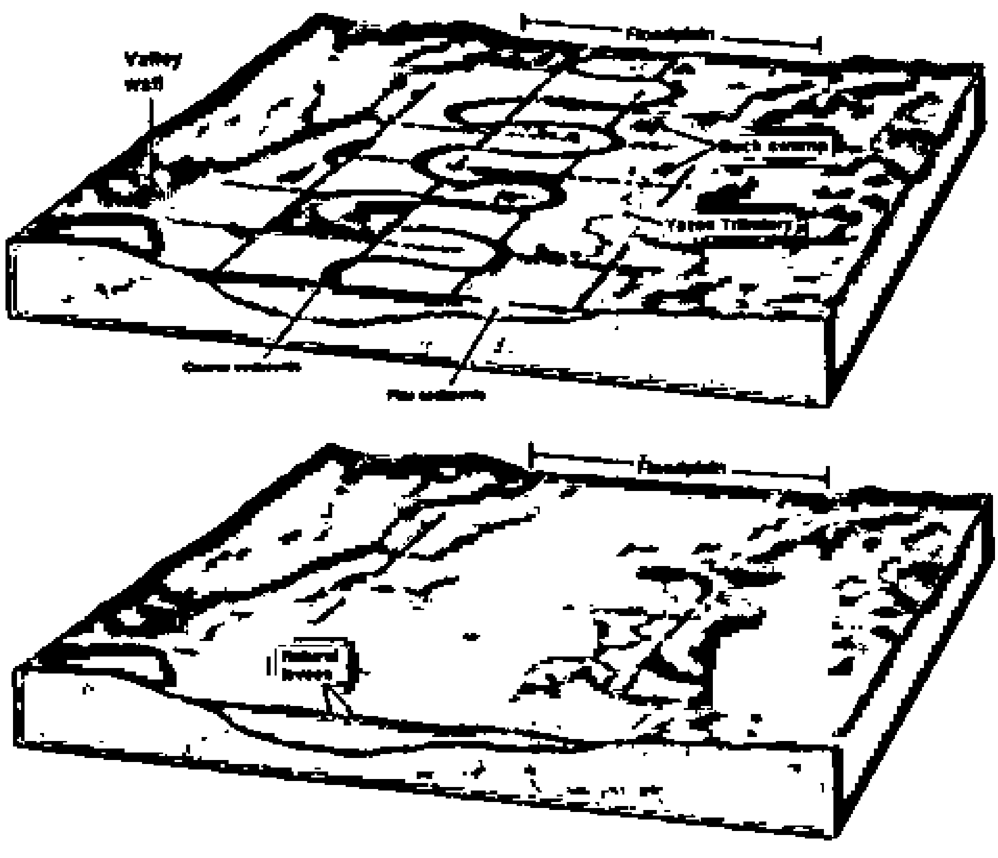


Figure 2.7: Vertical accretion due to overbank flow of river (Miller, 2010)

The floodplain formation process continues with time and its elevation increases due to overbank deposition. Wolman and Leopold (1957) developed a hypothetical curve (Figure 2.8) of floodplain elevation against time for Brandywine creek at Chadds Ford, Pennsylvania, USA. Hassan et al. (1999), developed a similar curve for Brahmaputra river floodplain chars (Figure 2.9). From the figures it can be seen that, rapid floodplain formation occurs in first ten years at Brandywine creek while the same phenomena occurs at Brahmaputra floodplain in first six years. Afterwards, this rate slows down to a constant rate in the Brahmaputra floodplain.

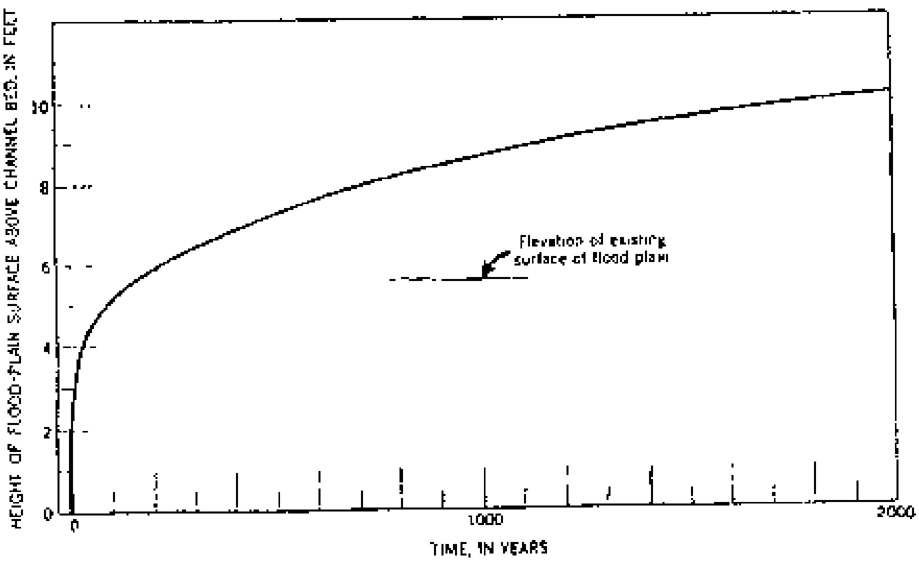


Figure 2.8: Hypothetical formation and rate of increase in floodplain elevation (Wolman and Leopold, 1957)

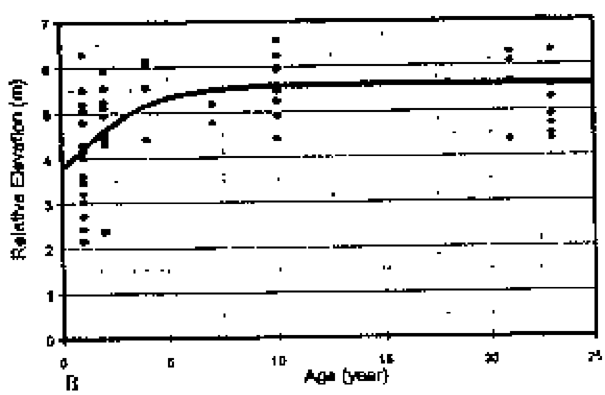


Figure 2.9: Relation between elevation and age of Brahmaputra floodplain chars (Hassan et al., 1999)

As the fringe between land and water based ecosystem, floodplains provide habitats for plant and animal communities, ranging from semi-aquatic to those on the margins of the floodplain.

Based on the physiographic features, five kinds of floodplain are classified, such as, active river floodplains, meander floodplains, piedmont plains, estuarine floodplains and tidal floodplains. Active river floodplains are the youngest alluvial land within and alongside the main rivers which is subject to alternate deposition of new sediments and erosion by shifting of channels within the main river course. Meander floodplain is relatively stable landscape with complex patterns of curved ridges (former river banks), basins (back-swamps) and cut-off channels, crossed by a few active river channels (tributary or distributary channels of the main rivers). Piedmont plains are gently sloped land at the foot hills where colluvial and alluvial sediments are deposited by rivers and streams subject to flash flood. Estuarine floodplains are smooth, almost level land with few or no river channels. Tidal floodplains are crossed by innumerable tidal rivers and creeks. Under natural conditions, the land is subject to flooding with silty water at high tide.

In Bangladesh, three distinct types of floodplains are observed (FAP 24, 1995). These are:

Active floodplain comprising natural levee and chars: The active floodplains of Bangladesh rivers are the most dynamic regions with high bank erosion rates and channel migration.

Seasonally drained floodplains or back swamps: These are adjacent topographically lower areas which work as storage basins with low flows both in transverse and longitudinal directions. These areas are mostly characterized by alluvial silt and clay deposits. Fine sediments are deposited in these areas through vertical accretion. The back swamps are at least a few decimeters lower than the natural levees.

Standing waterbodies and marshes. Standing waterbodies or marshes belong to topographically depressed areas known as haors, baors and beels with negligible flows. The total standing waterbodies in Bangaldesh are about 1,236 km^2, 60% of which is located in the Haor basin in the north-eastern part of the country. Haors are the large basins comprising of several small and large depressions, called beels. There are seasonal and perennial beels, which during the monsoon may become a single body of water together with the river, and remain under water for about half of the year. During winter, water begins to recede in these waterbodies, concentrating in the beels.

2.3.2 Characteristics of the Floodplain

Floodplain Hydrology: Floodplain hydrology is mainly governed by spill from river and flooding by precipitation. The transformation of precipitation into runoff is a complex process, influenced by a numerous climatic and physiographic factors. The precipitated water may be intercepted and taken up by plants; it may be stored in small depressions or lakes; it can infiltrate the soil; and it can flow over the surface to a nearby stream channel. This process is shown in Figure 2.10.

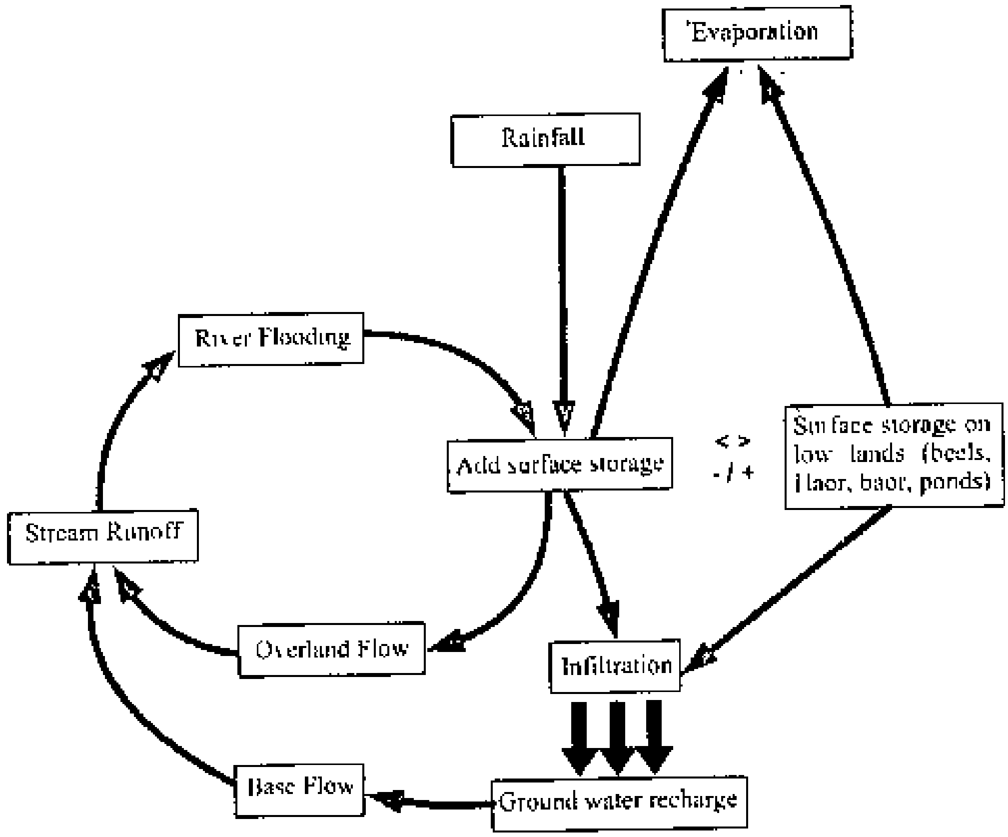


Figure 2.10: Flow movement in a floodplain

Rainfall and river flooding are the principal sources of water in the floodplains. Some of the precipitation that falls is lost as interception, due to infiltration and other abstractions. Large portion of the falling precipitation is added to the existing surface storage in ponds, beels, haor, baor etc. The bunds surrounding agricultural lands help to store rain water on the surface. When this water exceeds the storage capacity it overflows and goes to stream as overland flow. As rainwater reaches the land surface, it can infiltrate through pores between soil particles and reach the groundwater. A portion of the ground water, flows to stream as base flow. The river water flows to the land as flood water when it goes over the bank.

Habitat and ecology: Floodplains support a range of valuable terrestrial and aquatic ecosystems. The margins of floodplains provide habitats for plant and animal communities specialized to take advantage of this land - water interface.

The California department of water resources (2005) identified four major types of habitats for the floodplain management These include aquatic, riparian, wetland and upland habitat. The aquatic habitat include areas that have standing or moving water at some time during the year, such as rivers, streams, lakes, etc. The riparian habitats are areas that border rivers, streams and creeks and typically include the channel banks and over bank areas. Wetlands consist of special aquatic areas which often develop in transitional zones between aquatic and riparian habitats. These are either permanently or seasonally wet and support specially adapted vegetation and wildlife. Uplands are not the part of a floodplain but integrally linked with it. Upland habitats extend beyond the riparian habitats up to the top of the ridges separating watersheds. Human activities in the uplands can have profound effects in downstream floodplains. For example, increasing upland urbanization increases the amount of runoff and decreases the time needed for its discharge to the floodplain.

All of these habitats, along with their underlying physical, chemical and biological processes, make up the structure of floodplains. Figure 2.11 provides a conceptual illustration of these habitats and how they overlap (after EPA, 1989).

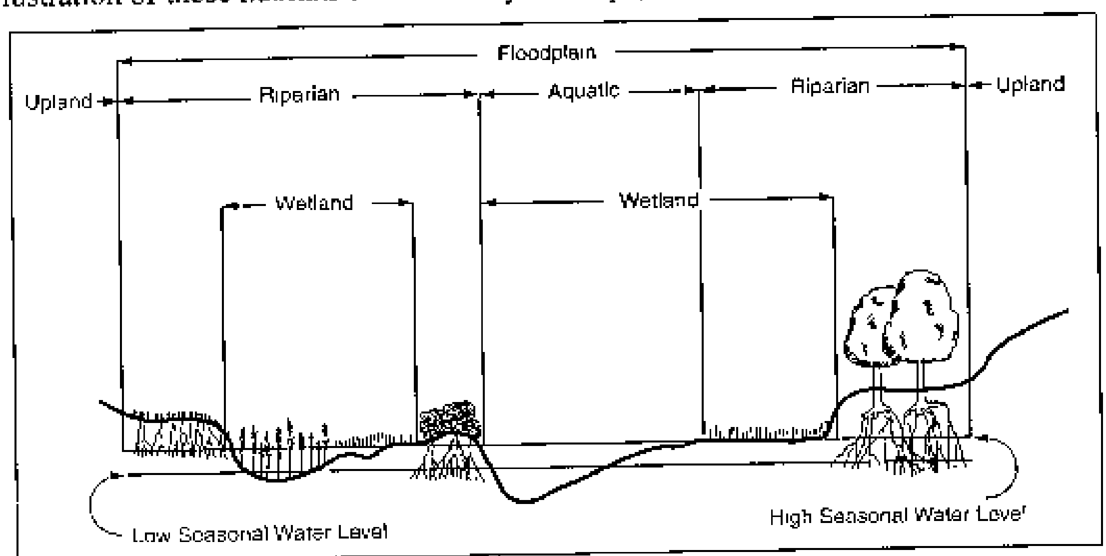


Figure 2.11: Floodplain habitat (Source: EPA, 1989)

Based on hydro-geomorphic characteristics floodplains are classified into three types. They are bankfull, active floodplain and terrace Bangladesh is an active and dynamic delta. Every 1-2 year flooding 20-25% of the country is regularly flooded and in an extreme case 70-80% of the country may be inundated in one in 100 year flooding. Whereas, in case of other floodplains, 5-10% may flooded in one in 100 year flooding.

Groundwater and surface water are linked and interdependent. Any change in groundwater will affect surface water and vice versa. For example, excess extraction of groundwater might lead to reduced base flow.

Ecosystem is a major resource of a floodplain and provides various services to people (Costanza, 2003; Emerton & Bos, 2004; Pearce et al., 2006). The ecosystem services are a subset of services provided by environmental flow. The services from environmental flow comprises of flow services (e.g. flushing of sediments, support to navigation) and ecosystem services via ecosystem functions. The availability of ecosystem services through ecosystem functions depends not only on environmental flow but also on the cultural, socio-economic and technical setting (Korsgaard, 2006) The influence of flow on aquatic ecosystem functions has been proposed by Bunn and Arthington (2002) by means of four flow-related key principles. These principles state that aquatic habitat availability, biotic composition and evolution of aquatic species depends on natural flow regimes and their connectivity while alteration of flow regimes contribute to changes in habitat and species composition in a ecosystem. According to several researches (Poff et al., 1997: Postel & Richter, 2003; Tharme, 2003), the sustainability of an ecosystem is influenced largely by natural flow regime of a river (comprising the five main components of variability, magnitude, frequency, duration, timing and rate of change).

Floodplains are supposed to be flooded regularly. Due to huge population pressure, people are even living in the river corridors It is estimated that 6 million people are living within the braided belt of Jamuna (FAP 16, 1995). This huge population in the floodplain is vulnerable to natural disasters.

Bangladesh being an active delta, it is very sensitive to any change/development or human intervention. Suppose a new landmass is forming by regular flooding and deposition of sediments But due to construction of an embankment its natural process of development might be hindered. For example, BWDB has constructed 10,000 km embankments and thousands of regulators to increase suitable land for agriculture production by protecting the land from flooding. storm surge and salinity intrusion. Whereas, Agriculture Ministry's main target is to increase food grain production by introducing high yielding varieties, application of chemical fertilizers, pesticides and use of modern technology. On the other hand, RHD and LGED are constructing new roads for improved communication and access to markets. The major target of all these departments is poverty alleviation. Unfortunately, these sectoral departments are all uni-focused instead of being multi focused. They lack cooperation and integration among them. As a result, none of these development activities can produce goods and services as targeted.

Land and water use have to be planned and development plans should consider the sensitiveness of the deltaic floodplain to any change. Resource management should look at productivity as well as regeneration function for sustainable management of resources. Finally, integrated land and water resource management plan is crucial for sustainable resource management.

Floodplain Resources and its interactions: Land and water are the two important floodplain resources. Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere. The components of the natural land can be termed as land resources, including physical, bionic, environmental, infrastructural, social and economic components, in as much as they are fixed to the land unit. Land has direct and indirect linkages with human being in every sense such as production system, economic, social and cultural activities.

Water resources are sources of water that are useful or potentially useful to humans. Many usage of water include agricultural, industrial, domestic, recreational and environmental activities. 97% of water on the Earth is salt water, leaving only 3% as fresh water (Gleick, 1996a). Out of these 3%, 68.7% is frozen in glaciers and polar ice caps and remaining unfrozen freshwater is mainly found as groundwater (30%), with only a small fraction present as surface water (0.3%) or in the air (Gleick, 1996a). Surface water is water in rivers, khals, lakes and wetlands. The total amount of surface water in the world is distributed in Lakes (87%), Swamps (11%) and rivers (2%) (Gleick, 1996a). Surface water is naturally replenished by precipitation and lost through discharge to the oceans, evaporation and groundwater seepage.

The total quantity of water in a system at any given time is dependent on many factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs; the permeability of the soil beneath these storage bodies; the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates. Human can often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Runoff quantities and velocities are often increased by paving areas and channelizing stream flow.

Soil moisture is the water that is held in the spaces between soil particles. Surface soil moisture is the water that is in the upper 10cm of soil whereas root zone soil moisture is the water that is available to plants, which is generally considered to be in the upper 200cm of soil. And the process of water entering into the soil is called infiltration. The rate of infiltration is maximum when the soil has stable structure and continuous pores to the surface. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.

Groundwater is water which may be flowing within aquifers below the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps and can form oases or swamps. Groundwater is also often withdrawn for agricultural, municipal and industrial use through man-made wells.

Groundwater is naturally replenished by surface water from precipitation, streams, and rivers when this recharge reaches the water table. It is estimated that the volume of groundwater is fifty times that of surface freshwater; the icecaps and glaciers are the only larger reservoir of fresh water on earth

Usable groundwater is contained in aquifers, which are subterranean areas (or layers) of permeable material (like sand and gravel) that channel the groundwater's flow. Typically, groundwater is thought of as liquid water flowing through shallow aquifers, but technically it can also include soil moisture. permafrost (frozen soil), immobile water in very low permeability bedrock, and deep geothermal or oil formation water. Groundwater is believed to provide lubrication and buoyancy that allows thrust faults to move.

Natural resources are very much inter-related and inter-connected. Included in the land resources are surface and near-surface freshwater resources Part of this moves through successive land unit. The local flow characteristics can be considered as part of the land unit. The linkages between water and land are so intimate at the management level that the water element cannot be excluded. Land as a unit is intermixed with water, with its land use in part depending on access to that water, and at the same time, the unit is affecting the quality and quantity of the passing water.

At the threshold of the twenty-first century, widespread poverty, food insecurity, and environmental degradation cause severe human suffering and threaten to destabilize global, regional, and national economic and ecological conditions (Andersen and Lorch, 1998). Due to unplanned and extensive use of land and water resources by humans, these resources are depleting at a faster rate. There is a rapid degradation of the environmental conditions. In Bangladesh, emphasis has been placed on crop production, as the growing population demands more food (Nishat, 2003). To meet this increasing demand more land has been brought under cultivation. In addition to this horizontal expansion, High Yielding Verities (HYV) were introduced to increase both intensity and yield. In the dry season cultivation is carried out by applying irrigation. Hence, it led to more usage of fertilizer and water usage for irrigation. Figure 2.12 shows the yearly fertilizer use scenario based on data from Bangladesh Bureau of Statistics (BBS). From the figure, it can be noted that in 1981 around 60 kg fertilizer was used for producing per metric ton of rice where as in 2004 this amount increased to 150 kg. Therefore, fertilizer usage is more than double within this time period. But the productivity did not increase at the rate of increase in fertilizer use. This may indicate the degradation of the soil productivity due to increased application of fertilizer. This soil degradation may also be due to the lack of flushing from flood water.

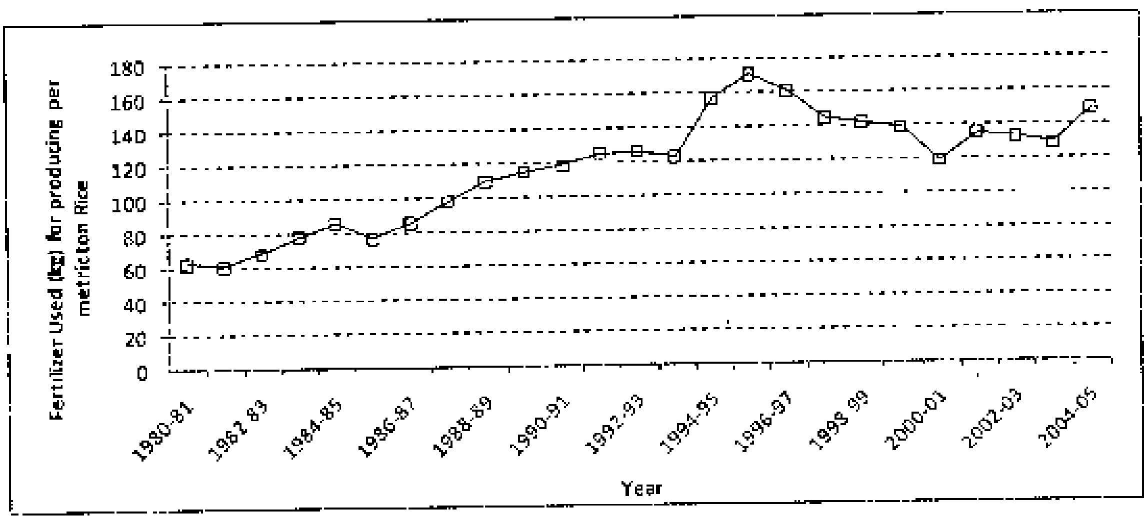


Figure 2.12: Fertilizer use scenario in Bangladesh

In addition to soil degradation, excessive use of fertilizer degrades water quality. On an average 372 kg of urea is applied to per hectare of agricultural land and 5.35% nitrogen of this fertilizer has gone to waterbody causing eutrophication which means loss of aquatic habitat.

Unplanned land use also causes water pollution. The chief sources of water pollution in the urban areas are urban runoff, domestic sewage (most of which is untreated), and untreated industrial effluents including heavy metals (from tanneries). The water of Buriganga river is seriously polluted by discharge of industrial effluents into river water, indiscriminate throwing of household, clinical, pathological & commercial wastes, and discharge of fuel and human excreta. Up to 40,000 tons of tannery waste flows into the river daily along with sewage (IEDS, 2003). In fact, the river has become a dumping ground of all kinds of solid, liquid and chemical waste mainly in and around urban population centres.

2.3.3 Floodplain Functions

Floodplains perform a multitude of complex functions that provide basic ecological support within the floodplain as well as valuable goods and services to society. According to Scodari (1997); Lee (1994) and ESCAP (1994), the functions of floodplains include both water and land related functions.

The water resources functions of floodplain are hydrological functions, environmental functions, ecological functions and socio-economic functions. Hydrological function includes maintaining natural channel processes and flows. Floodplains allow channels to maintain the natural processes like movement, migration, redundant old channel and maintain the whole morphological processes. Floodplains support and maintain flow movement during dry and wet season by natural levees and channels. Floodplains perform a wide range of functions such as base flow maintenance, detention of flood flow, and recharge of groundwater. Floodplains store water on the surfaces in form of soil moisture and in the groundwater aquifers. It manages the channel flows by providing increased area to spread water and resistance to flows with vegetation and helps in groundwater recharging through infiltration and percolation.

Environmental functions include maintaining quality of water, soil and air. Floodplain vegetation and soils (especially those associated with wetlands) serve as water filters by trapping nutrients and toxic substances, intercepting surface water runoff before it reaches the lake, stream or river. Flood flows leave nutrient rich sediments over the floodplains which improve soil quality for better agricultural production and environmental purposes. Vegetation on floodplains can improve air quality by photosynthesis. which removes carbon dioxide from the air and returns oxygen. Vegetation can also absorb ozone, sulphur dioxide, carbon monoxide, and airborne particles of heavy metals

Maintaining plant and wildlife habitats is ecological function. Floodplains maintain diverse plant and animal communities. Hydrologic and vegetation diversity provides important resting, feeding and nesting areas for many species. River corridors are frequently used as flyways for migrating birds. Aquatic and wetland areas provide habitats for fish. Inundated floodplains are important nursery and feeding areas of juvenile fish and other aquatic life.

Socio-economic functions of water resources in a floodplain mainly include maintaining water supply and sustaining agricultural food production. In addition to flow management, floodplains maintain water supplies by providing opportunities of water use from the surface and groundwater storage. Water could be used for domestic, agricultural, industrial, commercial and recreational purposes. Floodplains provide areas for agricultural food production and helps in making the agricultural land fertile by depositing silt and supplying irrigation water. As a result, productivity increases which leads to more food production.

The land resources provide various functions as part of the floodplain. These functions consist of maintaining production and life support, providing habitat and living space, acting as storage etc. Land is the basis for life support systems, through the production of biomass that provides food, fodder, fibre, fuel, timber and other biotic materials for human use either directly or indirectly. Land resources facilitate in maintaining terrestrial biodiversity by providing the biological habitats and gene reserves for plants, animals and micro-organisms, above and below ground. Land is a storehouse of raw materials and minerals for human use. Land provides the physical basis for human settlements, industrial plants and social activities such as sports and recreation (the living space function).

2.4 Decision Support Framework (DSF)

Decision Support Systems (DSS) has been developed and applied for solving problems in many sectors over past few decades (Fedra and Loucks, 1985; Koch and Allen, 1986; Or, 1991). DSS is defined as a computer system that helps to make decisions more effectively for semi-structured problems such as, water resources management (Barbosa and Hiiko, 1980). The concept and theories of DSS has been developed from two major research fields. The first, a theoretical research of organization decision-making at Carnegie Institute of Technology in USA during 50's and early 60's (Simon, 1976). The second, a technical work on interactive computing systems carried out mainly at the Massachusetts Institute of Technology (MIT), USA in 60's (Keen and Morton, 1978). At the early stage, the DSSs were termed as 'Interactive Computer Systems

(Keen and Morton, 1978; Loucks et al., 1985a,b), and later it was titled as Decision Support Systems.

Decision-making is general human activities performed in everyday life. McLeod (1995) identified four phases of the decision making process for solving problems such as (a) searching the environment for conditions calling for a solution, (b) investigating, developing and analysing the possible course of actions, (c) selecting a particular course of action from the above actions, and (d) assessing the selected particular course of action and/or past choice. These phases are similar to the previously developed Simon's famous model for the decision making process which had three phases: intelligence, design and choice (Simon, 1976; Power, 2002). This model has been broadly accepted as one of the base decision making models (McLeod, 1995; Srinivasan et al., 2000).

Decision making process depends on the type of problems. The problems can be structured, semi-structured and non-structured. If decision algorithms or rules are found for the above first three phases of the decision making process of a complex problem, as described by McLeod (1995), then the problem can be termed as structured. On the other hand, a semi-structured problem consists of one or two structured phases of the above three phases. A non-structured problem has no structured phases. Water resource and land use management are considered as semi-structured problems.

Better conceptualization of the problem is crucial to develop appropriate system to solve the problem. For instance, a Management Information System (MIS) can be used for structured problems, an Expert System (ES) for non-structured problem and a DSS for semi-structured problems (Keen and Morton, 1978; McLeod, 1995; Sprague and Watson, 1996; Sauter, 1997). Nevertheless, there are some exceptions where one type of system may be applied to solve different structured problem. For instance, DSS can be applied to solve non-structured problems (Watkins and McKinney, 1994).

2.4.1 Definitions and Components

The concept of DSS was developed by different researchers with different views. Gorry and Morton (1971) defined DSS, as a system that supports managerial decision makers in making decisions of unstructured or semi-structured decision problems. Silver (1991) defined a DSS as a computerized information system for making decisions for semi-structured problems. Barbosa and Hirko (1980) stated that DSS can be used to solve unstructured or semi-structured problems. A more comprehensive definition of DSS is given by Ginzberg and Stohr (1982). They defined DSS as a computer–based information system to support decision making activities in situations where it was not possible to have an automated system for performing the whole decision process. Similar concepts have been provided by Simonovic (1998) and Sprague and Watson (1996) with explanation of quantitative models and database elements needed for solving problem. With respect to water resources management, Watkins and McKinney (1994) stated that a DSS is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to support decision makers in solving relatively large and unstructured problems.

Similar to the development of DSS concepts, components of DSS are defined by different researchers. Sprague and Watson (1996) identified that the major components of DSS include a database, models, and a software system that allows the user, via an interface, access to database and models. These components are also supported by Johnson (1986), Labadie and Sullivan (1986) and Hopple (1988). A combination of Geographic Information Systems (GISs) and DSS, which is termed as Spatial Decision Support System (SDSS), has been developed by Walsh (1993) to solve problems with spatial dimension. This SDSS included three main components: database, model base and user interface. The GIS system was the operational environment of the DSS. Loucks (1995) pointed out that modern technologies such as GIS, optimisation and simulation models, genetic algorithms, neural networks, expert and knowledge bases, and statistical and graphical packages may be included in DSS.

A two-layer DSS design has been explained by Srinivasan et al. (2000) which include Conceptual Component layer and Implementation Component layer. The Conceptual Component layer is required technological capabilities such as data part for large volume of data handling, models part for describing and maintaining models that define rules for manipulating data, solver part for transforming model specifications to system components, interface part for user interaction with system components. The Implementation Component layer may have several parts such as relational database management systems, object relational database management systems, spreadsheets, visual interface, linking technologies.

2.4.2 Models and Tools Used in Decision Support Framework

Water resources management in a floodplain requires analysis of hydrological, hydraulic and economic conditions for planning, design and management projects. Usually the purpose of the project and data availability determines which methods or models will be used for analysis. For instance, hydrological analysis for flood control and management needs the peak discharge of certain probabilities of exceedance by frequency analysis, or preparation of the flood hydrograph through rainfall-runoff models. Statistical distributions and parameter estimation procedures are used in hydrological frequency analysis. Some popular distributions such as Pearson Type 3 (P3), Log-Pearson Type 3 (LP3), Extreme Value Type 1 (Gumbel or EV1), Generalized Extreme Value (GEV) and Exponential are used in frequency analysis. The Maximum Likelihood (ML), Probability Weighted Moments (PWM), Method of Moment (MOM), Least Squares and Graphical methods are generally used for estimating the parameters in frequency analysis (Cunnane, 1989).

The popular computer models available for hydrologic analysis of rivers and floodplain include HEC-HMS by the Hydrologic Engineering Center of U.S. Army Corps of Engineers (USACE), NAM model of DHI MIKE by the Danish Hydraulic Institute (DHI) and rainfall-runoff module of SOBEK-Rural by WL | Delft Hydraulics. The HEC-HMS includes distributed runoff model and continuous soil-moisture-accounting model and provides stream discharge and time series of peaks and volume totals for decision-making. The NAM model is a deterministic, lumped and conceptual Rainfall-runoff model accounting for the water content in several different storages. The rainfall-runoff module of SOBEK-Rural is a semi distributed model accounting for various types of land use, the unsaturated zone, groundwater, capillary rise and the interaction with water levels in open channels (WL | Delft Hydraulics, 2009).

The hydrodynamic models available for estimation of river flow and flooding comprise HEC-RAS by USACE, MIKE11 hydrodynamic module (HD) of DHI MIKE and 1DFLOW and Overland flow (2D) modules of SOBEK-Rural. In hydraulic analysis, the flood water levels are computed due to flood hydrographs. Usually steady and unsteady types of hydraulic models are used in flood modelling. The flood water levels due to a steady discharge such as the peak discharge are computed by the steady models, whereas total flood hydrograph are generated by the unsteady models. HEC-RAS can determine one dimensional, steady and unsteady gradually varied flow equation to predict water-surface elevation along natural rivers or constructed canals. The MIKE 11 HD uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries and can describe both sub-critical and supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). The 1D and 2D modules of SOBEK-Rural are implicitly coupled and solved simultaneously based on momentum balance and mass conservancy between separate computational layers while both layers use finite difference formula for volume and momentum equations based upon the staggered grid approach (WL | Delft Hydraulics, 2009 and Dhondia & Stelling, 2002).

Although. hydrological and hydraulic models are common in DSS for water resources management. view examples are found for socio-economic models used in DSS of water management. Onishi et al. (2007) presented water supply and demand management model in the Yellow river basin, China that incorporated socio-economic framework into decision making.

One of the principle techniques used for estimating urban flood risk reduction benefits has been the Property Damage Avoid (PDA) approach (Mays, 1996), which reflects the present value of expected property damage avoided by the project or policy. The benefits that can be obtained from the flood mitigation strategies in the Maribyrnong River in Victoria (Australia) had been calculated by the PDA Approach (Melbourne and Metropolitan Board of Works, 1986).

2.4.3 GIS and RS Application in DSF

With the development of DSS, Spatial and graphic data display and analysis (SGDDA) has become a very important part in the decision making process (Walsh, 1993). Geographical Information System (GIS) and Remote Sensing (RS) softwares enables users for gathering, storing, manipulating, and displaying geographically referenced information in water resources problems (Zheng and Baetz, 1998) Most of the applications do not use all functions to make complete integration with GIS which is essential for decision making process in complex problems (e.g. Chiueh and Lo, 1997). However, all DSS may not need to develop in GIS system environment Goonetilleke and Jenkins (1994) reported the use of GIS with hydrological models. Two broad approaches- "Loose Coupling" and "Tight Coupling" which integrate GIS with hydrological models were discussed in their paper. The "Loose Coupling" method uses external linkage, while the other uses GIS toolbox to implement the key elements of the model. Goonetilleke and Jenkins (1994) suggested that the Loose Coupling method can be used for integration of GIS with hydrological models. On the other hand, although Tight Coupling in DSS development does not use the whole GIS environment, it has advantages such as its consistency in data transfer, eliminating data transfer errors and faster simulation. ArcInfo GIS software was used to study a selenium discharge problem where location, concentrations and type of sample media of selenium were displayed on the map through GIS (See et al., 1992). Further, GIS tools were used to display water use data in Texas, USA using different colours on a three-dimensional map corresponding to the amount of water use (Schoolmaster and Marr, 1992). View based DSS were also enabled by GIS applications for landuse planning (Arentze et al., 1996). A GIS-based mathematical model for simulation of floodplain sedimentation was presented by Middelkoop and Van Der Perk (1998). The model consisted of two components: hydrodynamic WAQUA model and SEDIFLUX model (Van der Perk et al., 1992). The WAQUA model was used to simulate two-dimensional water flow patterns, while the SEDIFLUX model, based on a simple mass balance concept with less model parameters, was used to estimate the deposition of sediments. The models were applied to simulate floodplain sediment deposition over river reaches of the lower River Rhine in the Netherlands. The raster maps of observed sediment deposition during the flood in December 1993 were used to calibrate and validate the SEDIFLUX model. DSS coupled with GIS was also applied to urban storm water management to provide mode complex on site hydrological analysis (Sample et al., 2001). Moreover, GIS was applied in DSS for hydro-ecological studies. Urbanski (1999) presented the use of GIS for evaluation of the vulnerability of coastal waters and a method for mapping their vulnerability to algal blooms. The produced maps of vulnerability could be used to discover water sources in eutrophication. Lehmann and Lachavanne (1999) used GIS for processing data and presenting results of analysis and comparing the distribution of submerged macrophytes in Lake Geneva in Switzerland in the years of 1972, 1984 and 1995. In this study, GIS was used to map and store information of submerged vegetation, as its functions were powerful for easy interrogation, updating and plotting of spatial information at various scales, and providing a reference for future comparisons. In some cases, remote sensing techniques are often integrated with GIS techniques to solve spatial problems in water resources problems; for instance, the detection of flood hazard impacts in Southeast Florida in USA (Finkl, 2000), flood inundation modeling in River Murray in South Australia (Overton, 2005) and the assessment of hydrologic response of a watershed due to various land use and management changes (Sharma et al., 2001; Githui et al., 2009).

2.4.4 DSF in Resources Management

DSS has been applied to diverse resource management problems all over the world. Some of the examples are illustrated below.

Water Resources: Water resources management requires complex decision making process. Multiple issues and stakeholders involved in water resources sectors are linked to decision making. Examples of use of DSS in water resources and environmental management were presented in a special issue of water resources research in 1985 (Loucks et al., 1985a,b; Kunreuther and Miller, 1985; Fedra and Loucks, 1985; and Cosgriff et al., 1985). Labadie and Sullivan (1986) and Johnson (1986) explained separately the major components and theories of DSS for water resources management and the future development requirements. Loucks and da Costa (1991) described a systematic overview of the past research work in DSS in water resources, some of which are still used today for DSS development.

DeGagne et al. (1996) presented numerical model analysis of a DSS for analysis and use of stage-discharge rating curves. Cortés et al. (2001) explained how the results of Knowledge Management could improve some types of Environmental Systems, particularly Environmental Decision Support Systems (EDSS). These methodologies are still developing. For more complicated systems such as ecological systems, water treatment plants and technical devices, more complex reasoning should be considered for situation assessment that will help in decision making. To support this kind of problems, 'Consistency-based Problem Solving' approach has been investigated by Heller and Struss (2002). After development and generalization of the theory, they have applied the approach to a water treatment problem. Foxon et al. (2002) illustrated the development and application of a set of sustainability criteria for decision support considering the requirements of sustainability assessment into decision-making for water service providers. It was developed under the Sustainable Water Industry Asset Resource Decisions project that was intended finally to develop a multi-criteria analysis decision support system. These criteria were developed and tested in the UK and Romania. This DSS was developed to assess the relative sustainability of water/wastewater system asset development decisions. Emphasizing on the spatial aspects, a prototype of spatial decision support system (SDSS) was developed for integrated, real-time flood control in a river basin in Korea which provided integrated operational strategies to reduce flood impacts (Shim et al., 2002). Surface water planning policies with scenario based management strategies can be supported by DSS as presented by Ito et al. (2001) for Chikugo river basin in Japan. Disregarding the sound scientific principles, a DSS for rapid assessment of water resources has been proposed by de Kok and Wind (2002).

Land and Water Use: DSS for land and water use management has been applied to many cases similar to water resource management. van Walsum and Drent (1987) illustrated a DSS for environmental management with high-intensity land cultivation in The Netherlands. Wetland and forest landscape restoration projects in Mississippi river floodplain were supported by DSS for prioritizing restoration sites (Llewellyn et al., 1996). Several cases of DSS, some of them are enabled in GIS technologies, has been developed for agricultural land and water management (Matthews et al., 1999; Lefroy et al. 2000; Lohani et al., 2002). Westphal et al. (2003) provided examples of the development of a real-time DSS for adaptive management of the reservoir systems which is used for drinking water supply to Boston metropolitan area. In case of agricultural irrigation system, a DSS has been developed for regional water management in India that optimized groundwater withdrawal (Kumar and Singh. 2003) Parker et al. (2003) illustrated overview of multi-agent system models of land-use/cover change (MAS/LUCC models) and found that MAS/LUCC models are specially suitable for representing complex spatial interactions under heterogeneous conditions and for modeling decentralized, autonomous decision making.

Resolution of water use conflicts in watershed can also be supported by DSS. Zarghami et al. (2008) presented a group decision support system for water resources projects in Sefidrud watershed in Iran. A generalized conceptual water allocation framework considering interactions among agriculture and other water users in upstream-downstream areas in the river basin was developed by Letcher et al. (2007). In this model, nodal network approach was adopted where nodes represent the key point of extraction or instream use. Korsgaard et al. (2007) suggested that linkages among environmental flow, ecosystem services and economic values of water can be established using Service provision Index (SPI). This can provide efficient water allocation among stakeholders. Although, DSS for landuse planning are essential, combination of DSS results with stakeholders perspective may provide better planning strategies (Matthews et al., 2006).

Water Quality and Environment: DSS theories have also been applied to decision making for water quality and environmental system analysis. For example, a DSS for predicting the impact of alternative eutrophication strategies on water quality in reservoirs was applied by Grobler et al. (1987). Arnold and Orlob (1989) presented a DSS for estuarine water quality management. Newell et al. (1990) established a Graphical DSS named OASIS for groundwater contaminant modelling. All these applications are not DSSs as defined by current theories, because they are strong in numerical modelling but weak in decision support.

Considering the pollution loading as the decision variable, a DSS for estuarine water-quality management was used by Camara et al. (1990). The system was designed using the HyperCard. Srinivasan and Engel (1994) presented a spatial DSS for water quality in a river basin consisting of Agricultural Non Point Source (AGNPS) numerical model, GRASS (a GIS software) and other tools. An application of DSS for water quality planning has been developed by Lotov et al. (1997). The DSS included six subsystems such as (a) the data-preparation subsystem, (b) the subsystem for approximation of the Edgeworth Pareto hull of the feasible set in criterion space, (c) the subsystem for visual exploration of the decision maps, (d) the subsystem for decision computing, (e) the subsystem for decision display, and (f) the subsystem for preparation of output data. Moreover, a DSS has been developed by Chen et al. (1999) for estimating total maximum daily loads of various pollutants. The DSS included five integrated modules, namely the engineering module, the data module, the knowledge module, the total maximum daily loads (TMDL) module, and the consensus module. Geographical User Interface (GUI) is used to integrate all these modules.

2.4.5 Multi-criteria Analysis in Decision Making

Difficulties arise for natural resource planning and management when there are a large number of heterogeneous stakeholders, objectives, goals, expectations and stakeholder conflicts. Planning requires a multi-objective approach to make decisions in complex natural resource management. Multi-criteria analysis (MCA) is the most useful decision making approach. Community involvement is indispensable in multi-objective analysis approach to manage natural resources. Involvement of stakeholders in planning, management and policy analysis helps to resolve conflicts, increase public commitment and reduce suspicion between governmental agencies and stakeholders. The practical significance of MCA is that it improves the information basis of strategic planning, communication, and understanding in natural resource management. MCA can be used in interactive decision making for resource management. The procedure progresses in an interactive manner until the decision maker has found a satisfactory solution. In this manner, MCA provides a decision support system for policy makers. Sustainable resource management requires maintaining environmental quality and ecological integrity for future generations.

Multiple criteria analysis (MCA) is a framework for ranking or scoring the overall performance of decision options against multiple objectives. The approach has widespread and growing application in the field of natural resource management MCA is a technique that allows for the measurement and aggregation of the performance of alternatives or options, involving a variety of both qualitative and quantitative dimensions. A form of MCA that has found many applications in both public and private sector organizations is multi-criteria decision analysis or MCDA for short (also known as multi-attribute decision analysis, or MADA) (DCLG, 2009). Several criteria used for the selection of MCA techniques such as internal consistency and logical soundness. transparency, simplicity of use, realistic time and manpower resource requirements for the analysis process, ability to provide an audit trail, and Software availability, where needed. Generally six steps are used for multi-criteria analysis that includes Problem Identification, Problem Structuring, Preference Modeling or Decision Making, Examine the Result, Sensitivity Analysis and Select the best options.

The most commonly used methods used in MCA are: Scoring Method, Weighted Sum Method, Standardization Method and Analytic Hierarchy Process (AHP). In the scoring methods, perfoimance of alternatives is scored with respect to the criteria. These methods provide a simple means of evaluating the performance of different options over a range of different criteria. Scored by Participatory approach or using model tools.

Weighted summation is the simplest form of multi-attribute utility analysis that applies a linear relationship. It involves standardizing the scores across all criteria, assigning preference weights, multiplying the weights by the scores, adding up the resulting scores to obtain total weighted scores for each option, and determining the ranking of the total weighted scores. The weighted coefficients of various criteria are assigned on the basis of public consultation and expert opinion. The total value of the alternative is calculated based on the weighted sum method given in equation 2.1 (Marttunen and Suomalainen, 2005):

$$V(A) = \sum_i w_i v_i(a_i) \quad \text{Eq. 2.1}$$

Where, w_i is the weight of the criterion i, $v_i\ (a_i)$ is the score of the alternative with respect to criterion i and $V(A)$ is the value of the alternative A.

In standardization method, all scores are converted in the same unit. Standardization means that the score of a strategy 'with respect to a criterion' is expressed as a function of the score of the other strategies. The difference between the individual and the minimum score is divided by the difference between the maximum and the minimum score. The best strategy has a standardized score of one and the worst strategy has a standardized score of zero. Mathematically, the method is expressed for alternative k with respect to criterion j in equation 2.2 below:

$$STDS = \frac{(X - X_{min})}{(X_{max} - X_{min})} \quad \text{Eq. 2.2}$$

Where, STDS is the standardized score, X is the actual score, X_{min} is the worst (minimum) score and X_{max} is the best (maximum) score. Finally, the sensitivity analysis was carried out by changing weights of different criteria so that the role of each criterion on the selection of alternatives can be understood (Chowdhury & Rahman, 2008).

The analytic hierarchy process (AHP) possesses certain characteristics that make it a useful tool for natural resource decision making. The AHP hierarchy consists of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken down into sub criteria, sub-sub criteria, and so on as the problem requires (http://en.wikipedia.org). The AHP's capabilities include: participatory decision making, problem structuring and alternative development, group facilitation, consensus building, fairness, qualitative and quantitative information, conflict resolution, decision support and preferences structuring. There are various Applications of AHP in resources management such as peer networking, site-specific management, forest management planning, statistical analyses and software enhancements. The ability of the AHP to incorporate the human dimension (subjective preference) and to aid group decisions of choice is seen as the method's most noteworthy feature. Pair wise comparisons provide the basis for the AHP (Schmoldt et al., 2001). In the Pair wise comparisons method the criteria will be compared as to how important they are to the decision makers with respect to the goal, the aim will to derive quantitative scores and weights from qualitative statements of alternatives. This method can be used not only to assess relative criteria weights but also to assess the performance of options through pair wise comparisons (Janssen, 1994).

Improving decision making for natural resource management requires consideration of a large number of non-economic objectives, such as biodiversity, ecological integrity, and recreation potential. Decision making related to the sustainable use of natural resources is essential because increasing one benefit typically decreases other benefits. For example, converting a natural forest to a plantation forest increases timber output, but reduces wildlife habitat. Further, the values of environmental attributes, such as biodiversity, cannot be properly measured using monetary criteria: appropriate non-monetary criteria need to be developed.

MCA is required to facilitate better management and policy decisions for the variation in stakeholders' preferences for attributes and conflicting stakeholder interests and values. As the complexity of decisions increases, it becomes more difficult for decision makers to identify a management alternative that maximizes all decision criteria. There is a great deal of interest among policy makers regarding community involvement in collaborative efforts to manage natural resources. Stakeholder participation in decision making process improve public understanding of the policy making process. Over the past two decades, considerable attention has been focused on developing and using multi-criteria decision making (MCDA) techniques to identify optimal alternatives for managing natural resources. Involvement of stakeholder groups in the planning, management, and policy analysis through MCA helps to resolve conflicts, increase public commitment and reduce doubt between governmental agencies and stakeholders (Tanz and Howard 1991).

Management of water resources has become very important due to increasing scarcity and rising demand. Availability and development of water resources need to be evaluated in terms of household, irrigation and recreational needs, cost, global climate change and water pollution. In general, natural resource development, use and management decisions involve multiple conflicting objectives and criteria. MCDA has been widely used in environmental management, water resources management and energy policy analysis (Haimes and Hall 1974).

Integrated Watershed Management has emerged worldwide as the preferred model for watershed planning. Integrated Watershed Management uses the watershed as the basic geographic planning unit while integrating social, economic, ecological and policy concerns with science to develop the best plan Stakeholder input is the key to successful Integrated Watershed Management. However, stakeholder participation can present problems when the public is uncertain or unclear about the Integrated Watershed Management planning criteria. The Analytic Hierarchy Process is a decision method for assisting Integrated Watershed Management because it treats planning criteria and criteria weighting in an open and explicit manner (de Steiguer et al , 2003).

The management of wetlands needs to be changed in order to improve their quality and ensure that economic development does not degrade their health. Wetlands perform a variety of critical functions in maintaining healthy river systems and have ecological, hydrologic and economic value (Herath 2004). They improve water quality, replenish groundwater, retain floodwater, provide habitat for a diversity of plants and animals, trap sediment, reduce nutrients and remove contaminants. For the preference modeling to protect and manage wetlands MCA analysis is a milestone.

Forest management has become critical because of a multitude of competing uses and functions of forests, including timber harvesting, recreation, water supply, flood control, preservation of air, soil and water quality, biodiversity conservation and groundwater retention (Ananda and Herath 2003). The multiple and competing uses of forests have increased the frequency and intensity of forest management conflicts. For example, there have been major conflicts between timber harvesting and conservation of biodiversity in old-growth forests in the Pacific Northwest region of the U S. and tropical rain forests in the Amazon River Basin. By increasing the application of MCA in forest management the arising conflict can be minimized.

Rapid socioeconomic improvements driven by increased income and wealth have increased the demand for ecosystem services, such as aesthetic enjoyment and recreation. Nature-based tourism is an important income source in many countries and having a well-preserved environment is paramount for its success. Planning and management of natural areas are inherently difficult because of the multiple attributes of nature-based tourism and conflicts between use and preservation of those areas. Management of nature-based tourism and natural areas through MCA could ensure the quality of environment in any tourist spot without jeopardizes its ecology, culture and social values (Figgis 1993, Prato and Fagre 2005).

The *Malnichara* is one of the major channels in Sylhet. In this study, three alternatives of its improvement have been evaluated by the MCDA method. Hydrologically, the channel is divided into two portions: upper portion (*Choukidekhi-Kanishail*) and lower portion (*Kanishail-Topoban*). Both parts were analyzed separately. Nine criteria were selected from four groups of technical, economic, environment and social aspects. Technical and environmental criteria were assigned a weighed coefficient of 1 whereas economic and social criteria were assigned a weighed coefficient of 1.5. The interviews with stakeholders and consultation with experts were carried out throughout the study period from the selection of criteria to assignment of weighed coefficients and scores to alternatives. For both portions of the channel, sodding natural channel was found to be the best alternative (Chowdhury & Rahman, 2008).

In Finland, use of AHP in participatory natural resource decision making has attracted a lot of attention, especially within the forestry sector. With state-owned forests in Finland covering one-third of all forest land, AHP principles have been widely applied in participatory strategic forest planning. However, the first participatory applications were carried out in nature conservation planning (Kangas 1994). Individual voting, or solicitation. of expert judgments via pair-wise comparisons was used in the AHP that is a good match for including multiple stakeholders (Schmoldt et al , 2001).

Environmental impact assessment (EIA) is an intrinsically complex multi-dimensional process, involving multiple criteria and multiple actors. Multi-criteria methods can serve as useful decision aids for carrying out the EIA. AHP has been used to carry out EIA which has the flexibility to combine quantitative and qualitative factors, to handle different groups of actors, to combine the opinions expressed by many experts and can help in stakeholder analysis. The main shortcomings of AHP and some modifications to it to overcome the shortcomings are briefly described. Finally, the use of AHP is illustrated for a case study involving socioeconomic impact assessment. In this case study, AHP has been used for capturing the perceptions of stakeholders on the relative severity of different socio-economic impacts, which will help the authorities in prioritizing their environmental management plan (Ramanathan, 2001).

The application of the AHP to natural resource problems has been surprisingly limited. Despite its widespread use as a decision method, the AHP has received some criticism: 1) because no theoretical basis exists for the, formation of hierarchies, decision makers, when faced with identical decision situations, can derive different hierarchies, thus different solutions, 2) the rankings produced by the AHP are arbitrary because they are produced by a subjective opinion using a ratio scale and these arbitrary rankings can lead to "rank reversal," 3) flaws exist in the methods for aggregating individual weights into composite weights, and 4) an absence of a sound underlying statistical theory. Despite these concerns, the AHP remains immensely popular among private and public sector decision-makers (Schmoldt et al., 2001).

2.5 Research Need on Floodplain

Since the Brundtland report of 1987 (WCED), sustainable development has become the focus of discussions and debate throughout the world (for example; Falkenmark, 1988; Pezzey, 1992; Pearce, 1993; Serageldin, 1993; Rotmans and de Vries, 1997, Svedin, 1998). From the debate, one thing is clear, a more specific definition is needed to help those who are engaged in development work to evaluate their efforts with respect to sustainability (Loucks, 2000). In this regard, sustainable management of natural resources is a prerequisite for sustainable development while, procedural direction for implementing sustainable management is also required.

Land and water are essential and interdependent floodplain resources. There are individual research on the sustainable management of these resources (for example Kjeldsen and Dan, 2001; Steiner and Helmut, 1999; Xuequan and Gao, 2002 etc) but there is no study on the sustainable management of land and water resources together. This research intends to develop a framework for sustainable management of these two resources in a floodplain. Along with this, characterization of the floodplain functions on the basis of criteria and indicators will be base of this study.

The natural system is a pressure response system. Any human activity exerts pressure on the environment which actually changes its properties and functionality of the floodplain resources, which also affects societal needs and the ecosystem. This Pressure-State-Response Framework has been defined by OECD in the late 1980s. However, this framework starts with plan, policies and strategies, which creates pressure on the system. In reality, policies should be translated into economic activities, such as land and water use activities, which creates pressure on the system. This study will incorporate these issues in the framework.

Floodplain land and water resource management is critical for a floodplain country, like Bangladesh. Water resource projects in Bangladesh by BWDB and LGED are aimed to benefit the rural people. but they are deficient in several areas with respect to sustainability. For example, in the Early Implementation Projects, the integrated approach has been taken into consideration only in the fourth phase. The projects do not have an effective mechanism for ensuring peoples participation in project activities (Datta, 1999). The projects lacked proper and effective communication between the stakeholders and a clear conflict resolution system. As a result, the representation of various groups in committees became the cause of their ineffectiveness, or failure. The projects has been successful in involving institutions such as landless contracting society (LCS), embankment maintenance group (EMG) and NGOs in mobilizing the landless, with regard to construction and maintenance. The LCS and EMG activities have, to some extent, contributed to the income of the local destitute men and women labourers who, apart from manual labour, have very few alternative sources of income. Moreover, through consumption linkages, such activities have created indirect employment and income generating opportunities in other activities, at least within the project areas. Unfortunately. sustainability in terms of fair distribution of resources, safeguarding ecosystem and maintaining floodplain functions has not been addressed in EIP projects. The LGED projects strongly considered environmental mitigation measures using IWRM principles. Even then, environmental degradation could not be mitigated during project implementation (BUET et al., 2003) The projects contributed to poverty alleviation but not in safeguarding ecosystem. Further, floodplain functions as the principle of sustainability was not considered

To study the feasibility of these projects, benefit cost ratio (B/C). internal rate of return (IRR), environmental impact assessment (EIA) and environmental management plan (EMP) had been used. But EMP is not reliable as an ultimate solution. Moreover, no monitoring arrangement was made for EMP implementation. No baseline has been identified for these activities and the ecosystem was not properly addressed. In most of the cases, evaluations are done by observing the outputs, but the productivity and functionality of the resources are never taken into account.

A recent study shows that there is hardly any benefit of flood control and drainage (FCD) projects in deep floodplain areas (Chowdhury, 2003). The FCD projects specifically in wetland dominated areas were unsuccessful due to disruption of storage function of wetlands (Chowdhury, 2003). According to Dyson et al. (2004), providing for environmental flow is not exclusively a matter of sustainable ecosystems, but also a matter of supporting humankind/ livelihoods. Nevertheless, environmental flows are often undervalued and thus frequently omitted from decision-making (Emerton & Bos, 2004, Millennium Ecosystem Assessment, 2005). The national policies for land use and water resources management in Bangladesh has been established but not yet implemented. Further, practical aspects were not considered in the policy preparation. It lacks integration between different sectors of the implementing agencies (e.g. BWDB, BADC, LGED, RHD etc.) who are engaged in utilization and management of land and water resources. Some of the drawbacks of the projects are: lack in considering environment and equity criteria in a holistic way, mitigating measures instead of safeguarding had been implemented, risks were transferred from one area to another, access to opportunities is not equitably distributed, project benefits are not shared equitably and the project created opportunities and benefits from land acquisition and resettlement are highly skewed and served mainly large farmers and land owners instead of landless and marginal farmers. Hence, flood control or flood management should aim at reducing risks, increasing resilience and safeguarding ecosystems and this study will do that.

Most of the DSS developed for land use and water resources management considered only decision making for optimum resource use in terms of productivity and cost efficiency. Few examples are found which incorporated ecological sustainability as key elements of decision making process in water and land management projects GIS and RS technologies were used successfully in view-based DSS to make easier for decision makers. However, land and water management issues in floodplains are closely linked to social improvement and environmental sustainability. A comprehensive Decision Support Framework (DSF) will be developed and used in this study which will integrate these elements, which is needed for decision makers and also integrate social and ecological sustainability in floodplains.

Chapter 3

DEVELOPMENT OF DECISION SUPPORT FRAMEWORK FOR SUSTAINABLE MANAGEMENT OF LAND AND WATER USE

3.1 Development of Indicators to Characterize Floodplain Functions

This chapter describes methodology of developing the Decision Support Framework (DSF) for sustainable management of land and water use to attain three objectives as mentioned in Chapter one. Detail methodologies for accomplishing each objective are explained in the following sections.

The first objective is to develop indicators to characterize the floodplain functions. Floodplain is a natural resource, which produce goods and services to the society. Population pressure and social and economic development has made the floodplain environment to decline. Hence to protect and maintain floodplain functions it is important to characterize floodplain functions. Floodplains perform a multitude of complex functions that provide basic ecological support within the floodplain as well as valuable goods and services to the society. The functions refers to the capacity to support and control either natural system processes such as the storage of floods, facilitation of fish migration or the assimilation of wastes, or human and economic activities, such as supplying water for domestic purposes or providing navigable conditions in rivers. According to people's perception, floodplains have two functions: productive and service function. People grow rice and other crops in the field and catch fishes in the floodplain and beels, is defined as productive function. Service functions include the capacity of the floodplains to carry water, sediment as well as goods. Besides this, scientists classified floodplain functions as land related functions and water related functions. Water related functions include maintaining natural channel processes, managing flows, maintaining water quality, waste/soil quality. plant and wildlife habitats, agriculture and sustaining agricultural production etc. Maintaining production and life support, providing habitat, acting as storage of raw materials and minerals and providing living space are part of land related functions. Floodplain function should be maintained in a way so that it continues its functionality to serve the future generations. A set of indicators is needed to define the floodplain functions. Indicator is a parameter or a value derived from parameters, which provides information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter values. Indicators possess a synthetic meaning and are developed for a specific purpose (OECD, 1994). Floodplain functions for sustainable land and water uses are explained in the following sections.

3.1.1 Hydrology

Hydrological function refers to the capacity of the floodplain to regulate and store water and maintain connectivity between wetlands and rivers. Over the centuries, floodplains have been managing flood with natural features that provide floodwater storage and conveyance, reduce flood velocities and flood peak and finally to drain the excess water. Floodplains allow surface water percolation and ultimately facilitate groundwater recharge. In addition, releasing of monsoon water and providing it during the dry period is also an important function of the floodplain. Table 3.1 shows the hydrological functions of floodplain along with its indicators. These indicators have been developed based on three criteria. These include representation of the characteristics of the function; indicators can be evaluated by using models and tools or any logical function and sensitiveness to reflect changes in land and water use. For hydrological function five sub functions have been developed They are: regulatory, carrying, connectivity, storage and regeneration. The regulatory function refers to the capacity of the floodplain to alleviate river floods during the monsoon season through storage of peak river discharge in the floodplain. During the dry season a main function of the floodplain is to retain and supply water. This relates to the capacity of the system to store water during the monsoon and to make this water together with additional cross boundary river inflows and local rainfall, available during the dry period. Recharge is one of the important function which refills groundwater and surface water. One or more indicators have been developed to represent a sub function, which are shown in Table 3.1.

Assessment of the indicators of different hydrological functions requires specific methodologies. The data used for the estimation of indicators include both observed and modelled data. Change in monsoon and dry season water level values represent the differences between the long term average water level and the estimated water levels for different conditions. For this calculation, first the water level values at several important locations of the study area will be averaged for corresponding time period.

Then these values will be subtracted from the long term average values (1986-2004) at corresponding locations. Finally, these values will be averaged to find the change in monsoon or dry season water level.

Table 3.1: Sub-functions and indicators of hydrological functions of floodplain

Sub-functions	Indicators	Unit
Regulatory/carrying	Change in monsoon water level of river	m
	Change in dry season water level of river	m
Connectivity	Duration of flow in connecting river/ khal with beel/ waterbody	days
Storage	Groundwater storage (Permeable Area)	ha
	Flooded area	%
Regeneration	Recharge	Million m^3
	Estimated base flow	m^3/s
	Depth of groundwater table (from ground surface)	m

Duration of flow in connecting river/ khal with beel/ water body is assessed based on daily water level. This function refers to the capacity Number of connecting days at specific points will be assessed observing the water level value. Finally, yearly values of connecting days at each point will be averaged to generate one indicator value.

The storage function has three components, such as, surface storage, soil storage and groundwater storage. Of these, groundwater storage and flooded area (for surface storage) has been used as indicators and the other one is included in regeneration sub function, as well as in ecological function.

For simplification in calculation, groundwater storage is represented by permeable area, which facilitates the entrance of rainfall and other overland flow to groundwater table. In this study, the permeable area will include all unpaved area. For this total area excluding that of settlements and roads will be considered.

The flooded area is presented as percentage of the total study area For this estimation, at first, the peak water level values at different locations within the study area will be sorted from hydrodynamic model outputs. Then water surfaces will be generated from these water level data and corresponding GIS data of infrastructures (embankments, roads etc.) using Inverse Distance Weighted (IDW) interpolation technique in ArcGIS platform. The inundation depth maps will be generated by subtracting the Digital Elevation Model (DEM) and land use from the water surfaces. Finally, the area having depths of one meter or higher will be selected as flooded area.

The regeneration sub function has three indicators, such as, estimated base flow, recharge and depth of groundwater table. The recharge represents the regeneration capacity of groundwater. Whereas, base flow represents the generation of surface water flow from the groundwater flow and depth of groundwater table indicates the regeneration of groundwater. Recharge will be estimated from the rainfall and the flooded area. Estimation of rainfall recharge will be done utilizing the MPO suggested logarithmic formula from MPO Technical Report No. 5 (MPO, 1987). The formula is stated as;

$$Recharge\ in\ mm = A + B\ log\ (Annual\ rainfall\ in\ mm)$$

Where. A and B are two constants.

Distribution of flooding recharge depends on soil texture and particle size. According to IWM study in the Barind area (IWM. 2006b), particle size varies with elevation In higher elevation, particles are coarser and in lower elevation particles are finer. Consequently, recharge from flooding gradually decreases from high to low areas. In this research, an additional 12.5% recharge has been taken as recharge from flooding.

Computation of estimated base flow follows basic principle that base flow is the resultant flow of catchment outflow minus inflow plus surface water use. For estimation of this indicator, hydrological model (NAM) will be used. The groundwater table depth values indicate the groundwater availability condition. The depth of groundwater table will be estimated from hydrological model.

3.1.2 Environment

The function, which maintains the quality of water and soil of the floodplain, is the environmental function. Environmental function must maintain a rational movement between the biotic and abiotic components of the habitat. To characterize the environmental function, three sub functions have been developed for floodplain environment. These sub functions are: Adequate flow to maintain the floodplain environment, i.e, the environmental flow; land and water quality and biodiversity.

Environmental function allows the capacity of the system to deal with wastes and reduces the concentration of polluting substances to an acceptable level for the exposed environment, human and activities. The indicators selected to assess the environmental functions of the floodplain are shown in Table 3.2.

Table 3.2: Sub-functions and indicators of environmental functions of floodplain

Sub-functions	Indicators	Unit
Adequate flow to maintain the floodplain environment	Monsoon flow with respect to Flushing Requirement (200% of mean annual flow)	%
	Dry season flow with respect to environmental flow (20% of mean annual flow)	%
	Naturality of the flow	
Land and water quality	Fertilizer use	kg/ton
	Pesticide use	kg/ton

These indicators will be computed from various secondary data sources. The discharge data will be collected from hydrodynamic model outputs for different conditions. The fertilizer and pesticide data will be collected from the farmers through FGD and household survey along with secondary data from BBS publications and upazila level DAE offices.

Environmental Flow is a comprehensive term that encompasses all components of the river and its associated habitats, for example, wetlands, estuaries, floodplains, etc. It is defined as the water that is left in a river ecosystem or released into it, for the specific purpose of managing the condition of that ecosystem. There are four main categories of environmental flow assessment methods according to Jowett (1997), Gordon et al. (1992) and King et al. (2000). These are:

i) Hydrological methods

ii) Hydraulic rating methods

iii) Habitat simulation methods

iv) Holistic approaches

For the analysis of current research, Hydrological method specifically Tennant method (Mean Annual Flow Method) has been used (Tennant, 1976). It is based on the premise that the flow of a stream is a composite manifestation of characteristics, such as, size of the drainage area, geomorphology, climate, vegetation and land use. According to Bari and Marchand (2006), the monsoon flow requirement with respect to environmental flow for flushing is 200% of mean annual flow, while dry season flow should be good condition for aquatic habitat and the good condition requires 20% of mean annual flow during dry season.

For computation of monsoon or dry season flow, first the mean annual flow will be calculated for each of the selected locations. The estimated mean annual flow will be used to estimate monsoon flow requirement (200%) and dry season requirement (20%). The average flow during monsoon season (June-October) and dry season (November-May) will be estimated for different locations. Finally, flow values for dry or monsoon season are averaged to present a single value for the indicator.

The natural behavior of a river or stream is floods and ebbs (Figure 3.1), that is, the fluctuation of the level of water that allows the interchange of food between floodplains and rivers (de Graaf et al, 1999 and Bonetto, 1975).

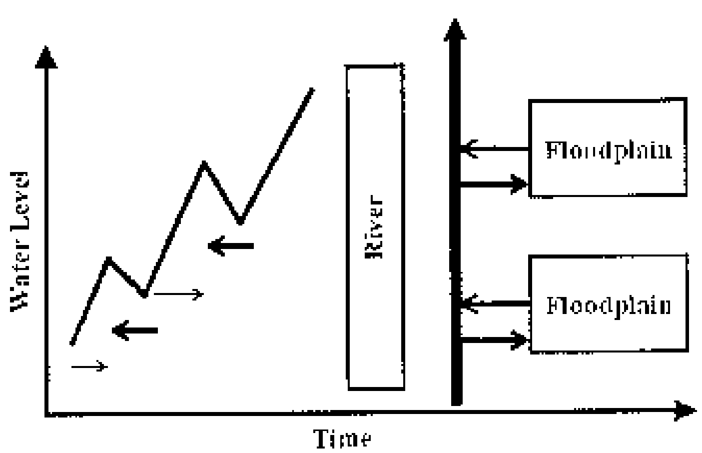


Figure 3.1: Interchange of food between floodplain and river with fluctuation of water level

To maintain the environment, natural behavior is critical. To analyze the naturality of flow of a river or stream, three scenarios will be observed. First, flow with no interventions, that is, a fully functioning natural system. Second, flow with interventions (regulators). Third, the natural system has been totally closed due to siltation or man-made closure. In this study, a factor for each of these scenarios is assumed. The factors are two, one and zero for first, second and third scenario respectively. For calculation of the indicator, factors for different rivers or streams in the study area will be assessed. Then these values will be averaged for one single indicator value.

Based on fertilizer and pesticide use data from field and BBS data, rate of fertilizer/ pesticide application for different conditions will be done. The total fertilizer and pesticide use will be computed from total cereal production, total fertilizer and pesticide use which is computed from individual application rates. Finally, it is presented as fertilizer/ pesticide used per ton of cereal production.

3.1.3 Ecology

One of the most important functions of floodplain is the maintenance of diverse characteristic of plant and animal communities. Hydrologic and vegetation diversity provides important resting, feeding and nesting areas for many species. Undisturbed floodplains have higher natural biological diversity due to connectivity resulting in greater productivity than a disturbed one. Connectivity between river and floodplain helps aquatic movements and migration. The wetland areas provide habitats for fish. Floodplains (especially wetlands) contain habitats for species of special concern. Inundated floodplains are important nursery and feeding areas of juvenile fish and other aquatic life and helps fish migration. The ecological functions have three Sub-functions which include: aquatic habitat, migration/movement and terrestrial habitat. The ecological functions of the floodplain along with the indicators are presented in Table 3.3.

Table 3.3: Sub-functions and indicators of ecological functions of the floodplain

Sub-function	Indicators	Unit
Aquatic habitat	Wetland area	ha
Migration/ movement	Favourable duration for hatchling movement	day
	Favourable duration for fish migration	day
Terrestrial habitat	Social forestry area	ha

The amount of wetland area indicates the opportunity and diversity of aquatic species. So, wetland area has been selected as indicator for aquatic habitat sub function For computing the wetland area, the total area of beels, khals and rivers within the study area will be considered.

For fish resources, availability of required flow during their migration and movement period is of great importance. According to Hassan (2002), fish hatchling/ migration period is May-July. Hatchling movement is possible when velocity is greater than 0.1 m/s and depth is more than one metre while fish migration requires a depth of one metre or more. For computing favourable duration for fish migration and hatchling movement, number of days fulfilling the depth and velocity criteria within the required period will be assessed for different locations and then weighted averaged using average discharge at corresponding locations.

In order to assess the terrestrial habitat condition social forestry area has been used as indicator. The social forestry area will be estimated using the following equation.

Social forestry area = 0.3 x Urban settlement + 0.5 x Rural settlement + 0.3 x Shoulder area of road

3.1.4 Socio-economic

Floodplains are highly productive and provide the increasing food demand of a growing population. The flat land, fertile soils and proximity to water have historically made floodplains valuable for agriculture. Human settlement and industrial development also occurs on floodplains for a variety of reasons including proximity to water supply, water transport, etc. In this research, four indicators have been considered as socio-economic indicators for three sub-functions, productivity, navigation and human habitat. The indicators are, rice productivity, fish productivity, navigable channel length and human settlement area (Table 3.4).

Table 3.4: Socio-economic functions of floodplain along with its indicators

Sub-functions	Indicators	Unit
Productivity	Rice productivity	ton/ha
	Fish productivity	kg/ha
Navigation	Navigable channel length	km
Provide human habitat	Population live in per unit settlement area	#/ha

The socio-economic indicators will be estimated from the land use patterns, cropping distribution, fish production, settlement area and population projection data. The data sources include BBS publications, national water resources database (NWRD), and RS/GIS data.

Based on the available crop and fish production data, rice and fish production for different conditions will be estimated. From this estimation the indicator values for rice and fish productivity will be assessed. The navigation channel length is considered as the unobstructed water body length (km) of navigation routes used by small water vessels to carry goods and people. This will be calculated by multiplying the lengths of each channel by a factor depending on the flow condition. The factor values are 1 for natural flowing channel, 0.5 for regulated channel and 0 for channel having closure or closed due to siltation or other causes. The navigation length of 2001 is taken as base value for the analysis. The indicator population per unit settlement area will be assessed dividing total population by total settlement area for different conditions.

3.2 Formulating Constraints based on Equity Criteria and Ecosystem Needs

The term constraint means the state of being restricted or confined within prescribed bounds. This study does not imply constraints as obstacle. Here constraints are development constraints which has two aspects such as social and environmental. Social constraints usually fix the minimum limit, which must be ensured, and environmental constraints identify the higher limit, which should not be crossed. The study considers two constraints, such as, equitable resource distribution and safeguarding ecosystem.

Equity derives from a concept of social justice. It represents a belief that there are basic needs that should be fulfilled, that burdens and rewards should not be spread too divergently across the community, and that policy should be directed with impartiality, fairness and justice towards these ends (Falk J, et al 1993). Equity needs to consider social, political and physical drives, whereas this research only focuses on physical resource distribution. It is presumed that equitable distribution of the physical resources (land and water) will create opportunity to achieve overall equity of the society.

3.2.1 Fulfillment of basic needs

The elements required for survival and to sustain normal mental and physical health of human beings are fundamental human needs. Basic needs include the demand to meet the necessary nutritional requirement from food and water, safe shelters, clothes, access to health and education services etc. Meeting these basic needs is the most important indicator of equitable resource distribution. Basic needs are met when people have food to nourish them, a safe place to sleep, and clothes to protect their bodies. It also include education, health assistance etc. This research has selected some of these basic needs as constraints, which are shown in Table 3.5. From the table, it is observed that safe drinking water, housing space, cereal and animal protein requirement are selected as constraint. According to WHO, every adult human being should take 2-3 litres of water per day (WHO, 1971). In case of housing space, the requirements vary according to the income level. For example, per capita housing space requirement for a lower income country like Bangladesh is 120 square feet (sft) and for middle income country it is 150 sft while for developed country it is 300 sft (Chiara & Callender, 1973).

Table 3.5: Minimum requirements of basic needs

Criteria	Constraints	Unit	Minimum requirements
Fulfill basic needs	Safe drinking water	lpcd	2-3 lpcd (WHO, 1971)
	Housing space	ft^2/capita	120 ft^2 (Chiara & Callender, 1973)
	Cereal (rice)	g/capita/day	400 g/capita/day (World Bank, 1985)
	Animal protein (fish)	g/capita/day	40 g/capita/day (Hosaain *et al.*, 2008)

In a developing country like Bangladesh, people are mainly dependent on cereal consumption for their daily caloric requirements. On average, per capita rice consumption in Bangladesh is 450 gm per day, whereas, FAO standard is 400 g/capita/day (World Bank, 1985) Therefore, it can be said that cereal consumption is more than the requirements. But still everybody is not getting the required amount. At the same time people are not taking required amount of protein. It is recommended that per capita fish consumption should be 40 gm/day (Hosaain et al., 2008). However, a major share of population is below these standards. But for equitable resource distribution these standards should be fulfilled.

With development the requirement of basic needs may change as income is a major driver of changing consumption patterns. In Bangladesh, the average calorie intake from fish is 26 kilocalorie/capita/day, whereas, in a developed country this amount is 46 kcal /capita/day (Hosaain et al., 2008). Therefore, it can be inferred with the changing income level consumption pattern may change

3.2.2 Fairness in land and water resource distribution

According to Beder 2000, equity implies a need for fairness (not necessarily equality) in the distribution of gains and losses, and the entitlement of everyone to an acceptable quality and standard of living. In this research, fairness in land and water resource distribution only refers to the fairness in opportunity of labour force to access to common property resources (subsistence fishing) and land resources. Thus the selected constraints of fairness in land and water resource distribution are defined in terms of employment opportunity related to agriculture and subsistence fishing (Table 3.6).

Table 3.6: Constraints of fairness in resource distribution

Criteria	Constraints	Unit	Minimum requirements
Fairness in land and water resource distribution	More than nine months employment opportunity in agriculture	Number	Depends on socio-economic state
	Percentage of settlement area within ½ km of the flooded area for subsistence fishing	% of population	50%

The employment opportunity does not remain same throughout the year. And this difference is mainly observed in agriculture sector than the others. In agriculture, labour requirements usually vary based on the cropping pattern and ultimately seasonality of the crops. It is observed that from September to November, the employment opportunity in agriculture is very limited. Therefore, there is a seasonal crisis during this period. So this research has taken temporal distribution of labour in agriculture as a constraint.

To calculate the temporal distribution of labour, at first, the employment is distributed throughout the year according to the seasonality of the crops and the labour requirement in different stages of the crops. For example, to cultivate per ha of Boro (HYV) rice 160 man-days is required and usually it is planted in January and harvested in May. 15% of this total labour required for land preparation, 15% for planting, 25% for inter-cultural operation and 45% during the harvesting period. Therefore, these 160 days will be divided among these five months according to the above mentioned proportions and multiplied by the area of the respective crops. Using this same procedure, the labour requirement for every crop will be distributed throughout the year and finally summing up the labour requirement for every individual month and converting them into man-month.

Accessibility to common resources is another constraint considered under fairness in land and water resource distribution. This constraint is mainly targeted to measure the accessibility for subsistence fishing. The percentage of settlement area within half km of the flooded area is the indicator selected to assess this constraint as it is assumed that settlement with close proximity to the floodplain will get better access to the floodplain fisheries. This indicator will be estimated using hydrodynamic model results and GIS overlay technique. At first, the flooded area will be generated for different conditions from hydrodynamic model results. Then using GIS, the flooded area will be overlaid over settlement area and the proximity analysis will be conducted. Based on the results of the proximity analysis, the percentage of settlement area within one km of the flooded area will be determined.

3.2.3 Safeguarding the ecosystem

Ecosystem services are required to sustain human life and enhance its quality. These services come from the ecosystem components such as soil, animals, plants, water and air, which usually differ across ecosystems. If these assets are depleted, the ability or capacity of the ecosystem to provide services also diminishes. The ecosystem is of significant social and economic value. It serves as underpin of our economic prosperity because it produces most of the living needs of humans and others. This research considers environmental flow during dry season, wetland habitat and floodplain vegetation area as constraints of safeguard ecosystem (Table 3.7).

For evaluating the environmental flow criteria, dry season environmental flow requirements will be checked at different locations. The minimum dry season environmental flow requirement is 20% of the mean annual flow. This value for different options will be computed from the hydrodynamic model results for different locations and then averaged to represent a single value.

Table 3.7: Constraints of safeguard ecosystem

Criteria	Constraints	Unit	Minimum requirements
Ensure environmental flow	Environmental flow (Dry season flow)	% of annual mean	20%
Protecting wetland habitats	Dry season water area	% of gross area	5%
Ensure water quality	Floodplain vegetation area	% of gross area	60%
Sustaining biodiversity	Aquatic species diversity	Score (on a scale of 6)	3

The minimum requirement for protecting the wetland habitat is 5% of the gross area. For estimating the constraint, total wetland area during dry season will be used. The area under beels and rivers during dry season is considered as dry season wetland.

Floodplain vegetation and soils (especially those associated with wetlands) help to maintain water quality by filtering nutrients and impurities, intercepting surface water runoff before it reaches the lake, stream or river. Surface water percolates into the ground, where the quality of water is maintained by filtering the impurities by soil. To ensure water quality, the floodplain vegetation area is important. The minimum requirement for this constraint is 60% of the gross area. The net cultivable area will be considered as the floodplain vegetation area.

Wilhm (1970) expressed the aquatic species biodiversity as shown in equation 3.1:

$$\overline{H} = -\sum_{i=1}^{s} (n_i/n)\log_2(n_i/n) \qquad \text{Eq. 3.1}$$

where H = species diversity, n_i = number of individuals in the *i* th species,

n = number of individuals in the sample, and s = number of species.

Generally, the species diversity value less than 1.0 indicate severely degraded conditions, 1.0 - 3.0 indicate moderately polluted streams, and greater than 3.0 indicate clean water streams (Wilhm and Dorris. 1968).

The species biodiversity mainly depends on three parameters. These are, connectivity, water quality and vegetation. Landscape connectivity is a function of both the environmental features of a corridor and the behavior of wildlife species that may attempt to use the corridor (Merriam, 1984). The general assumption underlying the value of landscape connectivity is that a fragmented landscape that is interconnected, is more likely to support viable faunal and floral population and maintain ecological processes, than a landscape that is comprised of only isolated fragments (Harris, 1984; Bennett, 1998). Habitat quality is rarely uniform in landscapes because of natural variation in topography, soils, and vegetation (Foster, 1980). Further, vegetation provides nutrients to aquatic life. In this research, duration of flow in connecting river/ khal with beel/ waterbody is used as connectivity, total fertilizer use during boro season as water quality and net cultivable area as vegetation. For the estimation of biodiversity, the values of three parameters are first normalized and then weighted averaged based on TOPSIS Method (Hwang and Yoon, 1981). Connectivity and vegetation is weighted on benefit criteria and water quality is weighted on cost criteria. Finally, the weighted averaged values are multiplied by 6 and presented on a scale of 6.

3.3 Development of Criteria and Indicators to Assess the Impacts on Socio – economic Improvement

Social wellbeing is a state in which basic human needs are met and the population is able to coexist peacefully in communities with opportunities for advancement. This is characterized by equal access to and delivery of basic needs (water, food, shelter) and services (health services and the provision of education). In case of income, not only the amount but its distribution is equally important. For example, in the last four decades, per capita GDP of Bangladesh increased from US$203 in 1975 to US$621 in 2008-09. However, Bangladesh has been unable to eliminate extreme poverty and hunger at the same rate as the GDP increment. In addition, a significant disparity exists in income distribution in the society. According to Ahmed and Byron (2006), the income gini co-efficient, a measure to assess income inequality, shows an increase from 0.451 in 2000 to 0.467 in 2005, mostly due to increasing rural inequality. A higher gini co-efficient reflects a worsening situation for income inequality. Income share of the lower tier people has decreased while the top 50 percent's has increased, widening the gap between the rich and the poor. The lower 50 percent of the population claims only 20.32 percent of total income. Therefore, economic sustenance is not enough to understand the socio-economic improvement of a country, its distribution, accessibility, risk reduction and increased resilience is also important. Floodplain produces goods and services to the society for the socio-economic improvement. To improve socio-economic condition, thirteen decision support indicators have been identified under 3 criteria: economic sustenance, food availability and public services. Improvement of socio-economic condition needs to be assessed for different land and water use activities in the floodplains. These criteria also have sub-criteria such as economic sustenance has five sub-criteria: gross income, income by occupation, savings, employment and risk. The sub-criteria of food availability includes production and nutrition. Table 3.8 presents the sub-criteria and the indicators of socio-economic improvement. A procedure has been developed to evaluate these sub-criteria using indicators. All these sub-criteria along with its respective indicators are described in the following section.

Table 3.8: Indicators of socio-economic improvement

Criteria	Sub-criteria	Indicators	Unit
Economic sustenance	Gross income	Income from land use	Million Tk
	Income by occupation	Income of landless farmer	Tk/year
		Income of fisherman	Tk/ year
	Employment opportunity	Percentage of employment	%
	Household Savings	Savings of farmer (Landless)	Tk/ year
		Savings of fishermen	Tk/ year
	Risk from flooding	Crop at risk from flooding	Mt
		Household at risk from flooding	Tk
Food availability	Production	Total rice production	Mt
		Total fish production	Mt
	Nutrition	Average calorie availability from rice and fish	kcal/capita/day
Public services	Access to public services	Number of population served by unit health center	Number
		Number of population have access to per km of road	Number
		Number of population have access to education center	Number

3.3.1 Economic Sustenance

The economic sustenance has five sub-criteria and eight indicators.

Gross Income

Income is a quantity received by an individual, a group or a nation that is usually recurrent. It ordinarily derives from wages, property rent, earned interest, or profits. It is a flow that accrues per unit of time (Serafy, 2009). Income can be derived from various sources, but this study only considers land use related incomes. Here land use includes agriculture, settlement, wetland, and other uses like transport, industry etc.

Income related indicators are computed based on land use and occupation. The basic principle used here is to collect a rate of income per unit land use for different land use from either field survey or other secondary data sources, multiply this by area under specific land use and finally get the total income. Gross income per year is calculated at constant prices for all the scenarios. To determine the gross income from the land, the area of specific land use is identified. Then income from unit area of that land use in a year will be calculated and multiplied with the total area of that land use to get the total income from that land use. Suppose for agriculture; the cropping pattern area will be identified. Then the income of per ha of agricultural land with different cropping pattern will be estimated. To estimate the income from per ha agricultural land, the input cost and output (production from that crops) for every crop types are calculated Then the production is multiplied by the selling price. Finally, the input cost is deducted from this price and total income from specific crop is obtained. This is the income of a land with a single crop. But if the cropping pattern comprises two or three crops, then individual income from every crop is calculated and all the income will be added to get the income from land uses. The income from this unit area is multiplied by that area of the cropping pattern and finally aggregating the income from all agricultural land.

Similarly, to calculate the income from wetland, only the capture fisheries are considered. Here per ha productivity (kg/ha) for different sources like beel, river and khals and floodplains are taken from fisheries statistical year book of Bangladesh and the prices of fishes are collected from field survey or other secondary data sources. In case of settlement, only the income from rural settlements will be considered which includes income from livestock and chicken. From field survey, the total number of chicken and livestock will be collected. Based on these data per ha income from rural settlement is computed for different scenarios.

To compute the income from industries only the income of the workers are taken. From field survey, the area and number of employees, their wage rate and seasonality of operation of different types of industries were obtained. Using this data, per ha income of the industry is calculated and multiplied by the total industrial area. Similar process is followed for growth centre. Finally, all the income from different land uses are added together to obtain the gross income.

Income by occupation

Besides the gross income, yearly income of the landless farmer and the fisherman will be computed. In order to estimate the future income of the farmers and fishermen, income by occupation has been calculated. The average land area cultivated by a landless farmer and the contribution of agriculture in his income will be collected through field survey. From the gross income of land, the income of landless farmer will be computed. In case of fisherman, the total income from the wetlands will be divided by the total number of fishermen of that respective year and thus the income of the fisherman will be obtained.

Employment opportunity

Population projection by age group is needed to project the employment requirement of the future generation. In a floodplain country like Bangladesh population is increasing. A recent demographic projection has revealed that middle age population (20-59) will increase at a higher rate than any other age group. From this, we can deduce, more people from the middle age group will join the labour force. Thus, providing employment to this increasing population will be a challenge for the government.

Agriculture is the single largest producing sector of the economy. It employs around 48% of the total labour force (MoF, 2009). Percentage of employment is selected as indicator to assess the employment opportunity. The employment by occupation will be calculated for different types of land use and then added all together to get the total number of employment. In agriculture, the labour requirement (man-days) per crop per ha is multiplied by the respective areas of the crop and then converted into man-year.

This is considered as the employment opportunity in agriculture. The employment opportunity in per ha of wetlands is multiplied by the area of the respective wetlands and thus the total employment in wetlands is calculated. Number of employment opportunity in the settlement is considered in this research as it is complex and also avoid double counting in computers.

Household savings

Savings is one of the most important indicators of socio-economic improvement. Increasing savings will increase community resilience and ultimately will improve socio-economic condition. According to Ragnar Nurkse's vicious cycle of poverty, less saving will lead to less investment which will lead to reduced income and increased poverty (Nurkse, 1952). Poverty is a complex societal issue. Poverty refers to the condition of not having the means to afford basic human needs such as nutrition, clean water, clothing, shelter, health care and education.

Since 1970s, in developing countries like Bangladesh, government has taken several measures aimed at eliminating poverty and social inequality. These measures mainly targeted at increasing the literacy rate, providing access to safe drinking water, family planning, and provide micro-credit to the poorest and most disadvantaged groups in the community. Though the government achieved some positive results but not at the expected rate. Bangladesh being a disaster prone country, almost every year the country faces natural disasters, which impedes the success of these initiatives particularly affecting the most vulnerable groups in the society. Hence, if the savings of the poor people could be increased, it will help the people to better cope with disaster i.e. increase the resilience of the society

In this study, the gap between income and cost for basic needs (food) will be assessed. Here, the cost for basic needs includes only the cost of food. However, the cost of basic needs also includes cloth. shelter, medicine, education etc. According to BBS food basket 2,122 kcal is required for each person per day. This food basket shows the food items and the amount of those foods a person should consume everyday to get that calorie, but this calorie requirement varies from country to country. Using the prices of those foods obtained from statistical pocket book of BBS, the cost of basic needs will be estimated. This food basket will be considered constant for all the scenarios. Savings will be calculated by deducting this cost from the income.

Risk from flooding

Risk is considered as the outcome of hazard and vulnerability. Hazard includes probable loss/ damage by a hazard event and intensity or frequency of hazard. Vulnerability includes the resources exposed for that hazard. Using this principle, risk from flooding will be computed in this research. For this, household asset and crop at field will be considered. The economic value of household asset and amount of crop production will be taken to estimate the risks.

The estimated average household asset values for different scenarios will be used for household risk assessment from flooding. For the risk analysis, damage percentage is required. A study on Brahmaputra floodplain (FAP 3.1, 1997a), shows that severe damage has occurred to 16% households in medium floods like 1995 (1 in 10 years) whereas, it goes upto 32% in large floods like 1988 (1 in 50 years). In this context. the household damage in rural areas is assumed to be 20%, while that of urban area is assumed 10% based on Islam (2006) for this research. The plinth level of houses in rural areas are normally above 1 in 5 year flood level, whereas, 1 in 10 year in urban areas. So, in a hundred year time, rural households are exposed 20 times while, urban houses are exposed 10 times. This exposure/ flood frequency represents the vulnerability. The average household asset value in the study area should be assessed from field survey or other reliable secondary sources. Using these asset values, damage percents and flood frequency, the potential asset at risk from flooding will be calculated. The resulting asset values represent cumulative household asset at risk from flooding for a 100 year period.

The crop production at risk from flooding is computed in a similar procedure. Here, the estimated aman crop production values are used for assessing the crop production at risk from flooding as aman is a monsoon crop and it is more susceptible to flood. The crop damage percentages will be assumed based on available field survey data or relevant studies. In this research, the MPO flood land type categories (MPO, 1987) will be used for assuming crop damages. This classification is based on depth of flooding on the respective land. The flood frequency is taken similar to that for rural areas. Based on the crop production values, damage percentages and flood frequency the potential productions at risk from flooding will be calculated. The resulting values represent cumulative production at risk from flooding for a 100 year period.

3.3.2 Food Availability

Food availability is one of the criteria for improving socio-economic condition for land and water use activities in the floodplain. Two sub-criteria: production and nutrition has been assessed under this criteria.

Production

This study considers food production of cereals and fish. Available cereal production is the most important indicator of food availability. If the demanded amount of cereal is available then it is called that food availability situation is achieved. In this research both the availability of rice and fish is selected as the indicators of food availability. To calculate the total rice production, per ha rice yield is multiplied by the total area under rice cultivation and per ha fish production of different types of wetland will be multiplied by the area of the respective wetland to get the total fish production.

Nutrition

In addition to land and water resources, healthy nutritious human resource is a key element for socio-economic improvement. On average, 75% of the calorie intake of the population in Bangladesh comes from rice (Bhuiyan *et al*, 2002). At the same time, fish is the main source of protein in Bangladesh. If the required/ standard amount of rice and fish demand can be fulfilled, a major share of nutritional demand can be met. Based on this assumption, the average daily calorie availability from rice and fish has been selected as an indicator of socio-economic improvement. Moreover, in this study, rice and fish production is also directly related with the selected land use.

To calculate daily average calories availability per person from rice and fish, first per day per capita average consumption of rice and fish will be computed (in grams). However, to obtain per day per capita average availability of rice, the total production of rice per year is divided by the population. Then this value is converted to daily consumption value. Now this value is multiplied by the caloric contain in per gram of rice. Usually one gm of rice contains 3.5 kcal (BIDS, 2001). Multiplying those values, average caloric availability from rice per person per day will be determined. The same procedure is followed to calculate the average calorie intake availability from fish per person per day. The calorie contain of per gram of white fresh water fish is 1.06 kcal (BIDS, 2001). Finally, adding these two values per day per capita calorie availability from rice and fish is obtained.

3.3.3 Public services

Access to public service has been identified as the sub-criteria for public services. The important indicators here are: access to health centre, education centre and roads. If the accessibility to the public utility services like health, education, transportation facility etc. can be improved, it will indicate an improvement of socio-economic condition. This criterion has two indicators such as number of population served/unit health center, and number of population having access to per km of road. These indicators are calculated by dividing the population by the number of health centres or total length of road respectively.

3.4 Development of Decision Support Framework

3.4.1 Conceptual Framework for Sustainable Land and Water Management

The concept of sustainability is improvement in the quality of life of the present generation while safeguarding the ability of future generations to meet their own needs. A better quality of life means a higher standard of living, usually measured in terms of income level and uses of resources and technology. The major challenge for developing countries, is feeding its ever increasing population According to FAO, world food production will have to double in order to provide food security for 7.8 billion people expected by 2025 (AFP, 2009). To meet the increasing food demand, most developing countries are mainly concentrating on food production without giving consideration to safeguarding the ecosystem. As a result, environmental degradation is occurring at a rapid scale. It is also inherent in the concept of sustainable land and water use that equity principle should be maintained in order to achieve economic, social and environmental sustainability. Equity and particularly intergenerational equity is the central ethical principle behind sustainable resource management. Equity consideration in water management is an important requirement for the promotion of goals of sustainable development (Chowdhury, 2009).

Floodplain contains a variety of ecosystems and habitats, including indigenous vegetation, wetlands, beels and rivers. Due to unplanned development activities, these valuable ecosystems have been degrading over the years. At the same time, ecosystems have a limited capacity to absorb the effects of environmental pollution. The consequence of increasing degradation beyond the absorption capacity of the ecosystem is resulting in the extinction of some animal and plant species. Thus, the principle of sustainability includes safeguarding the life supporting capacity of ecosystems. So, protection of significant habitats of indigenous fauna and flora should be ensured for achieving sustainable resource management.

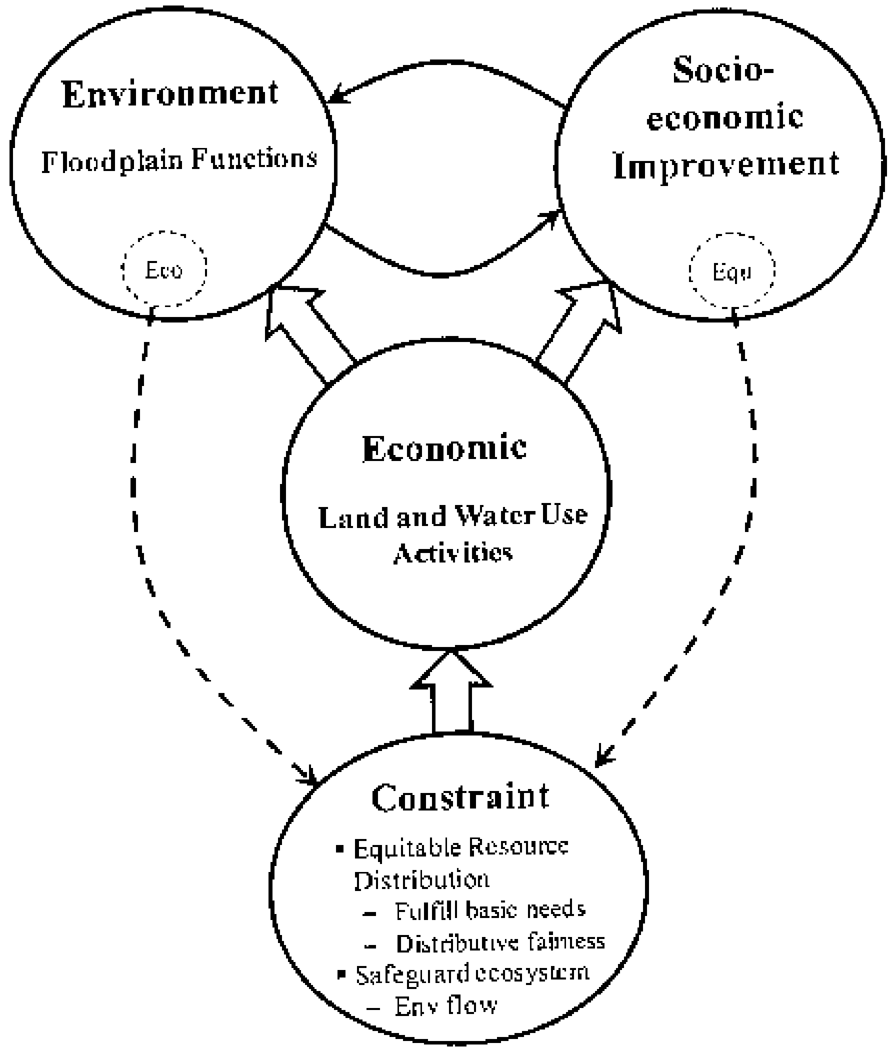


Figure 3.2: Conceptual basis for sustainable land and water use activities

The basis for sustainable resource management should be to improve the socio-economic condition of the society for the present generation by ensuring equitable resource distribution without depriving future generational needs In addition, maintaining the floodplain functions and safeguarding the ecosystem, so that land and water resources can continue to produce goods and services for socio-economic improvement. This sustainable development is illustrated in Figure 3.2.

In developing countries, most emphasis is placed on employment creation. However, it is not enough to address the temporal distribution of employment. The distribution of employment throughout the year is equally important. Unfortunately, not enough emphasis is given on whether the resources are equitably distributed. Not only that, its effect on the ecosystem is totally ignored. For these economics, two stage evaluation is needed before embarking on socio-economic progress. First, it should be assessed whether the project is ensuring equitable resource distribution and safeguarding the ecosystem. Second, the outcome should be able to improve socio-economic condition and also protect floodplain environment through maintaining floodplain functions.

The philosophy of utilizing natural resources for societal development is like sitting on top of a pyramid (Odum, 1971). The planners overlook at the reproductive and functional capacity of natural system which results in degradation of natural floodplain resources. This in turn creates acute threat to meet future generation needs. In this research, the pyramid has been reversed, that is, into an upside down pyramid as shown in Figure 3.3. In this approach, the planners should devise a system whereby, the present generation should not only be the user, but also the custodian of floodplain resources. They should utilize these resources for improvement of socio-economic condition and should also be able to meet the needs of future generation without depleting resources and degrading the environment.

Sustainable development model had three pillars: Economic, Environment and Social (Stevens, 2005). In this model, all three pillars are interlinked and have equal importance and therefore, are evaluated together. However, in this research, economic activity, such as. land and water use activities are geared toward socio-economic improvement. The socio-economic improvement cannot be sustained without a protected and functional environment as well as fair and equitable distribution of natural resources

Socio-economic improvement in conjunction with future generation needs should be one of the key development objectives. Different land and water use activities in a deltaic floodplain are essential ingredients to achieve these objectives. These activities utilize natural (floodplain resources) and human resources to produce goods and services for socio-economic improvement. Maintaining floodplain functions should be the basis for utilizing land and water resources in a floodplain for sustainable resource management. In addition, socio-economic improvement of the society cannot sustain without equitable resource distribution and safeguarding the ecosystem, which are the two constraints for sustainable land and water use as shown in Figure 3.3.

The conceptual framework for land and water use as shown in Figure 3.3, shows these are two competing objectives: socio-economic improvements and maintaining floodplain environment. However, there are two constraints in achieving these two objectives. Socio-economic improvement must ensure equitable distribution of land and water resources. To maintain floodplain functions, the ecosystem in a floodplain should be safeguarded. These two constraints act as an objective in fulfilling the constraints. Land and water use activities uses floodplain resources to achieve these two competing objectives. Not only that, it also meets the constraint requirement in such a way that it fulfills present generation needs without depriving the future generations.

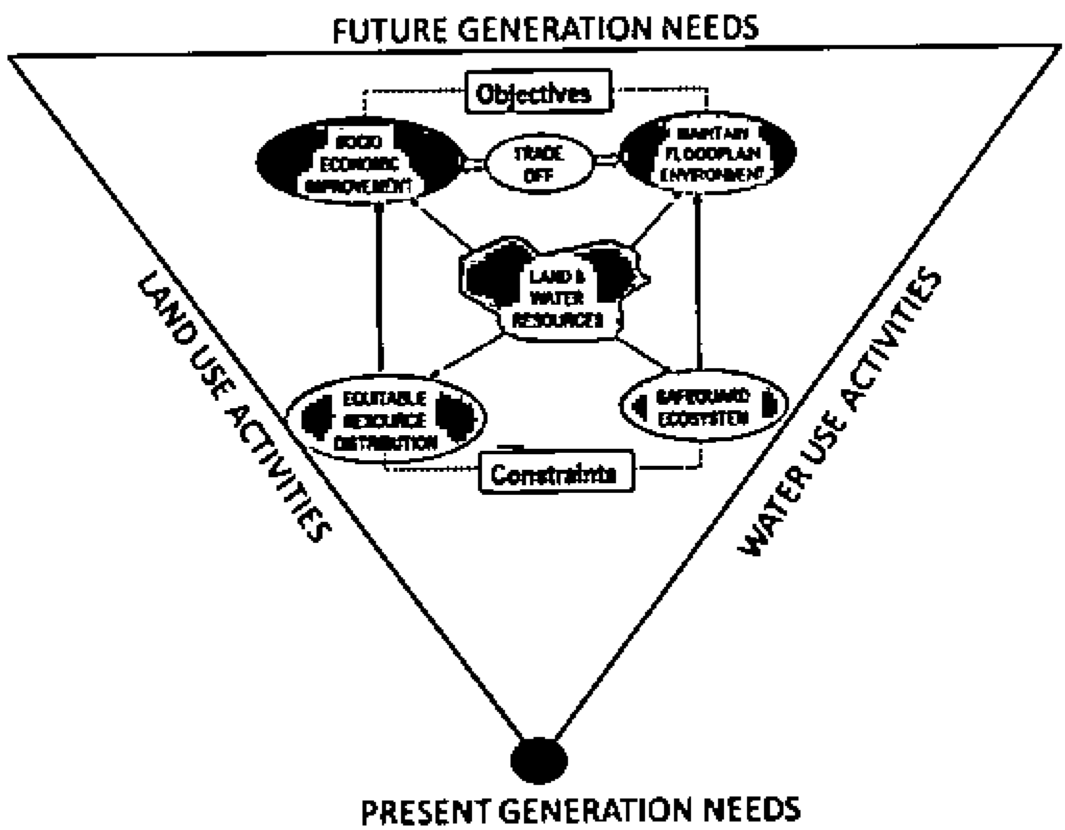


Figure 3.3: Conceptual framework for sustainable land and water use activities

3.4.2 Analytical Framework for Sustainable Resource Management

In the study, a decision support framework (a process to analyze and implement the conceptual framework shown in Figure 3.3) has been developed for sustainable land and water management (shown in Figure 3.4) to assess the changes and impacts of various options of land and water use activities in a floodplain. This framework comprises several components like, driving factors, activities, data and models. change in state, impact assessment, equity and environmental constraints, evaluation of impacts by multi criteria analysis (MCA) and recommended land and water use activities.

Driving factors include demands and needs from various social and economic aspects, government policies and plans, opportunities for resource use and flood management and several other external factors like climate change and upstream water management activities.

The options for land and water use activities are derived products of the driving factors. These activities originate from the driving factors and changes with changes in driving factors. These activities result in the changes in state of various functions of floodplain associated society and economy.

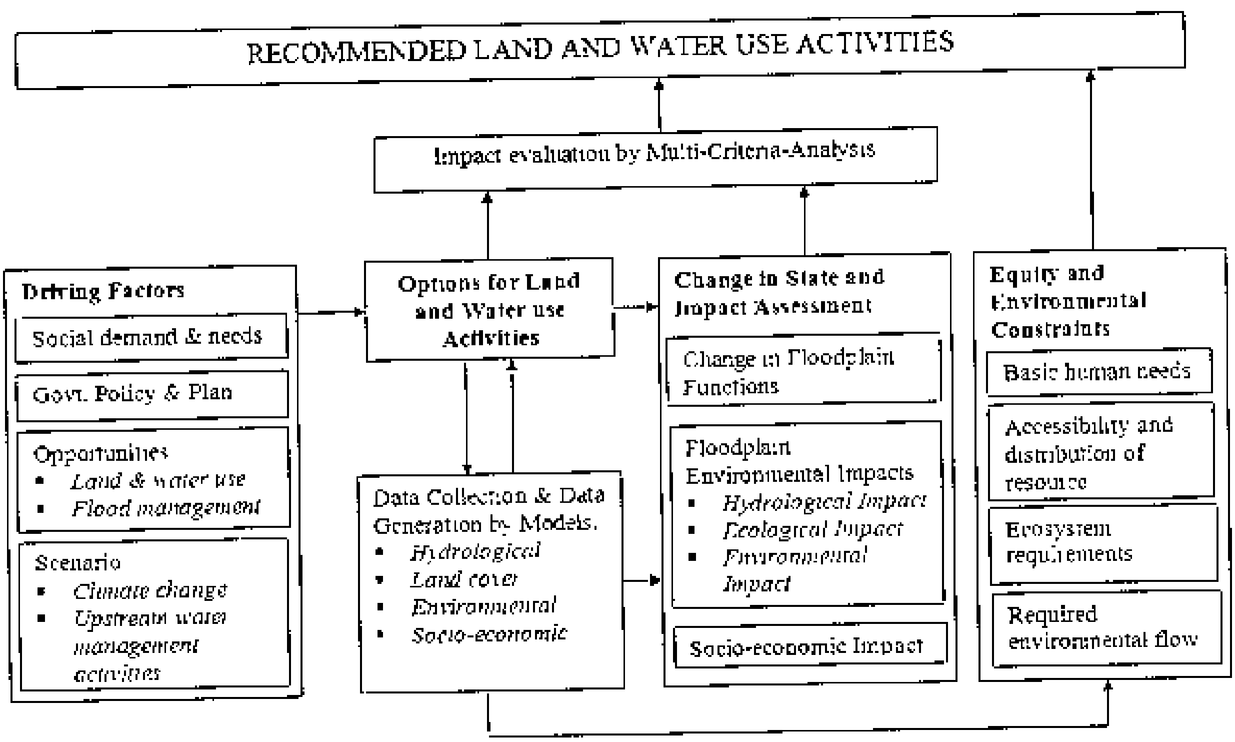


Figure 3.4: Decision support framework for sustainable management of land and water use in the floodplain

The data and models component is used for observation of changes due to various land and water use activities. Data types include hydrological, land cover, environmental and socio economic data. The available data will be collected from various secondary sources and if not available will be generated by hydrodynamic and hydrological models. The data and models component is dependent on driving factors and options for resource use

The changes in state and impact assessment is the next segment of the framework. It will be generated using data and models for various options of resource use activities. This segment includes changes in floodplain functions, floodplain environmental impacts and socio-economic impacts. The change of state will be assessed in terms of improvement or degradation of floodplain functions compared to historical data. The changes in floodplain functions include changes in state of various functions while the floodplain environmental impact comprises hydrological, ecological and environmental impacts. The socio economic impact include various impacts on income, employment etc. with changes in land and water use activities. The changes in state are influenced by driving factors and land and water use activities.

The equity and environmental constraints are the guiding conditions which ensure the equity in resource distribution and safeguard the ecosystem. The constraints include several criteria like, basic human need, accessibility and distribution of resource, ecosystem requirements and environmental flow requirements. The constraints measure various physical and socio-economic condition of a floodplain based on some threshold values which should be maintained to protect life and livelihood of people and also to protect the floodplain environment.

Two major objectives will be evaluated by MCA based on results from change in state due to different land and water use activity options. Finally, an option for land and water use activity will be recommended.

3.4.3 Computational Framework for Decision Support System

Based on the conceptual framework, a computational framework has been developed to evaluate land and water use activities in terms of measurable criteria and indicators for attaining sustainable management of land and water resources. The framework has two major objectives: protection of floodplain environment and socio-economic improvement. The sub objectives of maintaining floodplain environment are: maintaining hydrology, protecting environment and safeguarding ecosystem. Fulfilling basic needs, fairness in resource distribution, economic sustenance, access to public services and food availability are the sub objectives of socio-economic improvement. Each sub objective will be evaluated by one or more criteria. For example, maintaining hydrological conditions will be evaluated by three criteria, such as, maintaining regulatory function, maintain connectivity and maintain storage and regeneration.

Similarly, two criteria have been developed to evaluate fairness in resource distribution. These are: access to flooded area for sustaining fishing and temporal distribution of occupation.

All the criteria will be evaluated based on options of land and water use activities. The land use activities include agriculture, settlement, wetland and other use (infrastructure). The water use activities comprise irrigation, domestic use, environment and other use (industries). The land and water use options will be generated based on the driving factors like, policies, plan, strategies, people's preference, availability of resources etc. For each option, hydrological, hydrodynamic and land use models will be used to generate values for the indicators to assess the criterion and consequently the objectives and goal as shown in Figure 3.5.

Analytical Hierarchy Procedure (AHP) will be used to evaluate the criteria, sub-criteria and objectives in order to attain the goal. The AHP is a comprehensive methodology that provides groups and individuals with the ability to incorporate both qualitative and quantitative factors in the decision making process. Finally, an option for land and water use will be evaluated using AHP which will aid in decision making process.

3.5 Selection Criteria for Study Area

This research aims to develop a decision support framework for integrated management of land and water use in a floodplain. In order to test the framework, a study area should be selected based on the following criteria.

- It should be a floodplain: A floodplain is a strip of relatively flat land adjacent to a stream which is periodically overflowed during high water. So, the study area should have a flat topography, newly formed young and active floodplain.
- The area is adequate to represent a region or sub region: The decision support framework developed in this research is targeted to macro level planning. In order to test this framework a region or sub region is required where enough opportunities and alternative use options for land and water resources are available for implementing structural and non-structural measures.

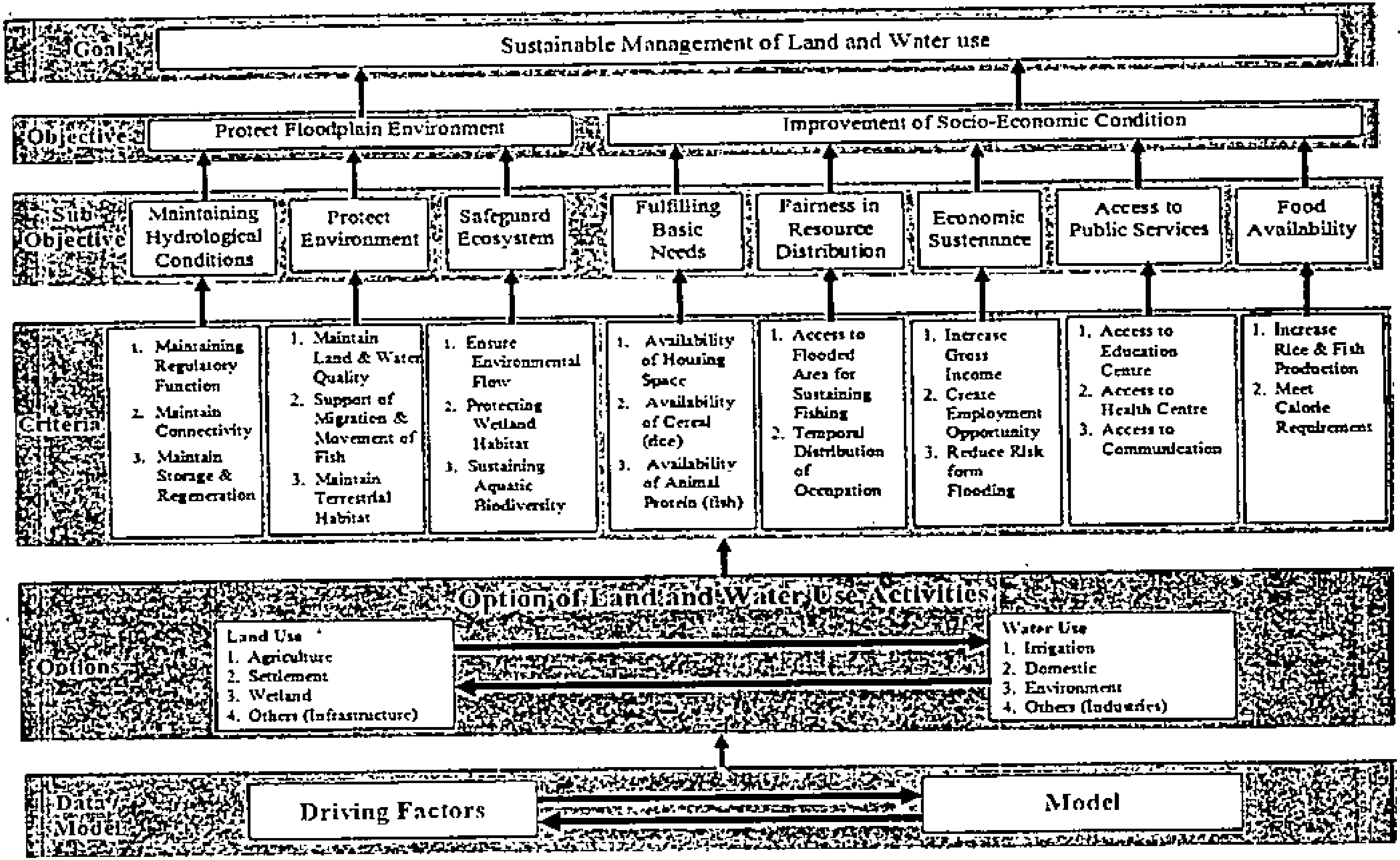


Figure 3.5: Computational framework

- Availability of land and water use information: In order to test the framework properly, detail information of land and water resource use in rivers, streams and floodplains are required. So, it is preferable if secondary information in the study area is available from hydrological and hydrodynamic models.
- Floodplain characteristics should prevail: The study area should be an active floodplain and the floodplain characteristics should prevail. To ensure this condition. the area should be free from major man made intervention such as embankment.
- Accessibility: This research needs data on various physical, social and economic parameters. In case of unavailability of data, information from the study area should be collected through surveys, focus group discussion or meetings with stakeholders. In this regard, good accessibility of the study area is important.

3.6 Data Source and Data Generation by Models

For assessment of the developed decision support framework data of various physical, social and economic conditions are required. Data needs can be classified in broad categories like socio-economic data, land use/ land cover data, hydrological and hydrodynamic data and environmental data. Details of data need, data collection and data generation by models are described in following paragraphs.

3.6.1 Socio-economic Data

This research requires various socio-economic data like income, employment, condition of basic needs, resource distribution, food availability etc. These data will be collected from both primary and secondary sources For primary data collection, Focus Group Discussion (FGD), Key Informants Interview (KII), and household survey will be done in the study area. Secondary data will be collected from available reports of Bangladesh Bureau of Statistics and other relevant organizations, local government offices etc.

3.6.2 Hydrological and Hydrodynamic Data

In order to assess the impacts of various land and water use activities in a floodplain area, time series data of rainfall, surface water level, discharge and ground water in the floodplain is required. For this data, hydrological and hydrodynamic model results will be needed. This data for the study area should be collected if model results are already available.

In this research, time series data of observed rainfall, water level, discharge and ground water will be collected from meteorological and hydrological measurement stations near the study area. For generating data in the floodplain under different land and water use scenarios. Sobek-Rural developed by WL | Delft Hydraulics and NAM model of DHI MIKE will be used. Sobek-Rural has two hydrodynamic modules, 1DFLOW for generating 1D analysis and Overland Flow (2D) for simulating flooding. Both of these modules will be used in the present study. For generating groundwater data in different locations of the study area NAM model based lumped rainfall-runoff analysis will be carried on dividing the study area into several sub-catchments considering the land use and topographic features and using GIS techniques like flow accumulation

3.6.3 Land use/ Land cover Data

The land use/ land cover data in the study area is of great importance. In this study, these data will be collected from remote sensing (RS) and GIS data. Using these data, land use maps for different time and scenario of land and water use will be prepared. The land use map preparation includes steps like, classification of different land use/ land cover from RS data, collection of statistical data, preferences of land use/ land cover etc. Three different temporal perspectives (Dry season crop coverage, Monsoon season crop coverage and other perennial land use) will be assessed using RS images

Monsoon crop in floodplain area of Bangladesh is mainly Aman. The area under Aman cropping can be accurately measured using RS images. RS images are of two types, optical and radar images. During monsoon, cloud covers the sky and optical images cannot penetrate the cloud. So, monsoon crop coverage cannot be assessed using optical images. The radar images can penetrate the cloud. and as a result, this is suitable for estimating Aman crop coverage. In the current study, Aman crop estimation will be done with RADARSAT ScanSAR wide beam images. Then, the single dated images will be used to generate the multi-temporal image and classified using ISODATA clustering techniques to delineate the aman area.

Each individual RADARSAT scene contains one channel of data and is produced by using a single microwave frequency known as the C-band (5.3 GHz frequency or 5.6 cm wave length). The nominal resolution of the ScanSAR Wide image and ScanSAR Narrow image are 100 m and 50 m respectively. ScanSAR Wide images are acquired in the SW2 beam position (incidence angle 20 – 46 and swath width 450 km) during an ascending orbit with beam combinations of W1, W2, S5 and S6. The beam combination of the ScanSAR Narrow image (SN2) is W2, S5 and S6 with 300 km swath width.

In case of monsoon crop coverage mapping, perennial land features like urban settlements (i.e., corner reflectors), rural settlements, forests, waterbodies, and seasonal variations in the agricultural fields will be considered. The dominant agricultural crop in the monsoon is the aman rice, which is a rain-fed crop and grows from June/July to October/November. Some of the depressed land areas restrict agricultural use and remain fallow due to the presence of higher water levels in those areas. Aquatic weeds such as grasses and hyacinths grow in these depressions, but their canopies are generally very low in percentage (typically less than 30%). Based on the land use/ land cover conditions described above, several monsoon land use classes will be identified from the multi-temporal image set. These land use classes are, open water, aman crop, other crops, rural settlements, built up areas and forest areas (if present). Figure 3.6 illustrates the methodology followed in preparing the aman crop coverage. In this process, the geo-referenced images will be stacked first to generate a multi-temporal data set. Through unsupervised classification, 100 classes will be generated with 30 iterations and with a convergence threshold of 0.95. A set of parametric signature will be produced based on statistical parameters of the image elements. Analyzing signatures and ground truth data, similar signatures will be grouped together and the classified image will be merged and recoded into seven broad classes. It is generally difficult to isolate the rural settlements and other crops from each other using the unsupervised classification approach. So, a set of signatures will be generated from the multi-temporal image using some previously known rural settlement area polygons. Using these signatures, a supervised classification will be done with the option of maximum likelihood classifier, and thus, the extent of rural settlement image plane will be generated. Then the extent of rural settlements will be merged with 7 broad classes image plane and finally the monsoon land use/ land cover map will be prepared.

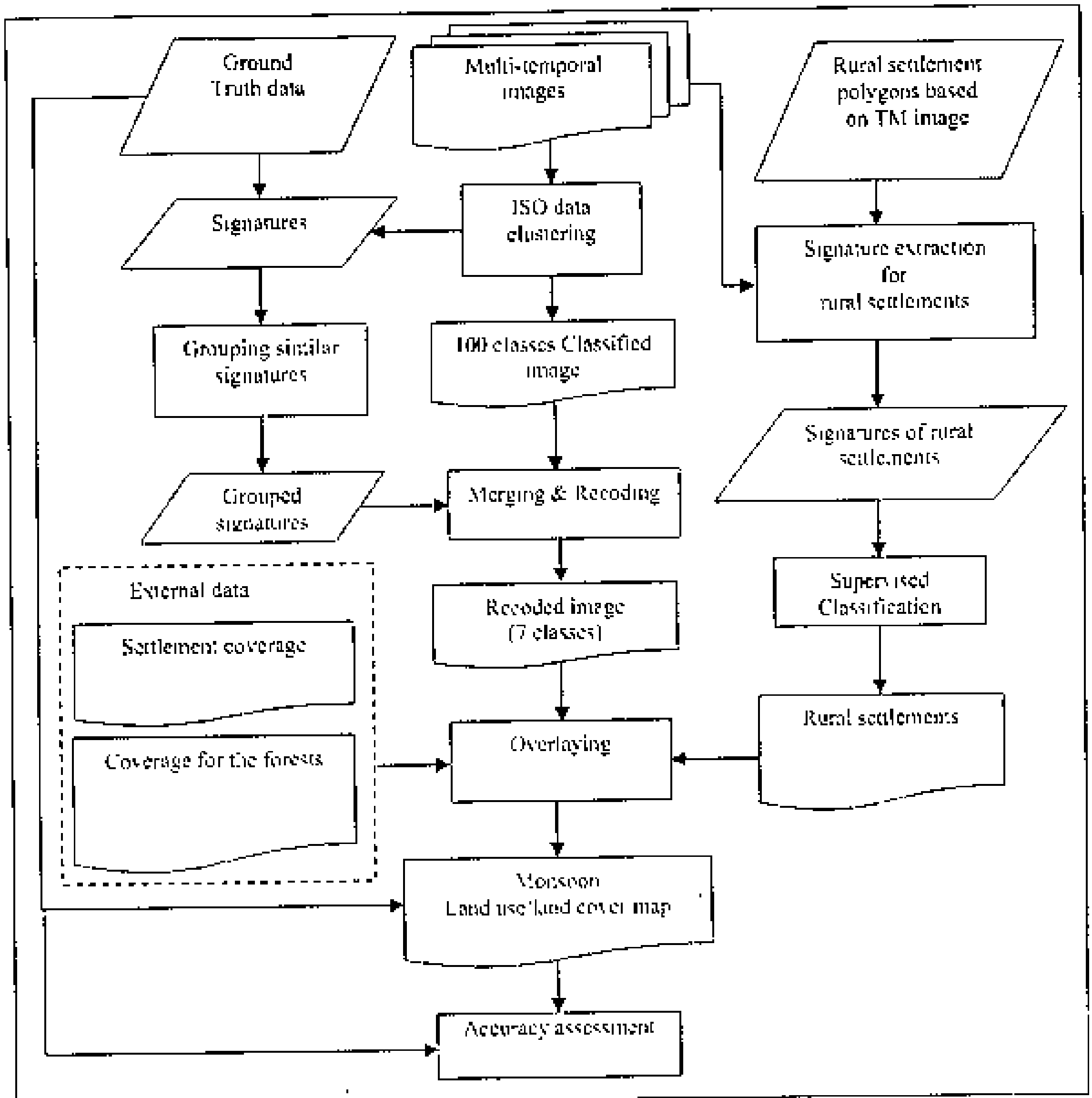


Figure 3.6: Schematic diagram of land use mapping

Figure 3.7 shows an example of merged signature patterns that can be used for unsupervised classification. In the merged signatures, the water (in all dates) and Built-up area (corner reflectors) were found in the lower and upper end of the DN values range respectively. From the signature pattern one can differentiate the damaged aman crop from the survived aman The survived aman shows an increasing trend in the DN values with the growth stages of the crop. The damaged aman crop shows a gradual decline in DN values with inundation. In case of rural settlements and other crops, it is clear that these two classes are mixed with each other. For identifying these two classes separately, a further investigation of supervised classification might be done.

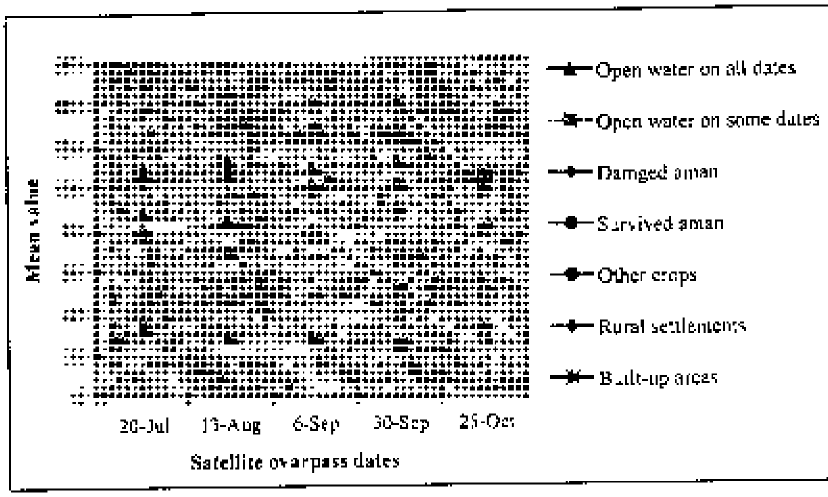


Figure 3.7: Merged signatures extracted from unsupervised maximum likelihood classification

Dry/ winter season crop in Bangladesh is mainly boro rice. During dry season the sky is usually clear and the optical images can capture any ground condition. So, for estimating the boro crop coverage, optical images from LANDSAT TM (resolution 30m), IRS LISS (23.5 m) and Terra MODIS satellites will be used. The MODIS (Moderate-Resolution Image Spectroradiometer) data of Terra satellite will be used for boro crop area mapping and estimation. MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra MODIS and Aqua MODIS view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands or groups of wavelengths. It has a viewing swath width of 2,330 km. Its detectors measure 36 spectral bands between 0.405 and 14.385 μm, and it acquires data at three spatial resolutions 250m. 500m, and 1,000m. Only one scene is required to cover the whole country. The ground resolution of the image is 250 meter and the bands used for the analysis are red, infrared and mid-infrared.

The RS optical images will be used in identifying other perennial land use or land covers like, settlements, waterbodies, khals, rivers etc. For this LANDSAT TM optical images will be used to generate multi temporal images. The land use coverage data for settlements and waterbodies will be estimated for 1991, 2001 and 2008. The data for 2001 will be generated from National Water Resources Database (NWRD) and the other two using satellite images from LANDSAT TM and also from Google Earth images. The perennial waterbody data have been captured by NWRD from SPOT89, LANDSAT97 and IRS images. This data will be used in the present study.

In preparing the land use maps, the year 2001 has been taken as the base. The prepared land use map gives four basic land use types. These types include agricultural use, water use, settlement use and infrastructures use. The basic methodology for preparing the land use map is presented in Figure 3.8. For preparing the land use maps, several data layers will be used. These are, remote sensing image derived data, land type classification, data from BBS and other secondary sources, crop suitability and local preferences All these data will be combined and analysed in GIS platform.

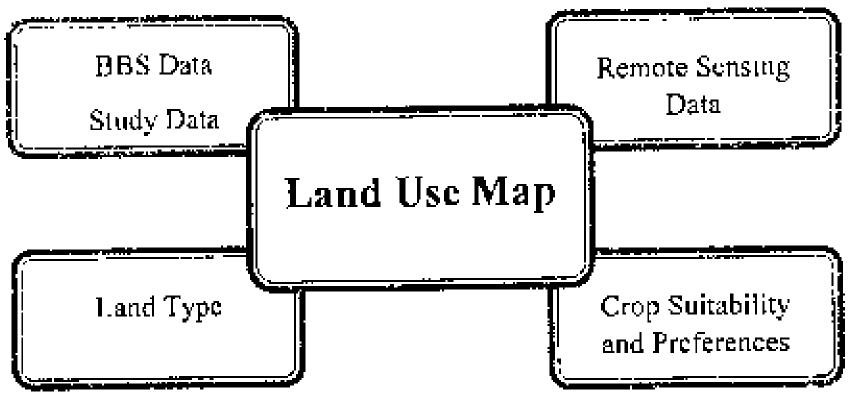


Figure 3.8: Land use mapping procedure

For GIS analysis, a Digital Elevation Model (DEM) of 25 metre resolution will be used. The width of road will be considered as 2 pixels. Width of rivers and beels will be assumed as constant (for beels the width is 4 pixels and for rivers is 6 pixels). In preparing the land use map, the sequence of GIS layers used in GIS analysis is assumed as, first agriculture, then settlement, waterbody, roads, embankments and finally river network.

3.6.4 Environmental Data

The environmental data for the study include environmental flow requirements, land and water quality represented by fertilizer and pesticide use, aquatic habitat represented by wetland area, terrestrial habitat represented by social forestry area, favourable duration for fish migration and movement, aquatic species diversity and information on flora and fauna species available in the study area. These data will be collected from both primary and secondary sources. Primary data like fertilizer use rate, information on flora and fauna species will be collected through field survey. The data required will be mainly collected from available secondary sources like relevant local government offices, statistical year books, hydrological and hydrodynamic models etc.

Chapter 4

STUDY AREA AND DATA ANALYSIS

4.1 Physical Characteristics

4.1.1 Location and Topography

The study area is in the Jamalpur district, which is located in the Northern part of North Central Region (NCR) of Bangladesh. It covers an area of about 600 square kilometers. The extent of this area spreads within the latitude of N-24^{0}46′ to N-25^{0}11′ and the longitude of E-89^{0}42′ to E-89^{0}57′ (see Figure 4.1).The study area includes floodplains of Chatal, Jhinai and Dadbhanga rivers, which are the distributaries of the old Brahmaputra and Jamuna river. The study area comprises of six upazilas in Jamalpur district. This area is bounded by Islampur and Jamalpur Sadar upazila of Jamalpur district, Dewanganj upazila on the north, Islampur and Madarganj upazila on the west and Sarishabari upazila on the south. The total area of each upazila and the contributing area percentage of those upazila to the study area are presented in Table 4.1.

Table 4.1: Upazila wise total area and contributing percentage to study area

Upazila	Total Area (km^2)	Upazila percent
Dewanganj	267	13
Islampur	343	30
Jamalpur Sadar	490	12
Madarganj	225	66
Melandaha	240	96
Sarishabari	263	10

From Table 4.1, it is observed that the study area comprises about 96% area of Melandaha upazila. 66% Madarganj upazila and 30% of Islampur upazila. Further, only 10% of Sarishabari upazila is under the study area.

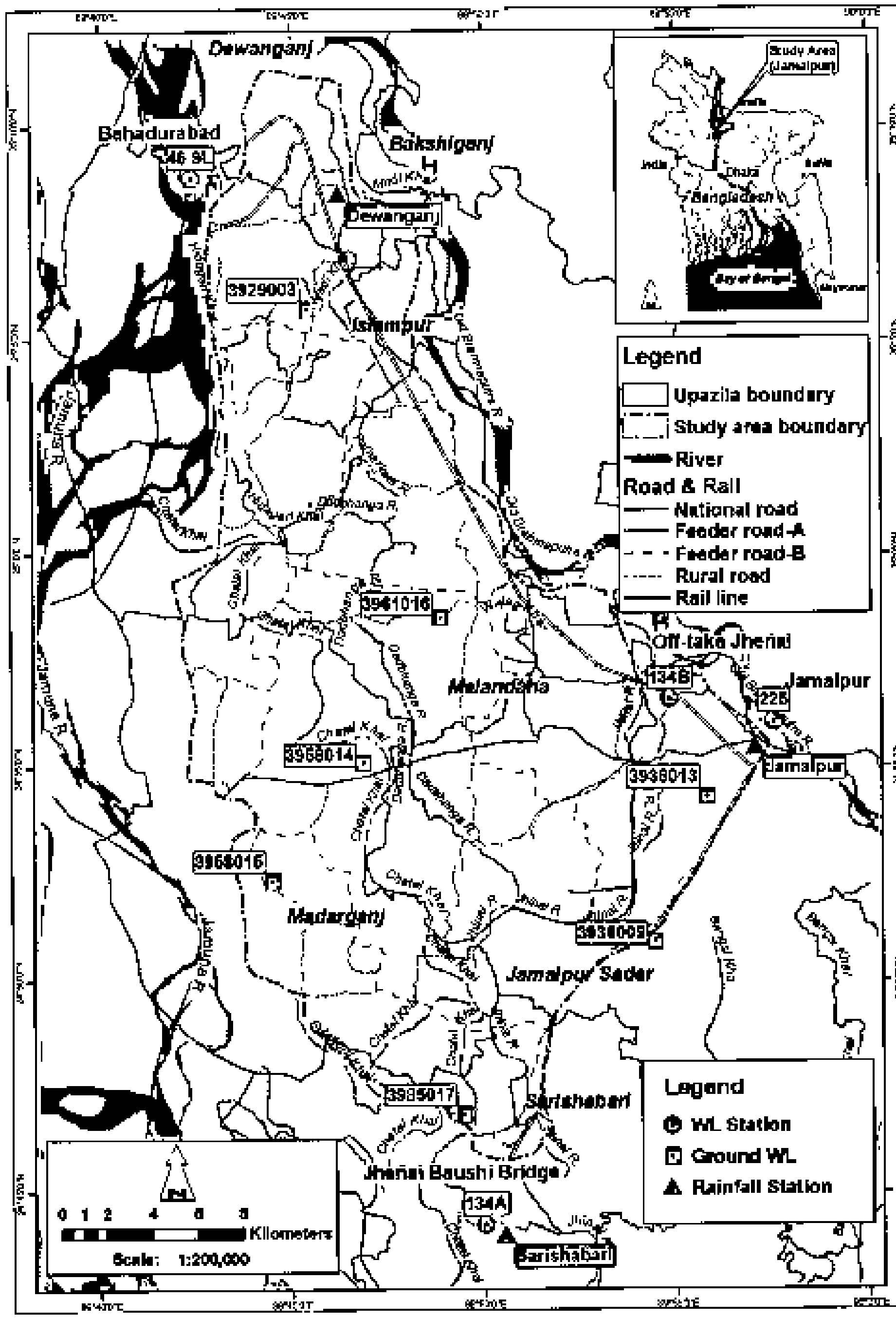


Figure 4.1: Location map of the study area

The topography of the study area has a general gradient from north to south. The elevation varies from 19.8 m to 13.7 m is measured with respect to the Public Works Department (PWD) datum of mean sea level. The maximum elevation of the study area is 20 m, minimum elevations is 10 m and mean elevation is 16.7 m. The topographical distribution of the area which is represented by Digital Elevation Model (DEM) is shown in annex-A. Table 4.2 presents the elevation distribution in the study area.

Table 4.2: Area distribution by elevation in the study area

Elevation (m, PWD)	Percentage of Area
8.48-9.92	0.08
9.93-11.36	0.36
11.37-12.80	0.72
12.81-14.24	2.45
14.25-15.68	17 75
15.69-17.12	40.12
17.13—18.56	29.75
18 57-20.00	7.20
20.01-21.45	1.58

4.1.2 Climate, Hydrology and River System

The climate of the study area is dominated by monsoon. The mean annual rainfall is 2,240 mm, but 90% of rain occurs in six months from May to October and only 2% of rainfall occurs between December to February. The distribution of rainfall according to the cropping seasons is different than that of general rainfall. During the pre-monsoon (Kharif-I) March to June, generally 20-25% of the total rainfall occurs in the study area. From June to October (Kharif-II) most of the heavy rainfall (74-80% of the total rainfall) occurs. The rainfall data was collected through NWRD sources from three rainfall observation stations of BWDB within a close proximity of the study area (see Figure 4.1). These three measuring stations are located at Jamalpur, Sarishabari and Dewanganj with their respective station Id's as 67, 32 and 62. The meteorological station data covers a time span of 1962-2005. Of these three stations, two are located inside the study area and the remaining one is on the periphery of the study area.

The mean annual temperature of the study area is 25°C. The average temperature ranges from 13°C to 28°C between December to February and 18°C to 28°C from April to September. During the Kharif-I period the temperature sometimes rises more than 35°C, while the temperature ranges in the study area during the Kharif-II season is from 25°C to 31°C. The annual evapotranspiration is 1,290 mm with deficit supply of 309 mm during the dry season. Therefore, the availability of soil moisture during the period (from December to February) falls short of crop requirements. There is no evaporation stations located in the study area. Two evaporation stations namely Bogra and Mymenshingh stations data are usually used for this area.

Rainfall and cross-boundary flows of different river systems are the principal sources of water in the floodplains. A portion of precipitation falls on the land and it is lost through infiltration, evaporation and other abstractions. Light boundary of agriculture fields also reserves some rain water from different rivers, particularly from two major rivers, Jamuna and Old Brahmaputra. Remainder of precipitation is received from stream flow that is stored in the study area as surface water reservoir in ponds, rivers, canals, beels and seasonal floodplains; as recharged form in the aquifer and as saturated form in the top soil or as soil moisture. A portion of the ground water flows to stream as base flow.

The hydrology of the study area is complex by nature of its surrounding rivers. The Jamuna and Old Brahmaputra River dominates the hydrological characteristics in the area. Besides these rivers there are several small rivers, seasonal and permanent waterbodies which have also been playing role in hydrological process in the study area. The study area is flat and complex in its flow pattern and sometimes it is difficult to predict the hydrological phenomenon.

Rivers, khals, ponds and wetlands are the main sources of surface water in the study area. And it is mainly used for fisheries, irrigation, domestic use, navigation and commercial purposes. Low lift pump, dhun, swing busket etc. are the most common mode of surface water irrigation. About 26 km^2 area is irrigated by surface water of which 13 km^2 is by low lift pump and the remaining 13 km^2 is by traditional method. A total of 31 Mm^3 of surface water is used for irrigation.

For hydrological data mainly water level and discharge is required for the analysis process. Water level data was collected from four BWDB water level stations. There are four Water level stations within or in the periphery of the study area. Of these four water level stations, two stations (Id 46.9L and 134A) are water level as well as discharge station and the remaining two are water level station. All these stations are maintained by BWDB. The name and Id of these stations are given in Table 4.3.

Water level hydrograph of Bahadurabad station, for the year 1979 is presented in Figure 4.2. (Hydrograph of the other three stations are shown in annex-A). The annual fluctuation between monsoon and dry season for the internal rivers, Old Brahmaputra and Baushi on an average varies up to 5m and that of Jamuna up to 6m which is an external river.

Table 4.3: Name and ID of hydrological data collection stations

Station Name	River Name	Station ID (BWDB)	Remarks
Bahadurabad (Tr)	Brahmaputra-Jamuna	46.9L	Discharge & WL station
Baushi Bridge	Jhenai	134A	Discharge & WL station
Off-take of Jhenai	Jhenai	134B	WL station
Jamalpur	Old Brahmaputra	225	WL Station

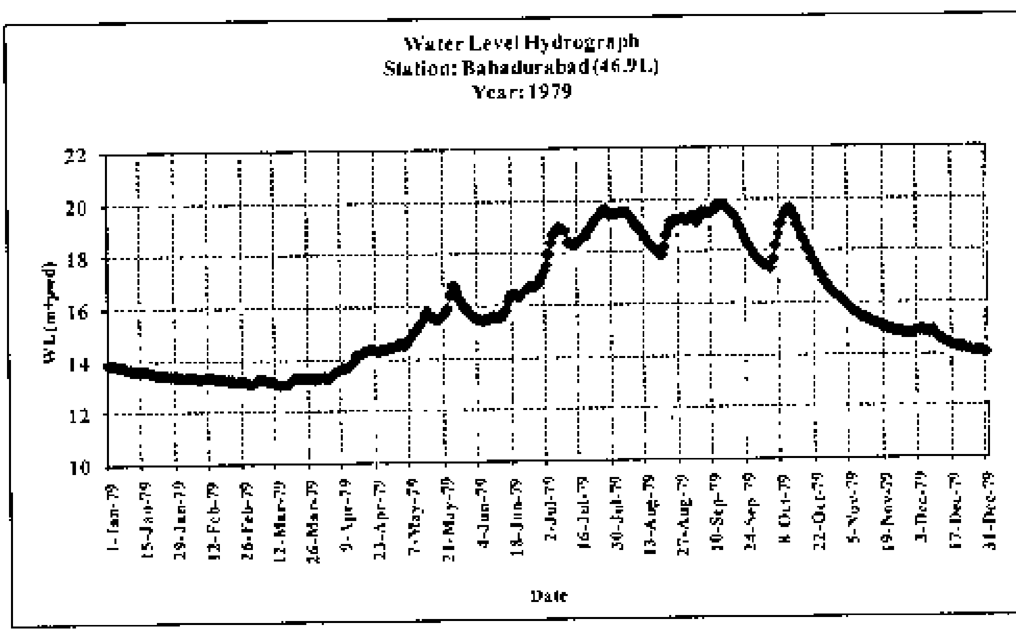


Figure 4.2: Water level hydrograph for Bahadurabad (49.6L) station

The discharge hydrograph of Bahadurabad station for the year 1979 is given in Figure 4.3, (Discharge hydrograph of Baushi Bridge and Mymensingh station are presented annex-A). The data of Bahadurabad and Mymensingh is available, but for Baushi Bridge Station, mainly wet season flow is available. These figures show yearly fluctuation of discharge between dry and wet season. At Bahadurabad station, dry season flow varies between 5,000 and 10,000 m^3/s and wet season flow varies between 10,000 and 66,100 m^3/s. In Mymensingh, dry season flow varies between 50 and 500 m^3/s and wet season flow varies between 250 and 2,600 m^3/s. The peak flow occurs during July to October. The flow at Baushi bridge ranges between 21 and 150 m^3/s.

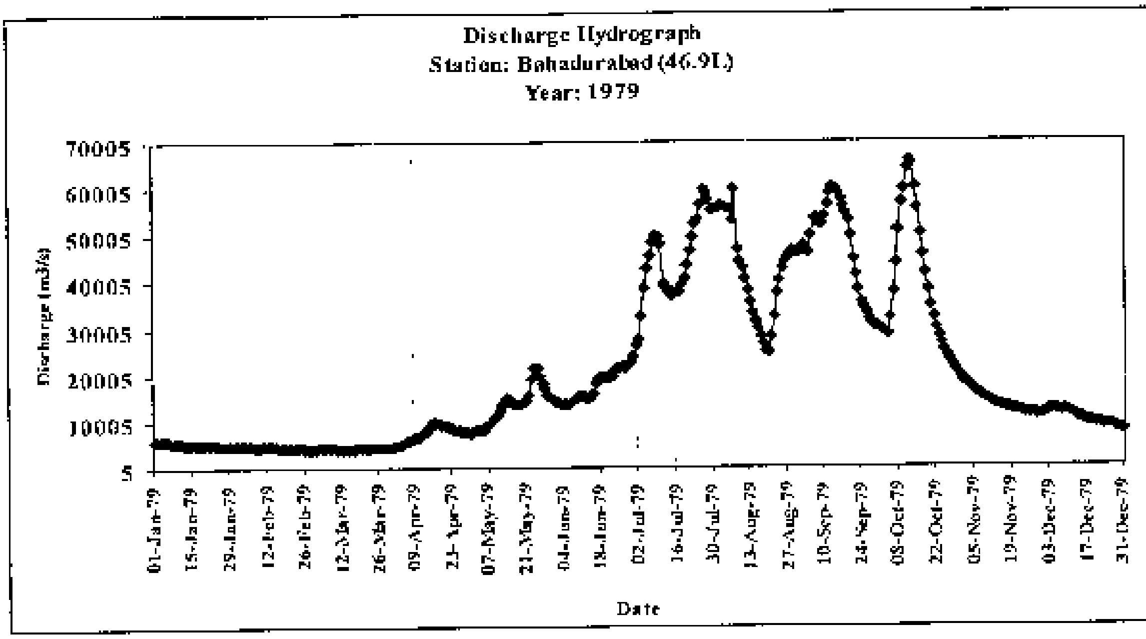


Figure 4.3: Discharge hydrograph of Bahadurabad (46.9L) station, 1979

Ground water is a major source of water, especially during dry season. The sources of ground water are rainfall and flood water. Groundwater is the main source of irrigation and it is also used for domestic purpose mainly as drinking water. Groundwater is abstracted by deep tube-well and shallow tube-well. In 2008, about 304 km^2 area was irrigated by groundwater and the amount of water withdrawal was 365 Mm^3. Groundwater data was collected from six groundwater observation stations. Groundwater level stations along with their ID's are presented in Table 4.4.

Table 4.4: Groundwater level stations with ID

Thana Name	Well Id
Islampur	3929003
Jamalpur Sadar	3936009
	3936013
Madarganj	3958014
	3958015
Melandaha	3961016
Sharishabari	3985017

Figure 4 4 illustrates the time series data of depth of groundwater table for Madarganj Stations (Groundwater depth of other stations are presented in annex-A). The figure shows a wide variation in groundwater table between dry and wet seasons. This variation shows decreasing groundwater table from January, reaching a peak decrease in April and then increasing in wet season. After September, the groundwater table again decreases. This variation is caused by abstraction of water from groundwater table for irrigation. Groundwater abstraction is mainly caused in the dry season and recharge occurs in the wet season. Ground water draw down even 6-7m and it varies from location to location.

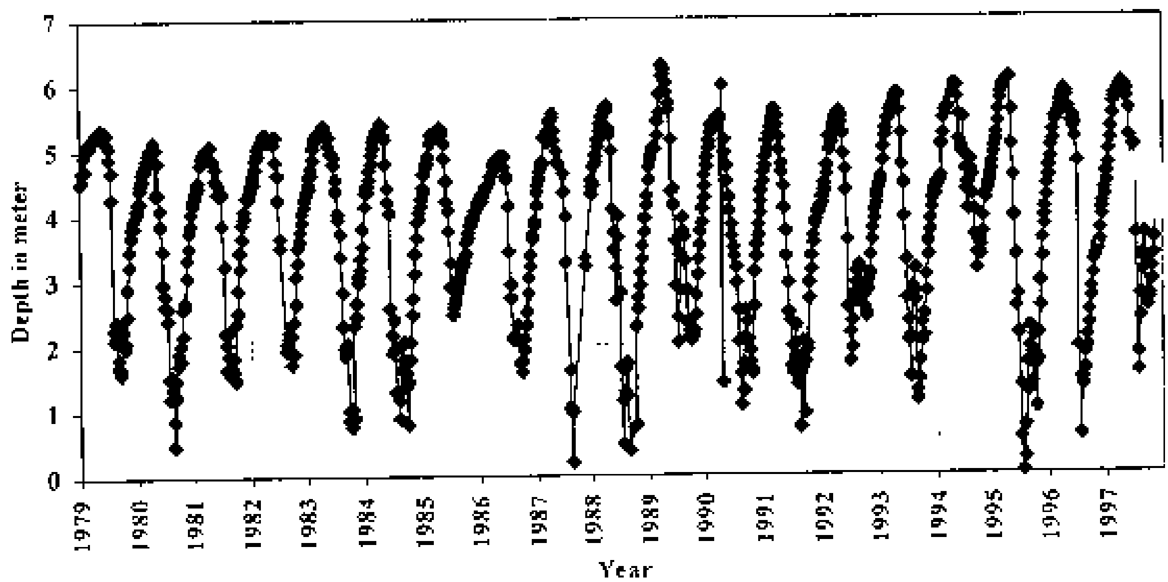


Figure 4.4: Groundwater depth for Madarganj (Well ID: 3958015)

The Jamuna and Old Brahmaputra are the main two rivers dominate in the study area. The Jamuna river is flowing by the west side and the Old Brahmaputra river is flowing by the eastern side of the study area The Chatal, Jhinai and Dadbhanga/Madardaha river which are the distributory of old Brahmaputra and Jamuna river are flowing over the study area. Besides the rivers. a number of khals criss-crosses the area. These rivers and khals play vital role in feeding water to the floodplain as well as in receding floodwater. These rivers and khals play an important role in recharging of groundwater for irrigating croplands, domestic and other usages.

The rivers are also responsible for accumulating floodplain. The study area lies within the Brahmaputra-Jamuna floodplain. On the basis of the relative age of the floodplain, nature of deposits and characteristics of relief, the physiographic unit, the study area has been classified as active floodplain, young floodplain and old floodplain.The study area is under three floodplains namely active Brahmaputra-Jamuna floodplain, Old Brahmaputra floodplain and young Brahmaputra and Jamuna floodplain. Among these three, Young Brahmaputra and Jamuna constitute 47% of the study area. Old

Brahmaputra floodplain constitute 46% of the area and the remaining 7% is under active Brahmaputra-Jamuna floodplain. These floodplains are frequently subjected to flooding from Old Brahmaputra, Jamuna and other internal rivers. The floodplain map of the area is presented in Figure 4.5.

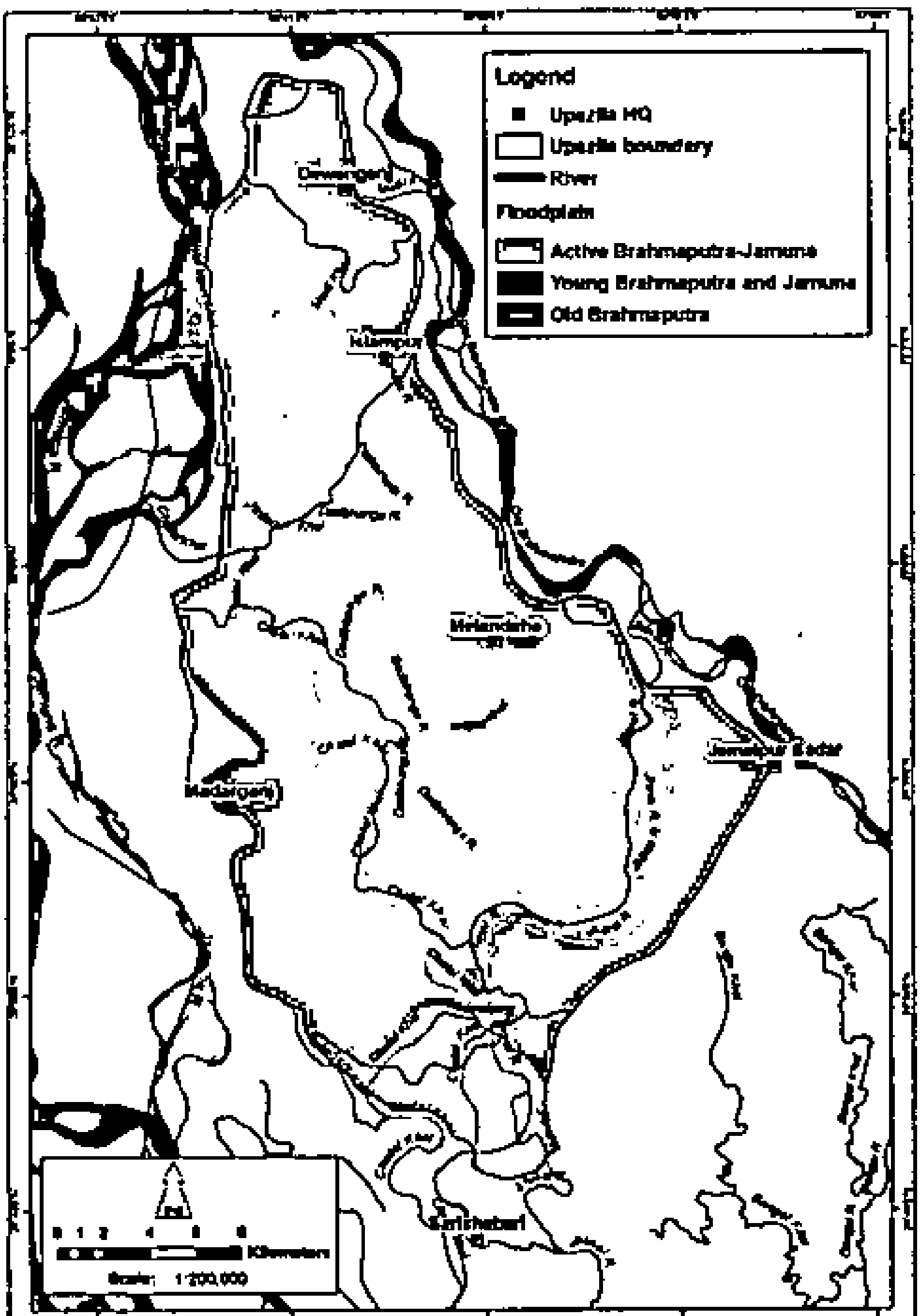


Figure 4.5: Floodplain type map of the study area

4.2 Environmental Settings

Environment and floodplain mainly depends on hydrological characteristics, habitat condition and man made interventions. Floodplain hydrology plays an important role to meet and maintain the ecological requirements of the respective habitats. There are three types of aquatic habitat, rivers, floodplains and beels. The terrestrial habitats include homeland and other habitats.

The natural forests are very few in the study area but public and private afforestation is scattered and increasing over the years. Social forestry is widely practiced in the study area. Roadside vegetation is observed along most of the roads (total length of road is 410 km) conducted under social forestry program. In addition, homestead vegetation is observed in the settlement areas. Homestead vegetation includes two types of plants: those cultivated for their economic value and those that are self propagating. There is no reserve forest in this area. Based on reconnaissance field survey, the afforestation along with roadside vegetation in this area mainly includes mehegoni, babla, akashmoni, shishu, kathal etc. Mehegoni is a dominant species of social forest in the study area. A list of the tree species found in the study area is presented in annex-A.

The wetlands support a wide range of flora and fauna in the study area. The common aquatic flora includes: Hydrilla (*Hydrilla verticillata*), Lotus (*Nelumbo nucifera*), Helencha (*Enhydra fluctuans*), Kalmi (*Ipomoea aquatic*) and Blue morning glory (*Ipomoes fistulosa*). Water hyacinth (*Eichhornia crassipes*) is the single most dominant species followed by Salvinia, Azolla and Lemna. The estimated total area of waterbodies in the study area is 8.5 km^2. There are some big rivers and a numerous khals criss-cross the study area. The length of the river is about 235 km and khal length is about 280 km

The hydrological cycle and the presence of perennial and seasonal wetland provide a diversified habitat for all biota, especially for fish. A more detailed description of the fish populations and species is shown in section 4.5.3. Among amphibians, Skipper frog (*Euphlyctis cyanophlyctis*) and Ornate Microhylid Frog (*Microhyla ornata*) is common and found in most wetland habitat and has been the most successful in adapting to the habitat. The common turtle species found in the project areas are Spotted Flapshell Turtle (*Lissemys punctata*). Common aquatic snakes include: Checkered Keelback (*Xenochrophis piscator*), Striped Keelback (*Amphiesma stolatum*) and Common

Smooth Water Snake (*Enhydris enhydris*). Further, common wetlands bird species available in the study area are Little Egret (*Egretta garzetta*), Little Cormorant (*Phalacrocorax niger*), Indian Pond Heron (*Ardeola grayii*), Common Kingfisher (*Alcedo atthis*), White Breasted Kingfisher (*Halcyon smyrnensis*), Common Snipe (*Gallinago gallinago*). There are few aquatic mammals. There is evidence of the presence of Common/ Eurasian Otter (*Lutra lutra*) and Fishing Cat (*Felis viverrina*).

The external river system in the study area i.e. the Jamuna and old Brahmaputra with a length of 98 km and 50 km on the western side and eastern side respectively. The total length of the internal river in the study area is around 380 km comprising of rivers Jhenai, Chatal and Debdanga/Madardhaw system. The study area consist of different types of waterbodies i.e. lowlands (beels), adjacent floodplains, and ponds. Beels are lowlands which are permanent or seasonal waterbodies and are generally linked through a drainage channel (khal) to another beel and/or an internal river. In the study area 93 waterbodies have been found. The waterbodies of the study area can be classified as permanent beels, seasonal beels and adjacent floodplain. The study area is hydrologically complex and dynamic that the assessment and classification of waterbodies is difficult. The area of beels or waterbodies vary seasonally and also year to year depending upon the nature of flooding which may originate from both river and local rain water. Statistics has been generated taking the length of the river by Thana. The statistics of Thana wise professional fisherman are shown in Table 4.5.

Table 4.5: Thana wise fisherman number and length of river segment in the study area

Thana	Length of rivers (km)	Permanent segment (km)	Seasonal segment (km)	Number of prof. fisherman
Melandah	42	13	29	440
Madarganj	37	23	14	575
Sharisabari	18.5	4.5	14	185
Dewanganj	6	0	6	47
Islampur	24 5	11.5	13	33
Jamalpur	8.5	0	8.5	0
Total	136.5	52.0	84.5	1280

(Source: FAP 3.1, *1997a)*

In the pocket of the seasonal beels, fish can survive during the dry seasons. The fish production of the fisheries by habitats is shown in Table 4.6. It can be observed that floodplain contributes around 180 tons of the total production, where as, in the beel area the production is highest being around 800 tons.

Table 4.6: Habitat wise production

Habitat	Length (km)	Area (ha)	Production (tons)	Production (kg/km)	Production (kg/ha)
Rivers	380	798	60.1	158	74.3
Beels		1550	798.5		514.1
Floodplain		1800	182.4		10.1
Total			1041.0		

(Source. FAP 3.1, *1997a)*

The productivity and biodiversity of floodplain depends on three crucial factors on fisheries, which are, timing and level of first floods into the area, changes in the extent and average depth of flood and changes of duration of floods. Therefore, considering these three factors, it is necessary to develop mitigation alternates.

4.3 Socio-economic Profile

The population of the study area is calculated according to the area proportion of the study area to Jamalpur district. The total population of study area is 6,32,160, of which, 16% live in the urban areas and the rest live in rural areas. This population belongs to 1,43,600 households (BBS, 2006). The ratio of male to female in the study area is 104:100. More than 60% of the population of Jamalpur district lies below the upper poverty line (receives calories 2122) as defined by World Bank (BIDS, 2001). The year wise distribution of population of the study area is presented in Figure 4.6 It is observed that the population of the study area is growing at a rate of 1.18% and the national growth rate was 1.39% in 2008 (BBS, 2006 and BBS, 2008).

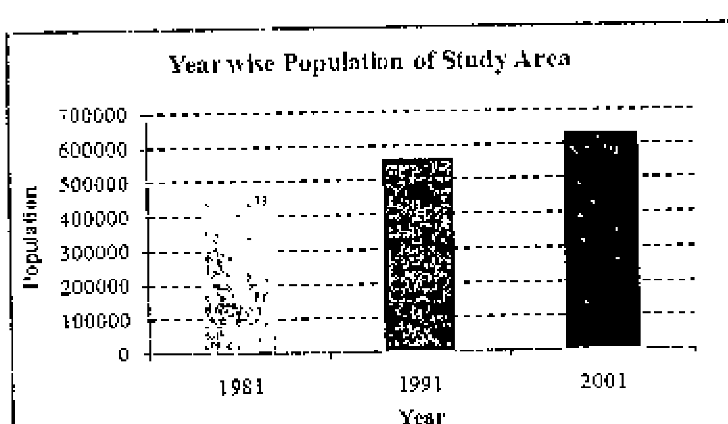


Figure 4.6: Year wise population distribution of the study area

The population of the study area are involved in a variety of employment opportunity (BBS, 2006) which is presented in Figure 4.7. From the figure, it is observed that about 64 % of the population are employed in the agricultural sector. Of which, 40% are agriculture farmers, and 24% are agricultural labour. The other livelihood groups are 12 % in business, 6% are involved in service, 3% are non-agricultural labour, 3% are involved in transportation sector, 1% are involved in fisheries, construction and industrial work and the remaining 9% are involved in activities like handloom, religious work etc.

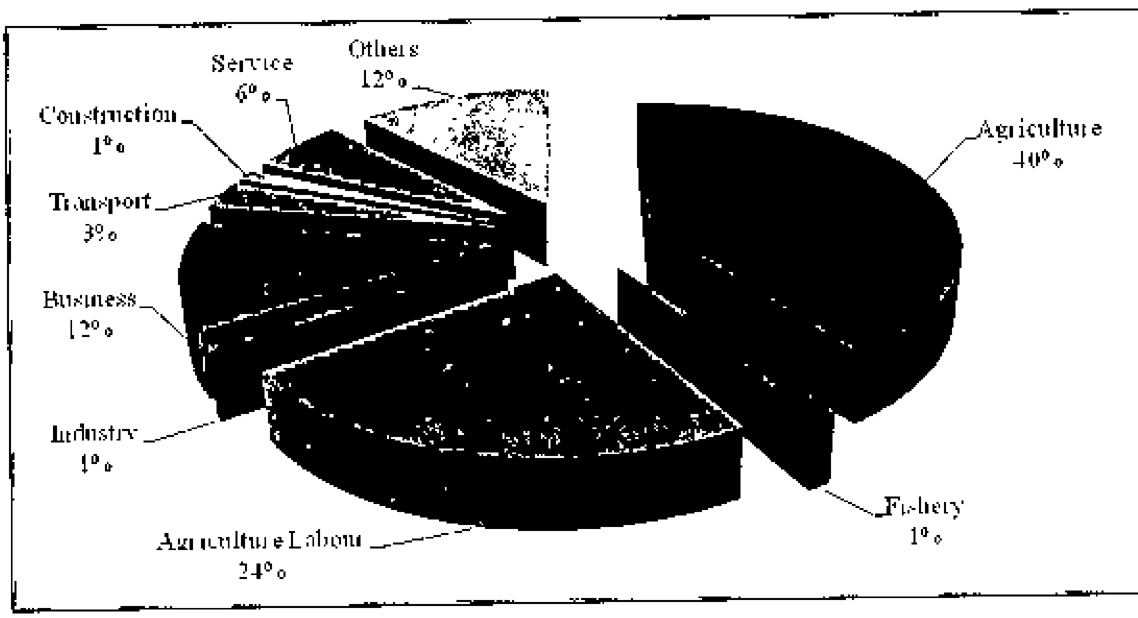


Figure 4.7: Different livelihood groups in the study area

Fisherman of the study area can be categorised as full time, part time and occasional fisherman (Hassan, 2002). A socio-economic pilot survey (FAP 3.1, 1997a) shows that 60% (within 532 sample households) are not involved in any fishing. Only 40% households practice fishing. The distribution of fishing households is shown in Table 4.7.

Table 4.7: Percentage distribution of fishing household type

Household Type	Beels	Floodplain	Rivers
Occasional	47%	41%	12%
Part-time	55%	29%	16%
All	52%	33%	15%

(Source: FAP 3.1, *1997a)*

There are 237 primary schools, 50 high schools, 40 madrasas and 6 colleges in the study area. The average literacy rate is about 32 %. However, the female literacy rate is lower than the male rate (BBS, 2006). Upazila wise numbers of educational institutions are presented in Table 4.8.

Table 4.8: Upazila wise number of educational institute

Part of Upazila under the study area	Primary School	High School	College	Madrasa
Dewanganj	17	7	1	1
Islampur	37	12	1	4
Jamalpur Sadar	33	11	2	2
Madarganj	67			19
Melandaha	76	18	2	14
Sharishabari	7	2	-	-
Total	237	50	6	40

The principal source of drinking water in the study area is tube-well. A small portion of inhabitants of this area use water from other sources, such as, tap, deep tube-well. pond etc. People use river, khal, pond water for their kitchen use and bathing purposes. Statistics show that about 91% of the population uses hand tube-well water, 1% uses deep tube-well water and 8% uses water from other sources like pond, tap. river water etc for drinking water (BBS, 2006). Hygienic condition of an area depends on the coverage of sanitary latrines. Only 18% household of this area use sanitary latrines, 51% use non sanitary latrines and 31% of the household with no latrine facility (BBS, 2006)

Health institutions in the locality, is mainly developed to serve the low-income people. Among the health institutes, some are operated by the Bangladesh Government, some are private and some are operated by the NGO's. The private health centres are expensive than the government operated ones. Pathfinder, USA implemented a project titled "The NGO Service Delivery Project (NSDP)" which surveyed family healthcare facilities in Bangladesh. According to the NSDP survey, there are 6 hospitals and 3 family health care centres in the study area. On the other hand, growth centres, mainly comprises of hats and bazars. Bazars are permanent market places and hats are usually held on once or twice a week. There is 1 growth centre in Jamalpur sadar Upazila, 3 in

Islampur, Madarganj and Melandaha upazila. The details about the health centres and growth centres in the study area are presented in Table 4.9.

Table 4.9: Upazila wise number of health centres and growth centres in the study area

Part of upazila under the study area	Hospitals	Family health care centres	Growth Centre
Jamalpur Sadar	3	1	1
Dewanganj	1	1	1
Islampur	1	0	3
Melandaha	1	1	3
Madarganj	-	-	3
Total	6	3	11

Source: NWRD

Terrestrial road is the principal mode of transportation of goods and communication in the area. The terrestrial roads are categorized into three major types, such as, national, regional and feeder roads. Regional roads are national highways which connects district headquarter. There are two types of feeder roads, A and B. Feeder A roads connects district headquarter with upazila headquarter and feeder B connects upazilas. Rural roads, mainly connects upazilas and unions. The details about the road length of the study area in 1991, 2001 and 2008 are presented in Table 4.10. It can be observed that over the periods road length has been increasing. For example, there is a total of 230 km road in 1991 which became 303 km in 2001 and 410 km in 2008. Besides roads, railway is also an important mode of transportation in this area. There is about 60 km railway lines in the study area. Railway is mainly used for transporting goods.

Table 4 10: Road length according to road type

Road Type	Road Length (km)		
	1991	2001	2008
Feeder road A	45	65	79
Feeder road B	74	103	138
Rural	112	134	189
Regional	0.85	0.85	0 85
Total	231	303	407

4.4 Problems and Issues

4.4.1 Floods

The study area is highly vulnerable to flood. Recent floods, in year 1988, 1995, 1998, 2004 and 2007. has cause lot of damages to lives and livelihoods. The major sources of floods in the study area are over bank flow from Jamuna river and internal river banks. In general, 80% of study area is under seasonal inundation. The north-east border of the study area which is about 20% of the total area is above normal flood level. The central part of the study area is mixed with high land and medium low land, which is subjected to shallow flooding. Around 40% of the area is under moderate to deep flooding, which is located in the western part of the study area. There is a small area which is under deep to very deep flooding. Normal seasonal flood starts in July and generally recede in September. The depth of floodwater in the study area varies from year to year. Nearly every year flooding occurs, mostly caused by over bank spillage of Jamuna river, old Brahmaputra and their distributaries. The regular floods are augmented by local rainfall in the study area. Sometime, this flood may cause major damages. Figure 4.8 illustrates open water extent flooding on three different dates of 1998 monsoon season derived from RADARSAT SCW images.

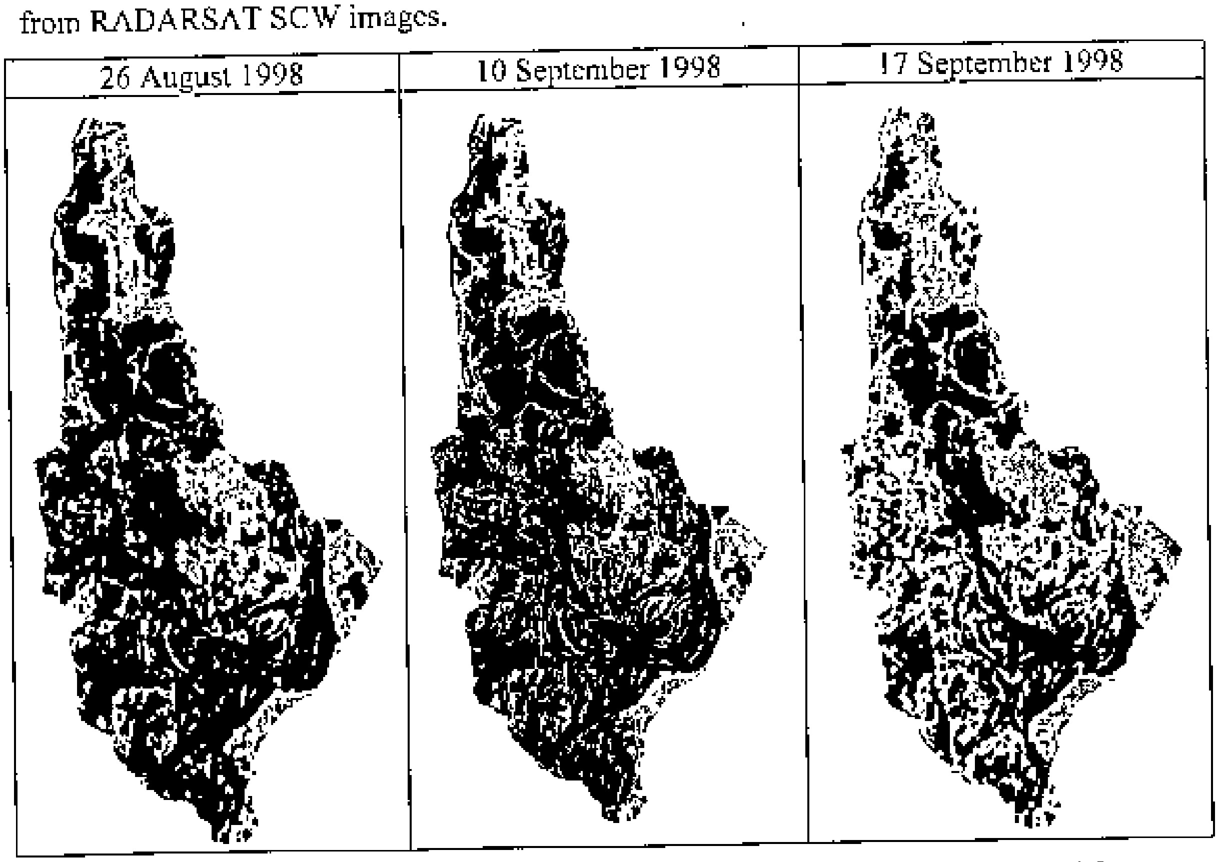


Figure 4.8: Open water extent (flooding) on different dates of 1998 flood derived from RADARSAT SCW image

4.4.2 Erosion

After flood, erosion is the major hazard in the study area. Every year river bank erosion is observed along the bank using time series of RS image for Jamuna and Old Brahmaputra river in the study area. Accretion was estimated in the study area during 1973-83 and found total accretion is much smaller than erosion. It is observed, from 1989 to 2009, about 1,225 ha land has eroded. Of which, about 210 ha was human settlement. This area provided settlement for about 10,000-15,000 people. Due to riverbank erosion they become homeless and had to migrate elsewhere. Frequent displacement is a great cause of poverty in this area. Figure 4.9 shows the eroded area.

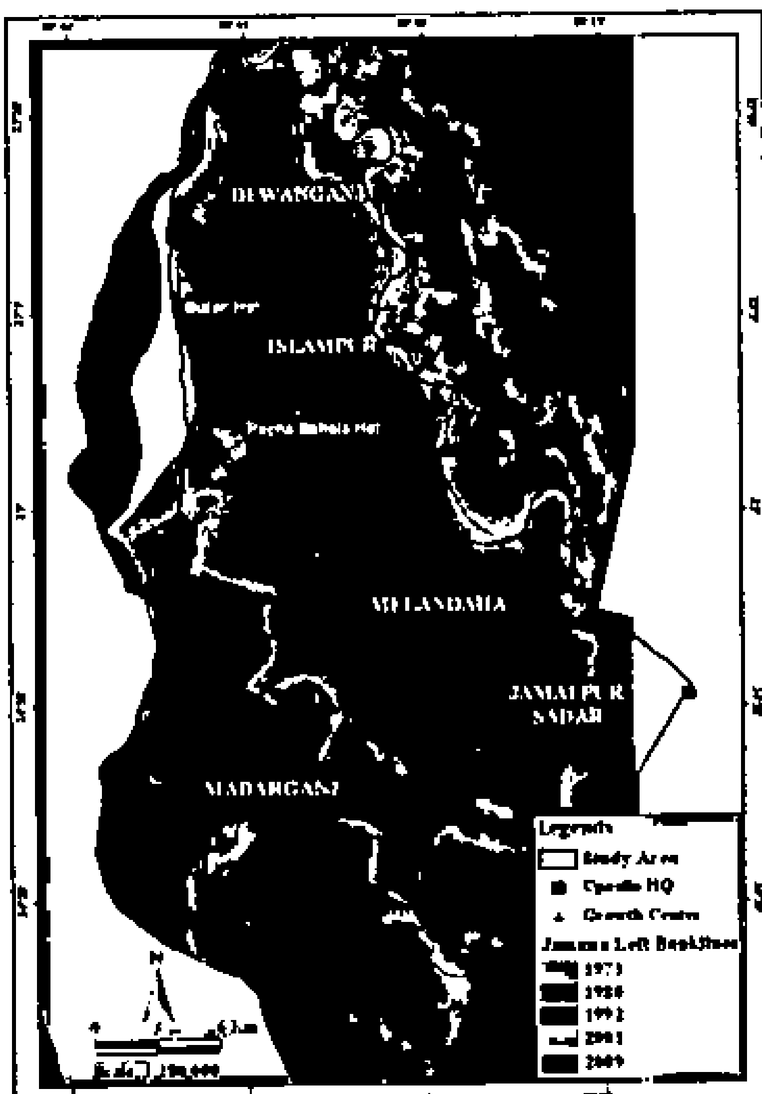


Figure 4.9: Dynamics of Jamuna left banklines

From Figure 4.9, it is found that left bank lines of Jamuna is shifting to the left due to erosion. At Dewanganj, the left bank lines of the river has shifted about 2.5 km to the left. At Pacha Behala Hat, it has shifted about 6 km and at Madarganj about 5 km to the left. However, after 1992, erosion has stopped at Madarganj. From the figure, it can be observed that Gutail hat which is only 70 km away from the river is highly vulnerable to erosion.

4.4.3 Environment

Increasing population and urbanization are creating continuous pressure on land and water resources which leads to degradation of environment. Besides this, due to unplanned and extensive use of fertilizer in crop fields, various types of chemicals are released from industrial production and continuous cultivation of high yielding crops, has caused the degradation of soil quality and pollution in land resources. As population is increasing rapidly, they need more land for human settlement and develop new infrastructure such as roads, markets etc. This land is mainly being converted from agricultural land and wetland. To meet the increasing food demand for the growing population, wetlands are also brought under agricultural production. To grow more crops, fertilizer is used at a higher rate causing degradation of land and waterbodies.

Due to erosion and geomorphological processes, rivers like Chatal, Jhenai and Madardaha often become silted by deposition of significant amount of sediments. In addition to natural processes, manmade interferences like construction of regulators, accelerate the siltation of rivers and tributaries. Off-take siltation hinders fish migration from river to beel and vice-versa. As a result, fish production is declining sharply. So far, in the last decade, 15% to 20% catch per unit effort (CPUE) has been reduced. Between January to May the connectivity remains dry even up to June. This phenomenon hampers the spawning and feeding migration of the carp as well as indigenous species of fish.

Over the years, human settlement and infrastructure, such as road, markets etc. have been increasing. As a result, impermeable area has also been increasing which has not only reduced recharge but also increased overland flow. Because of conversion of wetlands into agricultural land and infrastructure, it resulted in less surface water storage causing an increase in flooding.

Unplanned construction of roads, culverts etc. are causing drainage congestion in the study area. Culverts or other kinds of water passing structures on the roads are inadequate for proper drainage and thus flushing of water is being hindered causing water pollution and degradation of land quality.

The wetlands are being reduced and deterioration of quality of water causes reduction of biodiversity. The natural wetlands are habitat to a large variety of flora and fauna and it plays a crucial role in maintaining the ecological balance Many species of flora and fauna are being threatened resulting in the degradation of wetlands-based ecosystem. As the wetlands, start to disappear fishes become habitat less. Therefore, many fish species are in stress. Table 4.11 depicts the rare and unavailable species of fish in the study area.

Table 4.11: Rare and unavailable fish species in the study area

Scientific Name	Local Name	Local Status	
		Rare	Unavailable
Notopterus chitala	Chital		√
Batasio batasio	Bataiya/Batashi		√
Aorichthyes spp.	Guzi Ayeer		√
Anabas testudineus	Koi	√	
Channa marulius	Gazar	√	
Notopterus notopterus	Foli	√	

4.5 Land and Water Use

Four major types of land use activities are considered in this study. They are agriculture, wetlands, settlement and other use includes infrastructure/commercial use. Infrastructural uses includes land that is used for roads, educational institutes, health centres, growth centres etc. The percentage of land used for these four purposes are presented in Figure 4.10. From the figure, it is observed that about 78% of the land is used for agriculture, 16% for settlement, etc.

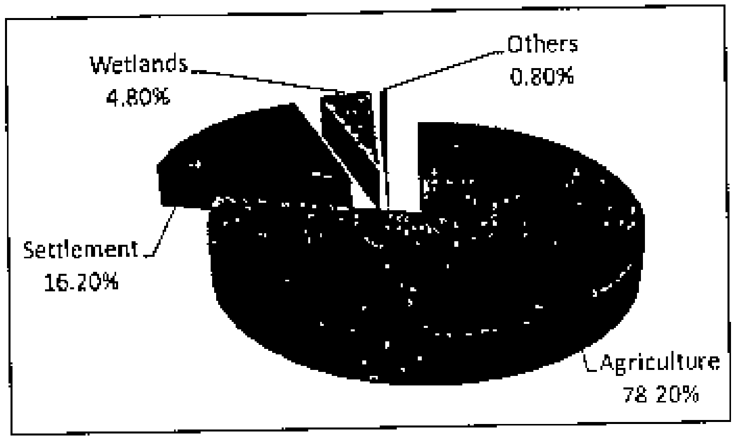


Figure 4.10: Major land use activities in the study area

Agriculture being the principal land use in the area, its activities consists predominantly of rice production in the varieties Boro and Aman, where the varieties are local and high yielding types. However, farmers generally grow two crops a year in the medium highlands (Boro and Aman) and a single crop (Boro) in the lowlands. In 2001 the total NCA was 47,819 ha, of which, total Aman area was 24,981 ha and total Boro area was 28,181 ha. In 2008, although the total NCA declined but individual crop area has increased being 25,258 ha and 31,775 ha for Aman and Boro respectively. The other important crops which grows in the study area are jute, wheat, mustard, sugarcane, potato, pulses, vegetables and spices. The main rice crops Aman and Boro grows in monsoon and dry season respectively. The study area is well known for its high quality jute production. Mustard has also been cultivated in the study area as a major oil seed crop.

The present area of wetlands (permanent waterbody) is 7.78 km^2. In 2001, there was 8.5 km^2 of beels, which has been reduced to 7.9 km^2 in 2008. Wetlands are essential ecological features. They are primary habitat for hundreds of species of fish, waterfowl as well as many other birds, mammals and insects.

The area of total settlement in the study area is about 99 km^2. Of which, about 19 km^2 is urban settlement and 80 km^2 is rural. Other uses of land include, land used for roads, infrastructures such as schools, colleges, markets, hospitals etc.

Water is mainly used for irrigation, domestic purposes, fisheries and commercial purposes as shown in Figure 4.11. From the figure, it is observed that irrigation use alone accounts for 92% of use, fisheries is 3.5% and domestic sector uses another 3.8%.

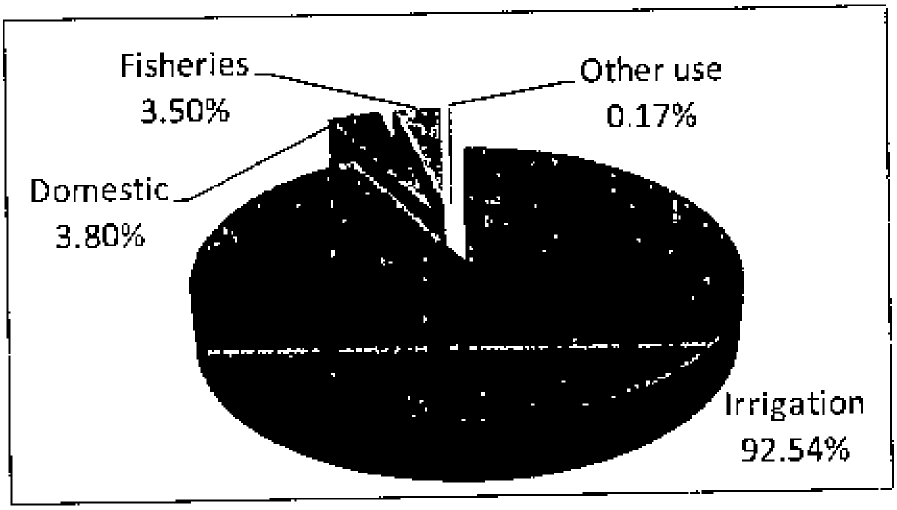


Figure 4.11: Major water use activities in the study area

Agriculture is the predominant economic activity in the study area and a main user of water. According to 2008 statistics, there are 451 km^2 of cultivable land in the study area, of which, 318 km^2 are irrigated land. Irrigation is carried out by different means such as Low Lift Pump (LLP), deep tube-well, shallow tube-well, hand tube-well, khals and traditional method (doons, swing baskets and others). Shallow tube-well is mainly used for irrigation, which irrigated 265 km^2 of agricultural land. The irrigated area in the study area according to the modes of irrigation is presented in Table 4.12.

Table 4.12: Irrigated area in the study area under different means

Mode of Irrigation	Irrigated Area (km^2)
Deep tube-well	25.2
Shallow tube-well	265.1
LLP	12.5
Traditional	15
Total	317.8

Domestic water uses include water used for drinking, cooking, washing, bathing etc. hand tube-well is the principal source of domestic water use. Fisheries are an important resource of the study area. Four types of fish production system exists in the study area. They are riverine fisheries, floodplain fisheries, beels and culture fisheries. Among the other uses of water include, water used for commercial purposes, such as, water used in the industries, growth centres etc. Some industries are operating in the study area but there is no data available on water use of those industries.

4.6 Socio-economic Survey Findings

In the study area, agriculture is the main source of income and farmers are the major livelihood groups. Dry season crop (Boro) and wet season crop (Aman) are considered as the main sources of income for farmers. Farmers are also classified as landless and landowner The land use dependent livelihoods are divided into six occupational groups. They are: landowner farmer, landless farmer, fisherman, wage labour, industry workers and workers in the transport sector.

Focus group discussion (FGD) was used as a tool to explore the socio economic data. The population in the study area are involved in diversified professions from farmer to rickshaw puller, from day labourer to carpenter etc. But for this research, land use dependent different occupation groups have been identified and six major occupation groups were selected for FGD. The study area comprises of five upazilas (shown in Table 4.13). In every upazila, one FGD was conducted on each occupation group. Some basic information was collected, such as, present status of basic needs and requirements, income and expenditure profile of each occupation group and season wise employment opportunity.

Table 4.13: Upazila wise list of FGD in the study area

Date	Place	Number of Participants
10.12.2009	Village: Nangla, Union: Nangla, Upazila: Melandaha, Jamalpur	38
13.12.2009	Village: Gila Bari, Mouza: Belgachha, Union: Chinaduli, Upazila: Islampur, Jamalpur	33
18.12.2009	Village: Paschim Tartapara, Union: Balijuri, Upazila: Madarganj, Jamalpur	34
12.02.2010	Village: Char para, Union: Mesta, Upazila: Jamalpur Sadar, Jamalpur	32
14.02.2010	Mondol Bazar ,Village: Kazlapara, Mouza: Kazlapara Union: Chikajani, Upazila: Dewanganj, Jamalpur	36

Key informants interview technique was also used to collect information on current agriculture practices, industries and growth centres in the study area. Key informants were selected randomly, who provided detailed information based on his or her knowledge and experience of a particular issue.

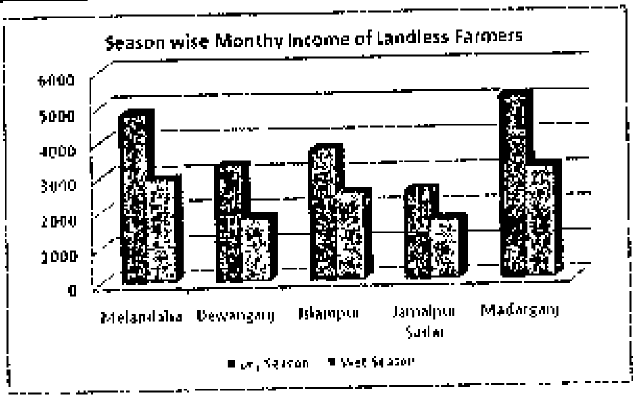
To find and validate the variations in the socio-economic data collected through FGD, some household survey was conducted in the study area Depending on the selected occupation, the samples for household survey were selected. The questionnaire used for household survey is given in annex-B.

4.6.1 Income and expenditure profile by different occupation

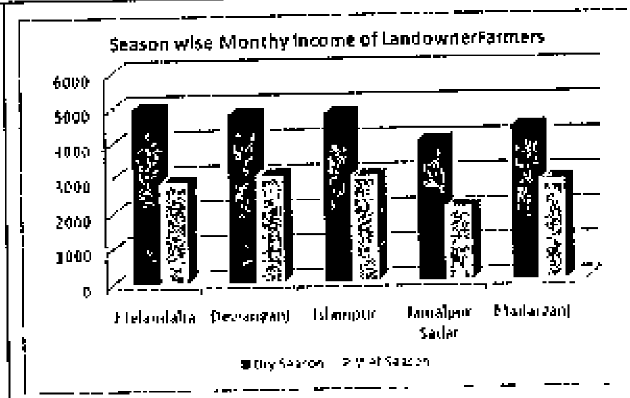
Upazila wise yearly income of different occupation groups are presented in Figure 4.12.

It is observed that income of farmers varies according to season. Income is higher in dry season than in the wet season. In dry season, landless farmer's income may vary from 3,000 Tk/month to 5,000 Tk/month while in the wet season, their income declines to 1,700-3,200 Tk/month. Fisherman's annual income is highest in Melandaha upazila (42,000 Tk) and lowest in Dewanganj upazila (14,000 Tk). Industrial workers annual income also varies between upazilas. It may vary from 24,000 Tk/year to 36,000 Tk/year. Wage labours and industrial workers income is almost equal in all upazilas.

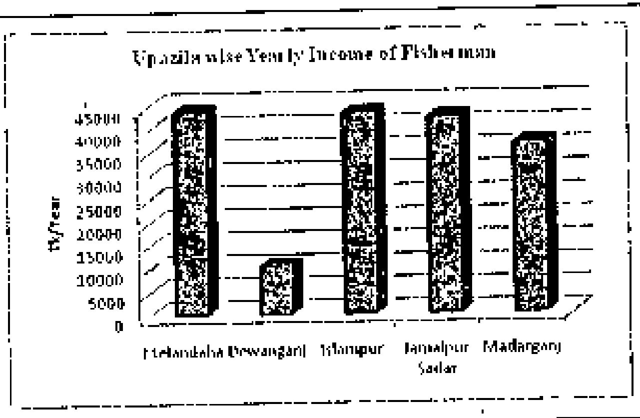
Expenditure profile of different occupation group is almost similar (Figure 4.13). Food is the main item on which the household of all categories spent their major share of earnings. It is observed that the households spent around 60 percent of their income on food Further, this expenditure on food depends on family size, age of family members and the income of households. Besides food, other household expenditure includes, shelter/housing, clothing, health, education, transport etc.



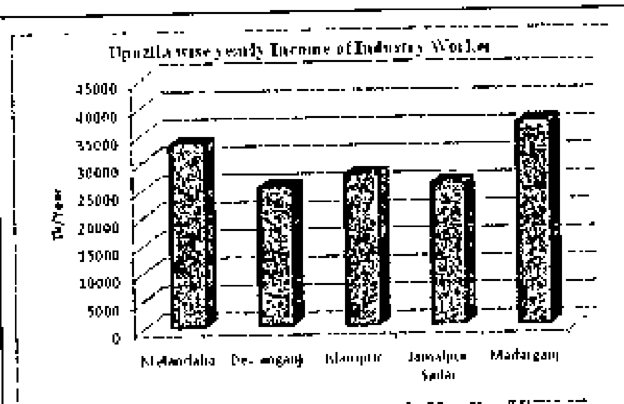
Upazila wise monthly income of landless farmers



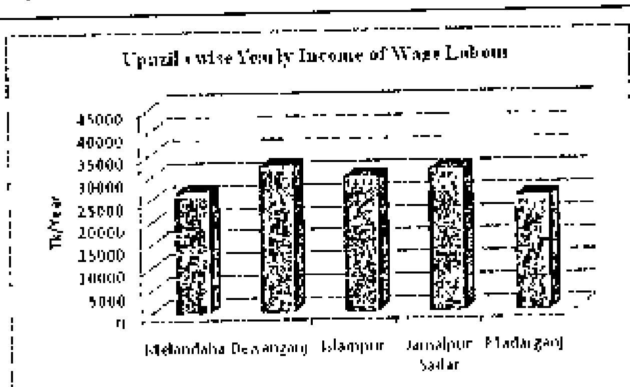
Upazila wise monthly income of landowner farmers



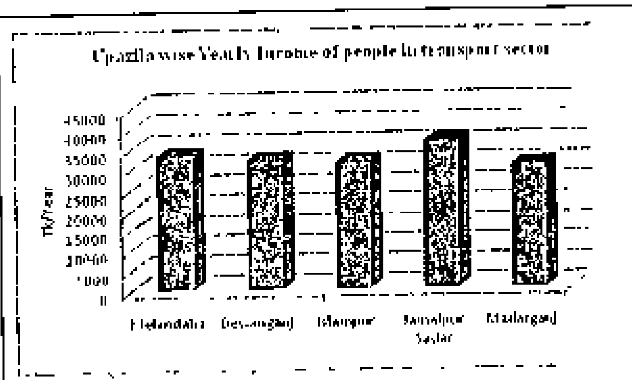
Upazila wise yearly income of fishermen



Upazila wise yearly income of industry worker

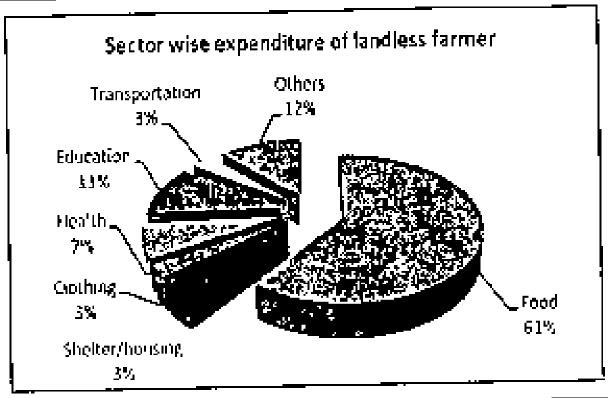


Upazila wise yearly income of wage labour

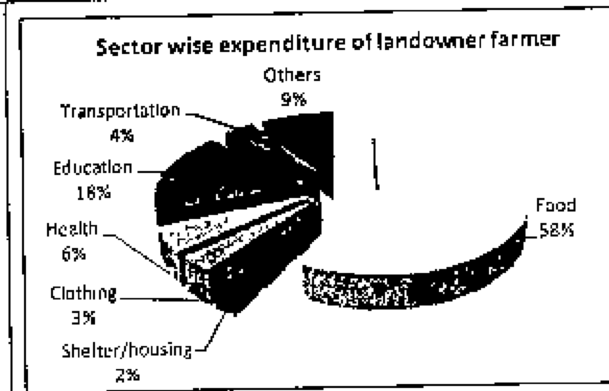


Upazila wise yearly income of population in transport sector

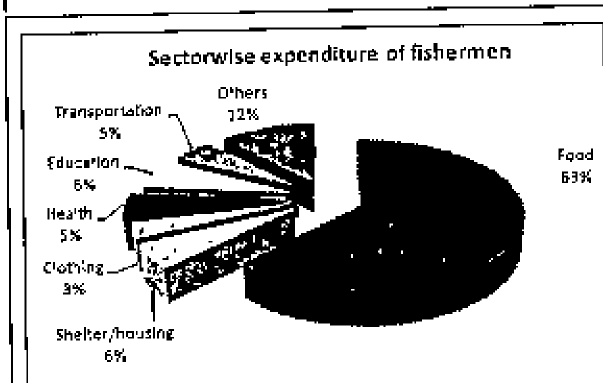
Figure 4.12: Upazila wise income profile of the selected occupation groups in the study area



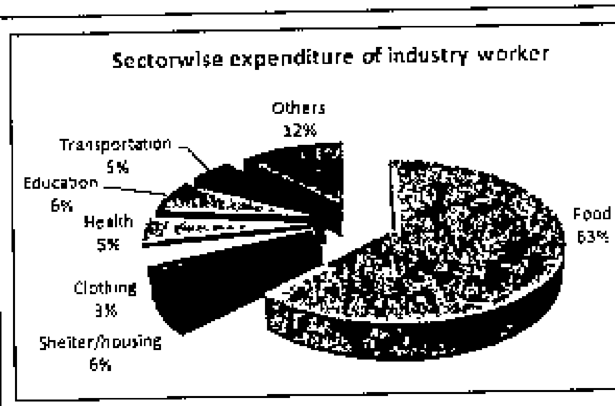
Landless farmer



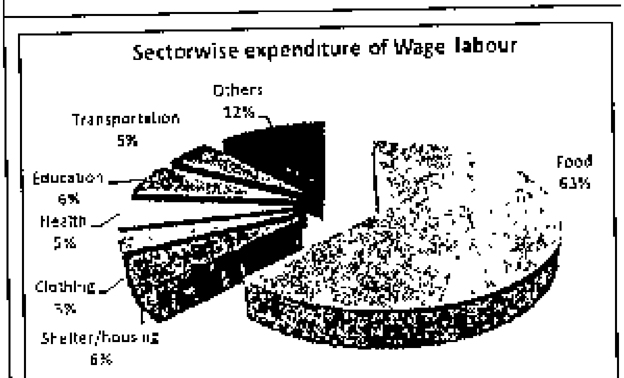
Landowner farmer



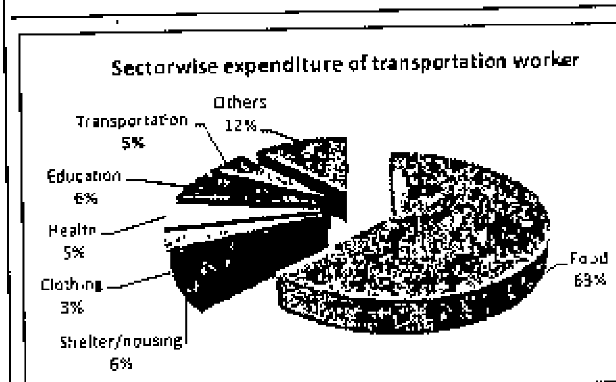
Fisherman



Industry worker



Wage Labour



Transportation worker

Figure 4.13: Sector wise expenditure profile of different occupation group

4.6.2 Assessment of basic needs

Foods, cloths, shelter, health, education, etc. are considered as basic human needs. In this study, current consumption and requirements of food (rice, fish and water), living space of the population of the area were collected. According to FAO standard, per capita cereal requirements per day is 397 gm, but our national average consumption of rice is 460 gm/capita/day (BBS, 2006). The per capita rice consumption in the study area is shown in Figure 4.14. From the survey, it is observed that only 10 percent of the population consumed less than 397 gm/capita/day and 20% of the population were found below current national consumption.

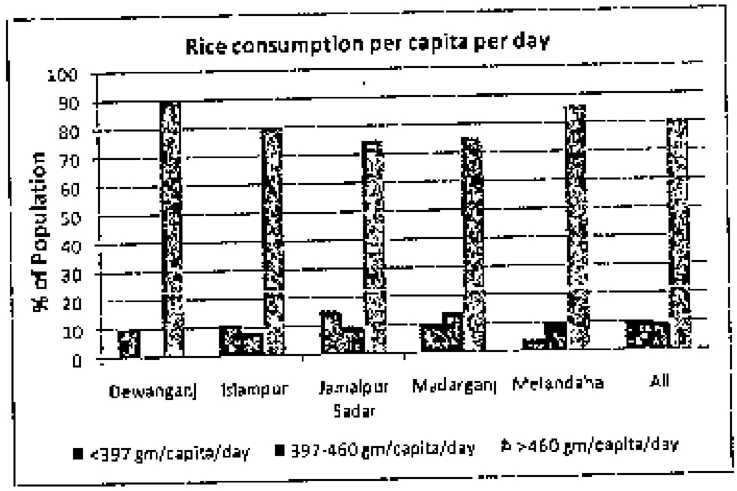


Figure 4.14: Distribution of population against the rice consumption standard

Fish provide the main source of animal protein in Bangladesh. Fish also supplies other essential nutrients to reduce malnutrition in urban and rural areas. It can be inferred from Figure 4.15 that the current state of fish consumption in the study area is not satisfactory. Average fish consumption in the study area is lower than both the national average of 37g and international requirements of 49g (Hossain, et al., 2008). Further, it is observed that, 44 % of the population in the study area are below the national average and 53 % of the population cannot meet the international standard.

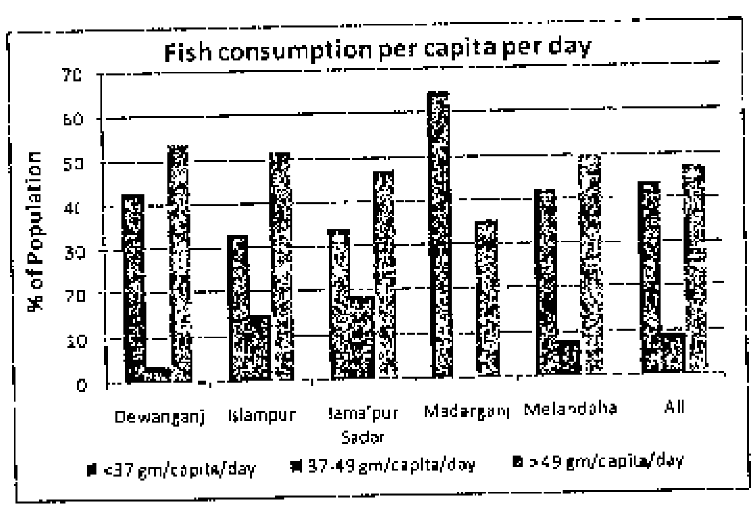


Figure 4.15: Distribution of population against the fish consumption standard

Access to sufficient and safe drinking water is a basic human right. The survey findings reveal that in terms of quantity, people are getting sufficient amount of water for drinking. Tube-well is the principal source of water for drinking and other use. Though, some people are taking water from ponds and other sources for drinking and their daily uses. So quality of this water source is not ensured for all population in that area.

In developing countries the standard living space per person is 120 ft2 (Chiara, & Callender, 1973). The survey revealed that in the study area only 16 % of the population are living with more than 120 ft2 space as shown in Figure 4 16.

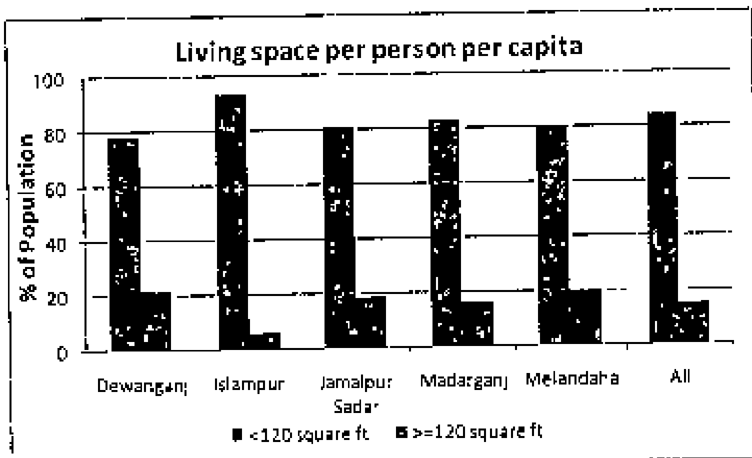


Figure 4.16: Distribution of population against the living space standard

4.6.3 Land utilization for commercial purposes

Agriculture is the major land use in the area. Besides agriculture, a small portion of land is used for commercial purposes such as brickfield, poultry farming, rice mill, markets, and industries etc. The details of the industries in the study area are presented in Table 4.14. Some of the very common types of industries are surveyed to determine how much land is occupied by each type of industries, how much input (water) is used, how many people are employed and the seasonality of operation. Detail of the survey finding are presented in annex-C.

Table 4.14: Upazila wise number of industries

Thana	Brick field	Closed brick field	Rice mill (auto)	Rice mill (normal)	Poultry farm	Fish hatchery	Saw mill	Milk vita	Ice cream
Dewanganj	1	0	0	2	0	0	5	0	1
Islampur	1	0	4	13	0	0	10	1	2
Jamalpur Sadar	0	0	1	5	1	0	5	0	1
Maderganj	3	2	4	7	7	1	18	0	5
Melandaha	8	4	8	52	5	2	34	0	6
Total	13	6	18	79	12	3	72	1	14

Rice mill is common in the area. Five rice mills were surveyed in the study area and it has been observed that two types of rice mills are operated. One is auto rice mill and the other is non-auto rice mill. Non-auto rice mills are very common. The list of the surveyed rice mills are shown in Table 4.15. Usually rice mills operate from February-October month and it remains almost closed from November-January. It has been observed that almost 80% of the work is conducted within these 8-9 months.

Table 4.15: Details about surveyed rice mills

Name of Industry	Location	Area	Rice Prod.	Labour input (Man-year)			Water use	Electri cost
		ha	ton	Permanent	Temporary	Total	litre	Taka
Mrs Broti Rice mill	Jamalpur Sadar	0.61	1034	3.89	21.52	25.41	35000	2925
Milon Auto Rice milling plant	Melandaha	0.61	3011	2.51	66.62	69.13	4000480	6300
Nobab Auto Rice milling plant	Islampur	0.34	591	3.63	20.48	24.11	800000	1620
Alal Rice mill	Dewanganj	0.14	46	1.25	6.30	7.55	4500	234
Salim Rice mill	Madarganj	0.49	266	1.99	16.78	18.77	514286	4675
Average		0.438	989.6	2.66	26.34	29.0	1070853.2	2267

Usually auto rice mills can produce three times more than the non-auto ones. With an increasing land area the production of rice mill increases but at a decreasing rate. The average production from all the rice mills accounts around 1,000 tons. Rice mills provide a wide range of employment opportunities. A rice mill with half a hectare land area usually provides employment for 35 people Of which, only 3 or 4 people work permanently and the rest are seasonal workers. Among the workers, a significant number is women. A discrepancy is observed between male and female workers wages. Females get less wage than a male worker Usually male workers wage vary from120-160 Tk/day where as, female workers wage vary from70-100 Tk/day. Employment is also related to production. It shows that for producing per 1000 tons of rice, on average 40 man year is needed. Of which, only 5 man year is permanently employed and the rest 35 man year is employed seasonally. Water is used for paddy processing to produce rice. It shows that on average, for producing per 1000 MT of rice 15000 Mm^3 of water is used.

There are approximately 24 brick fields in the study area. They produce million of bricks annually and thus meet the demand for construction material for buildings and streets. In this study, five brick fields were surveyed from four upazilas. The name of the brick fields along with their location and area are given in Table 4.16.

Table 4.16: Details about surveyed brick fields

Name of industry	Location	Area	Brick Prod	Labour input (Man-year)			Soil use	Water use
		ha	million	Permanent	Temporary	Total	m3	litre
Badsha Brick Field	Melandaha	2.13	3 8	12	68.9	80.9	8495	1425
Sadia Brick Field	Jamalpur Sadar	0.61	2	7	60 75	67.75	4248	720
RLB Brick Field	Dewanganj	0.81	2	7	63	70	2830	750
Rxx Brick Field	Madarganj	1.62	1.5	5.4	58	63.4	4200	650
Bashona Brick Field	Madarganj	1.6	2.5	12.76	64.4	77.16	4000	1312
Average		1.354	2.36	8.83	63.01	71.84	4754.6	971.4

The majority of brickfields are located along rivers since boats deliver soil and fuel. Production time in a brick fields is 5-6 months per year. On average 0.75 hectare of land is needed to produce a million brick About 70 man-year is working per hectare. Of which, only 10 man-years is permanent and the rest 60 man-year is required temporarily. For producing per million of bricks 55 man-year is needed. Soil and water are the main inputs in brick production. For producing 2 millions of bricks 4,000 m3 of soil and 1,000 l3 of water is used.

For the past decade, poultry farming has been one of the fastest growing and most promising sector that has contributed significantly to the Bangladesh economy. Poultry sector is playing a vital role in the reduction of poverty, malnutrition and unemployment problems of our country. There are 21 poultry farms in the study area. The details of six poultry farms, that have been surveyed, are shown in Table 4.17. The average production value from the farms accounts for about five lacs taka and the required labour input is 4.92 man years.

Table 4.17: Details about surveyed poultry farms

Name of the farm	Location	Area	Prod. Value	Labour input (Man-year)			Water use
		ha	Taka	Permanent	Temporary	Total	litre
Jarip poultry farm	Islampur	0.05	303750	1.2	1.2	2.4	3900
Bhai Bhai Agro poultry farm	Islampur	0.61	1417775	6	3	9	54000
Khan poultry farm	Melandaha	0.40	570500	3	2.7	5.7	2415
Lal Miah poultry farm	Madarganj	0.02	116000	1.5	2.9	4.4	3420
Parul poultry farm	Madarganj	0.02	60000	1.65	1.45	3.1	2000
Average		0.221	493605	2.67	2.25	4.92	13147

Two types of growth centres are found in the study area: hat, which is held once or twice a week and bazar which opens every day. Six bazars were surveyed in this study. The average sale per day from these growth centres are nearly three lacs taka The details about the growth centres are shown in Table 4.18.

Table 4.18: Details about the growth centres

Upazila	Name	Types	Area (ha)	Number of Shops	Employment	Sale/day
Dewanganj	Kamarbari Bazar	Regular	0.13	24	30	80000
	Maulvibazar	Regular	0.13	32	40	50000
Melandaha	Fulkocha Bazar	Regular	0.27	30	44	100000
	Adra Bazar	Regular	0.81	50	35	100000
Madarganj	Gabergram Bazar	Regular	0.95	30	65	1000000
	Amritala Bazar	Regular	0.41	25	50	400000
Average			0.448	31.83	44	288333

Growth centres provide a wide range of employment. However, the number of employment depends on the number and the size of shops. Usually per day 500-1,200 people gather in every hat/bazar. It is observed that people from 4-5 km distance also come to the hat/bazar. These hat/bazars are the main place of buying and selling of products.

4.6.4 Conflict and preferences of land and water use activities

The fishermen of the study area want some protection of water against its use for irrigation. They also want to keep at least the present area of wetlands without further degredation. The restoration of wetlands is also possible since most of the wetlands are khas land. Over the years, these common resources have become private property. Even the wetlands owned by government are being grabbed by landlords.

Most of the roads lack enough opening, and as a result, during the monsoon road act as a barrier to reach water from the river to the beels and hinder drainage of water. They want to improve the quality, connectivity and functionality of the wetland.About 20 years ago, water used to be retained in the beels and khals till March. But now, water level in the khals, beels are declining due to extraction of water for irrigation by deep tube-well and shallow tube-well.

The local population have complained that over usage of fertilizers in the crop field is causing water pollution in the nearest waterbodies. As a result, fish and other aquatic organisms are becoming endangered. In Dewanganj upazila, Panifal (a special kinds of fruit) is cultivated in the waterbodies. But panifal requires fertilizer for its growth After application of fertilizer on that waterbodies fish mortality rate has increased.

Farmers want to convert the wetland into agricultural land. According to them most of the wetlands are already silted and fish is not available in the wetlands. Both farmers and fishermen want augmentation of water in the rivers and khals during the dry season. They want immediate dredging of rivers and khals. Presently, there is no mechanism to manage this common property resources. The government should take an initiative for better management of these resources with community participation.

The local population do not want to increase the road length anymore because they do not want to lose agricultural land. They want to increase the capacity of the roads by widening the roads and reduce the flood risks of the roads by increasing the road height. They suggest that feeder type B road can be converted to feeder type A, feeder type A can be converted to regional roads and regional roads can be converted to national roads. It is also important to reduce the flood damage of these roads by creating more opening in them. In this regard, local people have suggested that pipe culvert can be installed after every 100-150 metre on the road. The people also recommended roadside tree plantation for economic and environmental perspective.

Smoke from rice mill and brick field creates pollution contributing towards health hazards. Brick fields burn tires usually during night, which releases bad smell. Bad smells are also released from poultry farms. Sometimes hatcheries drain out excess water to the nearby field that damages the standing crops in the field. Saw mills are usually located along the side of rivers, khals and near growth centres. It creates noise pollution. So people are reluctant to have saw mills near a settlement. According to the local population, industries should be set up in places which are away from the pourashava, distant from human settlement and good communication access. Unfortunately, concerns of local population are never considered in deciding to set up industries.

Usually people want to stay where they are. But when it is not possible to remain in the existing settlement or expansion of existing settlement, people choose suitable land for new settlement based on the criteria like; close proximity (100-150 metre) from the existing settlement, high land and preferable agricultural fallow land (land remains fallow in the Boro season), 250 metre close proximity from the nearby roads etc. Usually people do not build settlement in an open field. One possible reason is that they feel insecure in an isolated place. Moreover, building settlement in an open place also creates some problems to the neighboring cropland. Such as their chickens might damage the crops, trees of the homestead might create shadow on the nearby crop field.

In the survey conducted, some responders stated that about 10-15% of cultivable area remains water logged during monsoon. If the drainage systems can be improved then additional areas can be brought under Aman cultivation. One of the major problem of Aman cultivation is its dependence on rainfall for cultivation. But rain water cannot fully meet the water demand for Aman crop. Therefore, dependency on rainfall should be reduced and supplementary irrigation facility should be provided for better production. People have started practicing supplementary irrigation facilities and they are getting better production. Therefore, Aman is vulnerable to both flood and drought. In the FGD, none talked about controlling flood. The participants stated that they need water without sand in the monsoon, irrigation facilities when it is required and good drainage to convert more land to Aman production.

Access to good seed and electricity is a major problem for Boro cultivation. Although, some of the farmers collect seed from BADC but do not get expected production. As access to electricity is limited, irrigation cost is high. The farmers do not have any problem regarding fertilizer. The farmers want agricultural extension officer to visit regularly and advise them to get better production. The farmers also do not face any problem regarding tube-well irrigation. But LLP users have problem as rivers and khals are drying up. The farmers were asked what they will do if they need more production as population increases. The farmers realized that horizontal expansion is not possible, therefore, they would like to go for vertical expansion. One agriculture extension officer recommended that hybrid and super hybrid is the way to increase agricultural production. A group of farmers suggested for wetlands and river banks to be converted to agricultural land.

4.7 RS and GIS Data

Remote sensing (RS) and Geographic Information System (GIS) can play a fundamental role in assessing land and water resources. Remote sensing offers the advantage of analysing long term (years to decades) temporal and spectral data sets over relatively large regions (local to global scale) and thereby monitor the temporal, spectral and spatial variations of objects at the earths surface (Baumgartner et al., 1996). On the other hand. GIS technology can provide resource managers and decision makers with tools for effective and efficient storage and manipulation of remotely sensed information and other spatial and non-spatial information (Estes, 1992). RS data coupled with conventional data (e.g. hydrological, climatological, topographical etc.) within a GIS framework give a digital representation of the temporal and spatial variations of selected variables and can serve as input to various analysis tools.

The following sections illustrate the GIS and RS data layers used in the study and the methods used to derive the data layers from available RS images.

4.7.1 RS data

Remote sensing data includes satellite images of different category and date. Two types of RS data have been used in this research from CEGIS archive. These are: optical and radar images. The available RS data of CEGIS archive covering the study area is listed in Table 4.19. The optical images are effective for identification of land use for agriculture, settlement, rivers, wetland etc. during the dry/ winter season. During wet/ monsoon season it is difficult to assess land use from optical images due to cloud coverage. To overcome this problem, radar images are used for assessment of wet season crop coverage.

Table 4.19: Available remote sensing data

Satellite	Sensor	Resolution	Acquisition dates
Optical images			
Landsat	TM	30 m	28-02-89, 30-01-90, 8-03-92, 11-03-93, 25-01-94, 15-04-94, 28-01-95, 28-11-95, 31-01-96, 18-02-97, 5-02-98, 4-11-98, 23-01-99, 28-03-99, 19-02-00, 28-01-01, 20-11-01, 24-02-02, 28-03-02, 13-04-02 and 26-01-03.
IRS	LISS	23.5 m	10-02-04, 17-01-05, 5-02-06, 9-12-07, 13-02-09.
Terra	ASTER	15 m	14-01-07.
IRS	Pan	5.8 m	27-02-00 and 8-03-03.
Radar images			
RADARSAT-1	SN2	50 m	10-09-98.
RADARSAT-1	ScanSAR	100 m	17-09-98, 26-08-98, 6-09-00, 13-08-00, 20-07-00, 25-10-00, 30-09-00, 8-08-01, 1-09-01, 21-06-01, 25-09-01, 15-07-01, 3-08-02, 16-06-02, 10-07-02, 27-08-02, 7-11-02, 20-09-02, 14-10-02, 29-07-03, 15-09-03, 5-07-03, 11-06-03, 22-08-03, 9-10-03, 12-05-04, 5-06-04, 29-06-04, 23-07-04, 9-09-04, 16-08-04, 16-07-04, 23-07-04 and 3-08-07.

Land use maps are primarily prepared from the remote sensing data. RS data is mainly used to classify the images to delineate the land cover/land use for the study area. The method used to classify the SAR and optical image to generate wet and dry season land use has already been explained in chapter 3. After the classification of available image for year 2001 and 2008, the field data taken from FAP 3.1 has been rectified and improved to adjust with the land use classification The Agriculture Land use has been filtered from images and other types of land, such as, settlement, water body and infrastructures which are digitized from the available Satellite images. Using this data, the land use maps have been prepared as raster grid. Land use map for year 1991, 2001 and 2008 has been prepared to see the land use changes on agriculture, wetlands and settlement. The grid values represent the code of different type of land use. But land use maps prepared from remote sensing data are not so accurate because the images available are of coarser resolution. Therefore, these primary land use data are adjusted using the field survey data. The field surveyed cultivation statistics of 1997 of the study area have been collected from FAP 3.1 report (FAP 3.1, 1997a).

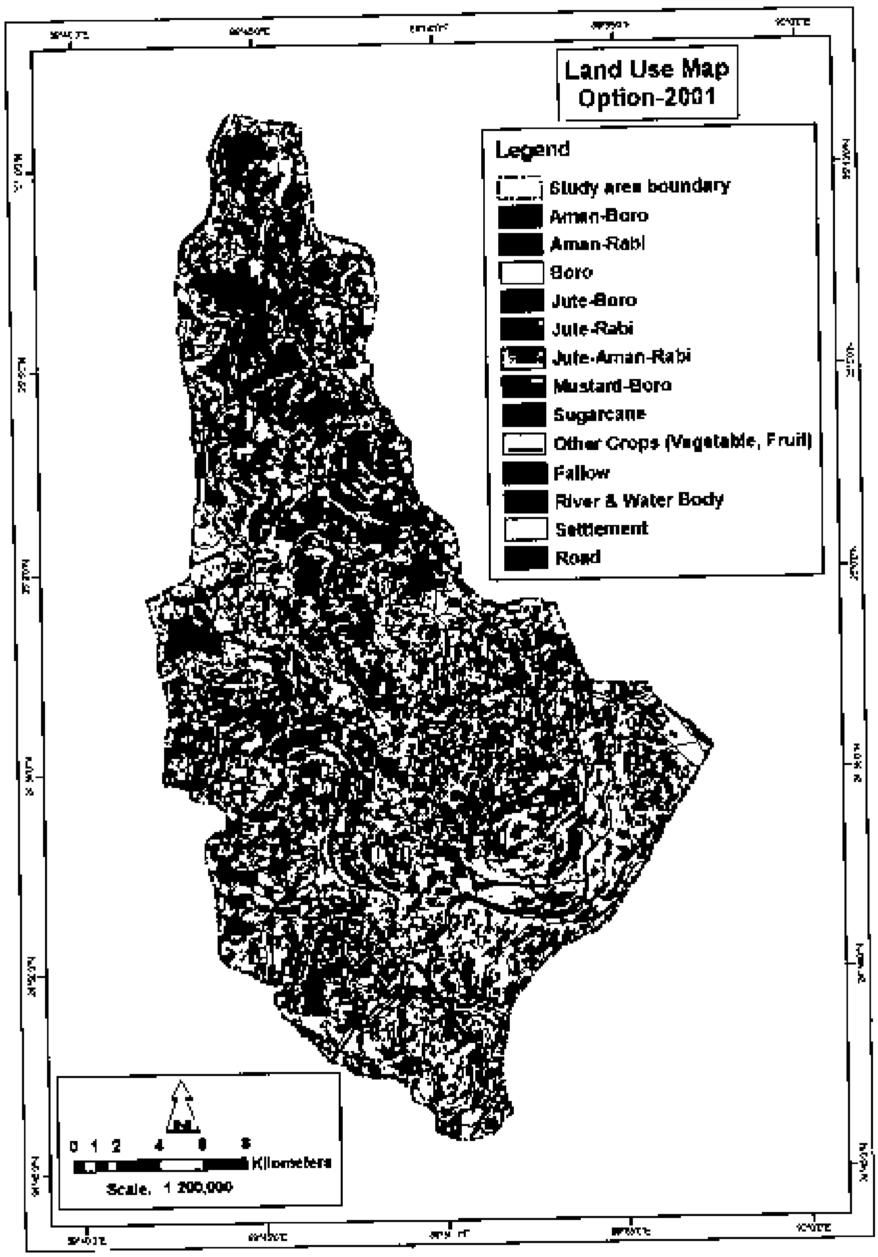


Figure 4.17: Land use map showing different cropping patterns in the year 2001

Land use maps prepared from remote sensing data of 2001 shows greater cultivated area than the 2001 field survey data. The agricultural statistics of 1997 is taken from FAP 3.1 Agriculture Report (FAP 3.1, 1997a) has been assumed as the statistical base of 2001. The ratio of different type of crop and cropping pattern has been maintained in the filtered land use maps of 2001. The extent and acreage of Aman (monsoon crop) area has been estimated from classified RADARSAT ScanSAR wide beam images of 1991, 2001 and 2008 and for estimating the dry season crop, i.e Boro crop coverage, optical images from LANDSAT TM (resolution 30m), IRS LISS (23.5 m) and Terra MODIS satellites are used. The Aman and Boro cultivation area have been slightly increased and jute and sugarcane cultivation area have decreased slightly from the 1997 data to adjust with the 2001 land use maps. Rabi and other crop area have decreased from 1997 statistics. Aman and Boro cultivation has been calibrated against the land use model results.

Land use maps of 2008 have been prepared from remote sensing data primarily. For preparing the land use maps, several data layers were used. These are, remote sensing image derived data, land type classification, data from BBS and other secondary sources, crop suitability and local preferences. All these data were combined and analysed in GIS platform. Because of coarser resolution these land use maps have been adjusted from the land use maps of 2001 (Figure: 4.17). The results (Figure 4.18) show that Boro cultivation area has increased and the Aman area is almost the same. Sugarcane and Rabi cultivation area have decreased and Jute cultivation area is half of that of year 2001.

Agricultural land use of 2001 and 2008 has been simulated against RS classified image. After calibration, errors have been summarized for the two crops in Table 4.20. where omission and commission error has been shown against remote sensing data for the crops. Regarding Boro, omission error is 18% and commission error is 37%, while for Aman, it is 20% and 12% respectively. An error mapping has also been done for both crops. It is clearly seen in the table that the model delineated as Aman area matched 63% with remote sensing data, whereas, Boro matched about 88%. Further, 2008 model shows 20% less in Aman cultivation and 15% less in Boro cultivation from field data.

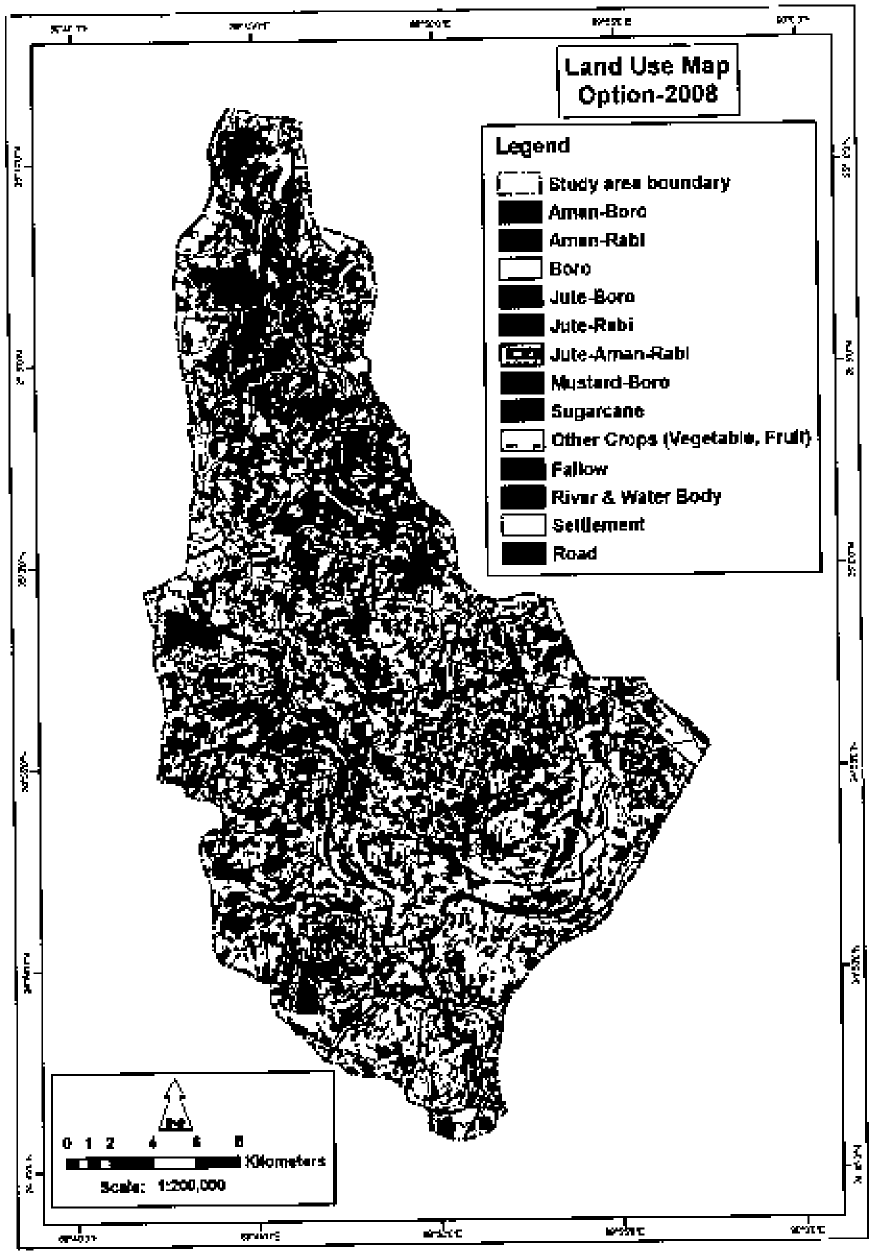


Figure 4.18: Land use map showing different cropping patterns in the year 2008

Table 4.20: Accuracy, omission and comission error of crop model with respect to classified RS image for Aman and Boro

		Accuracy	Omission error	Comission error
Crop model with RS	Aman	63%	18%	37%
	Boro	88%	20%	12%

The RS optical images have been used in identifying other perennial land use or land covers like, settlements, waterbodies, khals, rivers etc. For this LANDSAT TM optical images were used to generate multi temporal images.

4.7.2 GIS data

Several GIS data layers have been used in this research. These data sets provide the base for analyzing different parameters and conditions required for developing the decision support framework. GIS is very important and useful in planning and research purposes.

Infrastructure data needed for this research are embankment, railway, roads, industries and growth centres, health centres and education centres. Figure 4.19 illustrates the various infrastructures in the study area.

The Mahmudpur-Delalerpar FCD scheme is located in Madarganj and Melandaha upazilas of Jamalpur district. This scheme area is 2665 ha and it is a small type FCD scheme. The starting and completion date of the scheme are 1990-91 and 1994-95 respectively. The main surrounding rivers of the scheme are Chatal on the west, Jharkata in the south-west side and Dat Bhanga river on the western side. The scheme has a 13.6 km long embankment on the bank of Chatal and Jharkanta River. About 1890 ha land under the scheme is available for cultivation. The cropping intensity of the area is 165%. There are about 1,955 ha of capture fish habitat area and about 5 ha of culture fish habitat area inside the scheme. The GIS data layer of embankment for the study area has been collected from the NWRD database.

There are four types of roads in the study area. These are: National Highway, Regional Highway, Feeder road and Rural Road. The GIS data layers for road coverage in the area are for three time span 1991, 2001 and 2008 The source of 1991 road coverage is the topographic maps, the 2001 coverage has been collected from NWRD and the 2008 coverage has been prepared by updating NWRD coverage from geo-referenced Google Earth image.

The study area contains two major railway lines. Main railway line which is being connected from Jamalpur to Bahadurabad runs along the north-east limit of the study area. The other line runs along the southern limit. The railway network GIS layer has been used in the study is from NWRD.

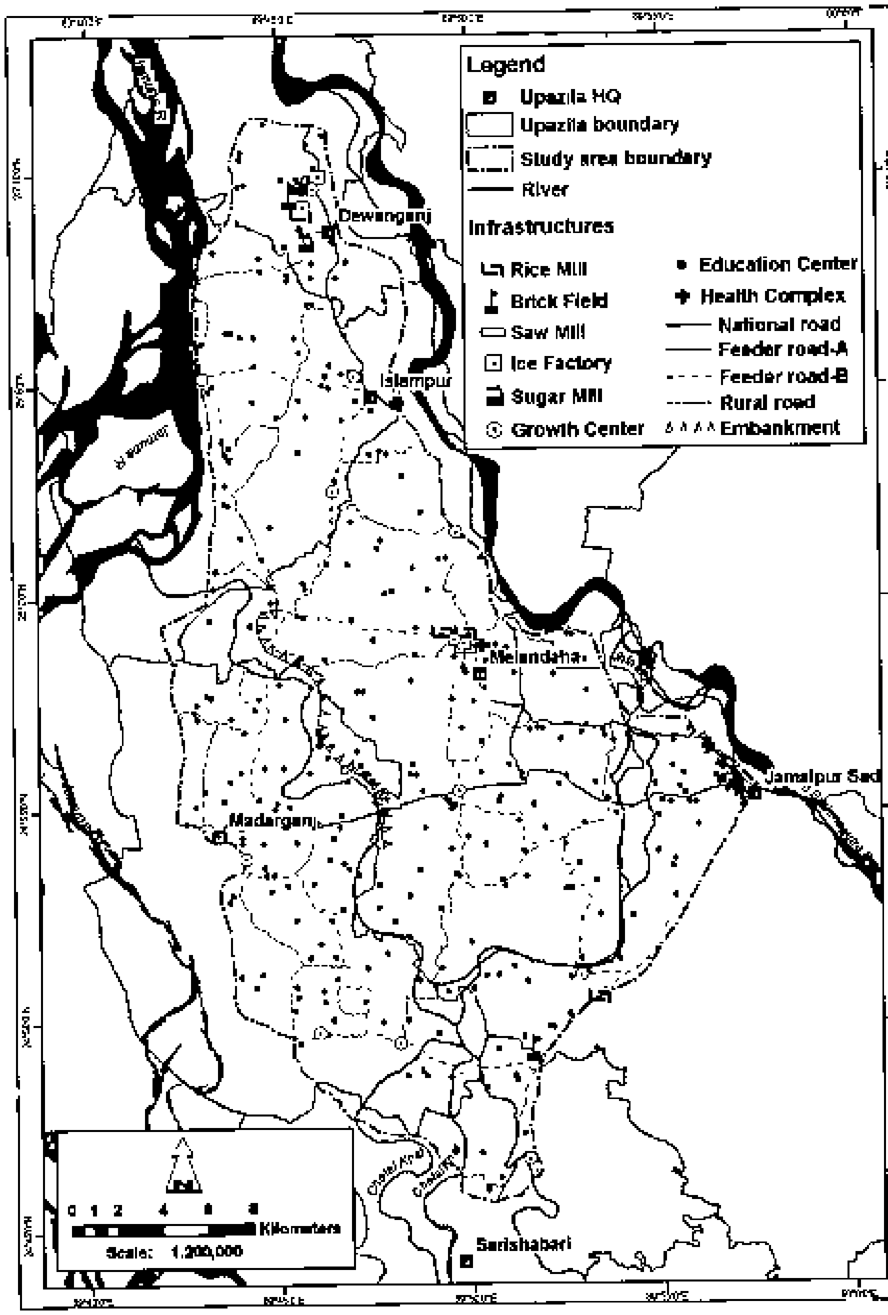


Figure 4.19: Infrastructures in the study area

A detail river network with recent alignment is the key information required for analysis. The GIS data layer of river network have been used from NWRD. This detail river system has been captured from SPOT89 and LANDSAT TM image. This GIS layer has been edited further to include river order and flow direction. There are two types of river system in the study area: 1) the external river system i.e. the Jamuna and old Brahmaputra with a length of 98 km and 50 km on the western side and eastern side respectively. 2) Internal river system represented by the Jhenai (36km), the Chatal

(55km) and the Debdanga/Madardhaw system which is linked to the completed network of secondary channel (khals). The total length of the internal river under the study area is around 380 km.

The study area consist of different types of waterbodies i.e. beels (local depressions), adjacent flood plains, and ponds. Beels are lowlands, which are permanent or seasonal waterbodies and generally linked through a khal (drainage channel) to another beel and/or an internal river. In the study area there are 118 beels covering 1550 ha and among them 32 permanent beels covering around 500 ha. The waterbodies in the study area can be classified as permanent beels, seasonal beels and adjacent floodplain. The area of beels or waterbodies varies seasonally and also year to year depending upon the nature of flooding which may originate from both river and local rain water. The coverage of waterbodies of the study area has been collected from RS images of three time period.

The GIS data layer of settlement coverage in the study area has been prepared for different time periods, 1991, 2001 and 2008. The 2001 coverage is used from NWRD captured LANDSAT TM images. The 1991 and 2008 coverage has been prepared using RS optical images from LANDSAT TM, IRS and Terra satellites. Figure 4.19 illustrates the settlements in the study area.

The GIS data layer for soil texture of the study area has been collected from NWRD, which has digitized and converted the SRDI soil maps of 1:50,000 scale to GIS platform For crop suitability analysis, groundwater modeling, hydrodynamic and hydrological modeling the soil texture data is needed. Table 4.21 presents the distribution of soil texture in the study area. From the table, it is seen that the predominant soil types are Loam, Clay Loam and Clay.

Table 4.21: Soil texture distribution in the study area

Soil Type	Percentage of area
Clay	22.3
Clay Loam	27.2
Clay Loam/ Sandy Loam	1.03
Clay/ Clay Loam	0.02
Loam	37.3
Sand	4.27
Sandy Loam	1.94
Sandy Loam/ Loam	5.91

4.8 Model data

To generate floodplain data, hydrodynamic and hydrological data were used. In general, land use, flooding information observation data was not available for the study area. Hence, floodplain data has been generated using models.

4.8.1 Hydrological model

The hydrological model 'NAM' is a deterministic, lumped and conceptual Rainfall-runoff model accounting for the water content in upto four different storages. As default, NAM is prepared with 9 parameters representing the Surface zone, Root zone and the Groundwater storages. The hydrological model was used to simulate and estimate the depth of groundwater table and to find the limits of ground water abstraction. The whole study area has been divided into 6 sub-catchments from GIS based water shed analysis using DEM. Figure 4.20 shows the sub-catchments of NAM model.

Sub-catchment is defined as an area of land from which rainwater drains into a reservoir, pond, lake, river or stream. The sub-catchment boundary is defined as the local sub-catchment area. Considering the land use and topographic features of Jamalpur study area and using GIS techniques like flow accumulation, the sub catchments boundary have been selected.

Several parameters have been used in NAM model. These parameters have been assumed for different sub-catchment based on the values used for North Central Region Model (IWM, 2006a). These values are presented in annex-A. Rainfall and evaporation data has been collected from BWDB For determining the areal average precipitation and evaporation weighted average method has been used The results of NAM model have been calibrated with the Groundwater fluctuation graph of the observation well. Figure 4.21 shows the calibration for sub-catchments 3 with the observation wells (calibrations of other sub-catchments are presented in annex-A).

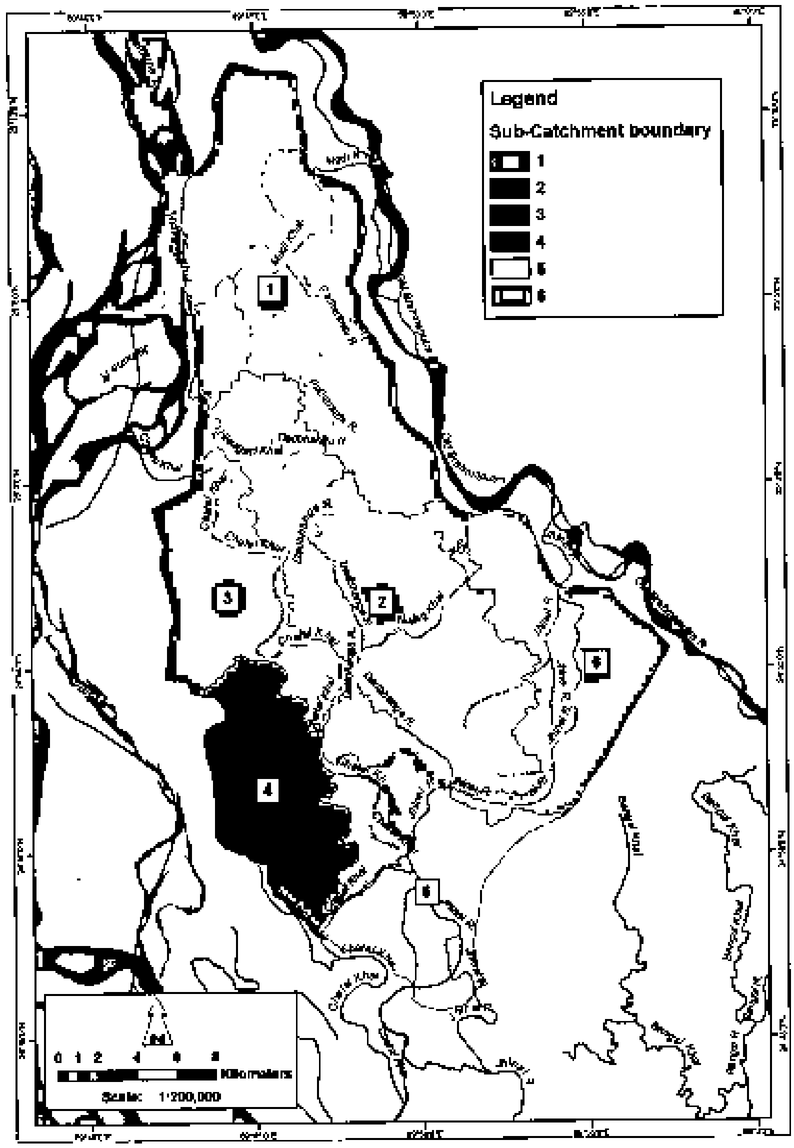


Figure 4.20: Sub-catchments of hydrological model in the study area

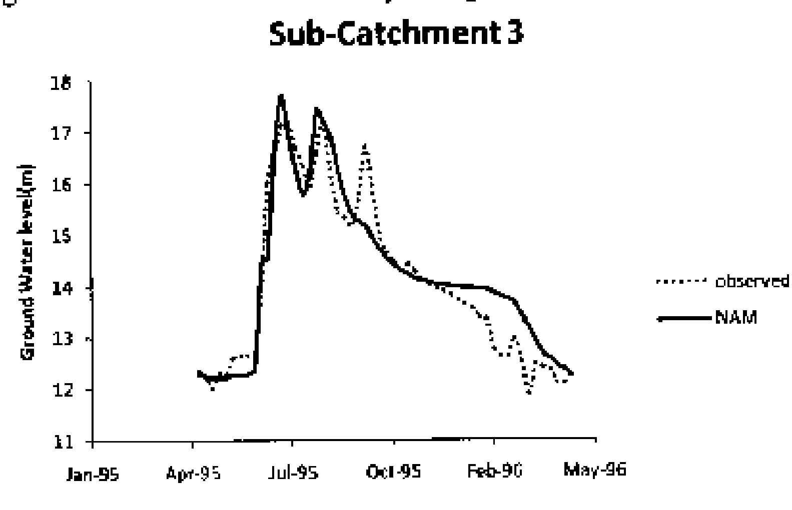


Figure 4.21: Calibration of sub-catchment 3 with observation well JAM014

From the NAM model the bottom level of Groundwater Table (GWT) for different states have been determined. The bottom level of GWT was 6.5m from the ground level in 2001 and 7.1m in 2008.

By increasing the irrigation area and thereby increasing the irrigation requirement, the declination of the groundwater table has been plotted. From the graphs, it is observed that for most of the sub-catchments with the current irrigation requirement, the groundwater table has been lowered to 5 to 6 m. Hence, there is no potential for withdrawal of water using hand pump for domestic use.

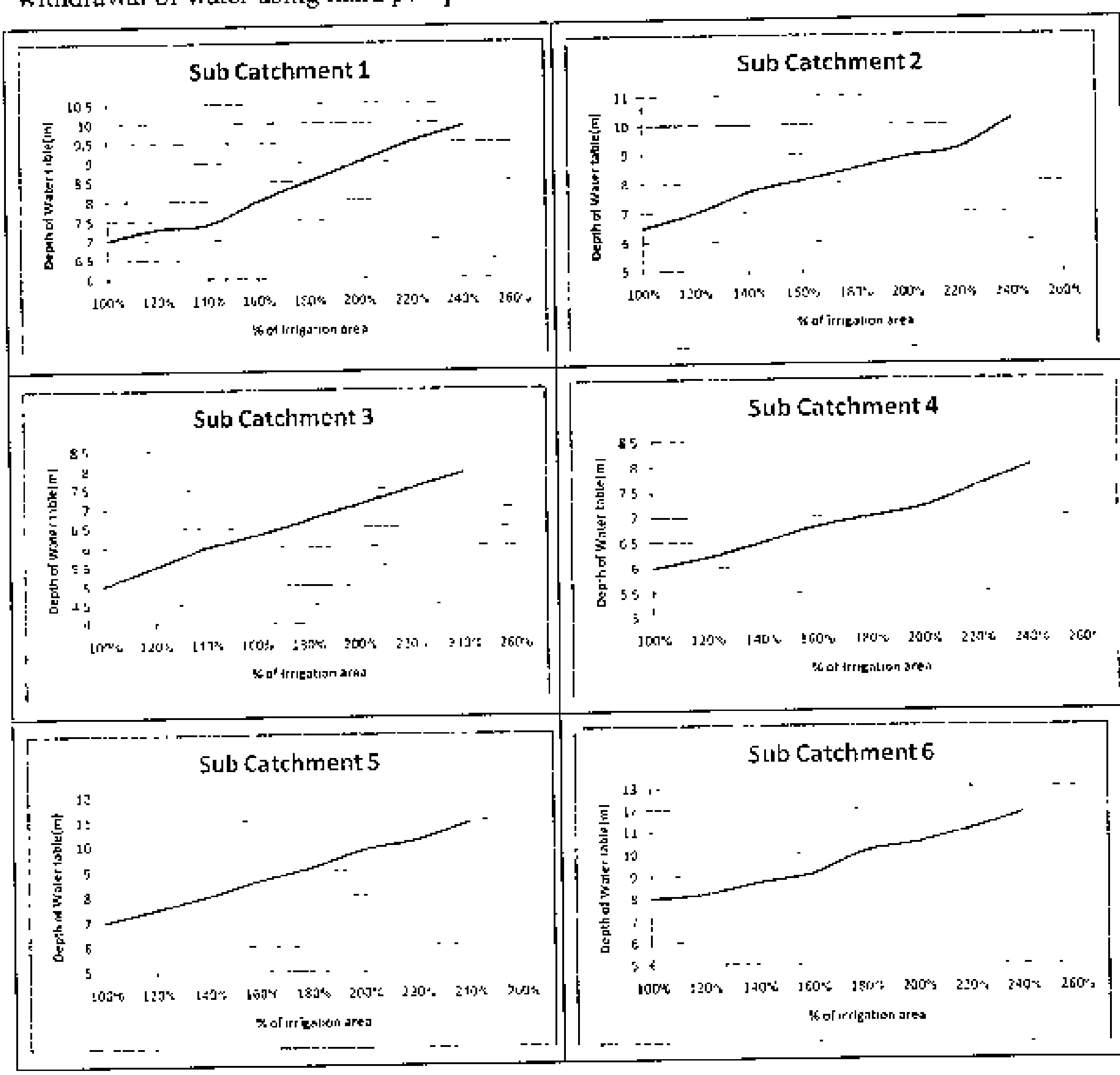


Figure 4.22: Lowering of groundwater table with the increase of irrigation area

The hydrological model demonstrates that even if the whole area is brought under irrigation using groundwater as source, the groundwater table will be fully recharged by the rainfall without declining. A simulation has been carried out to estimate the depth of groundwater table from land surface for incremental use of groundwater irrigation for all sub-catchments as shown in Figure 4.22. It shows that, in sub catchments 1 and 5 maximum suction limit (7 metre) have been reached and in sub catchment 6, the groundwater have been over exploited. In sub catchments 2, 3 and 4 more extraction of groundwater is possible. By keeping the groundwater table within the suction limit, maximum possible irrigation area is 354 sq. km. in the study area.

The recharges have also been estimated from the MPO suggested logarithmic formula from MPO Technical Report No. 5 (1987b).

$$Recharge\ (mm) = A + B\ \log(Annual\ rainfall\ (mm))$$

Where , A=-10744 , B=-3547, for the study area

The values of A and B has been taken from MPO's technical report no. 5 and IWM's report. From the estimation of the equation it is found that recharge from rain was 454 Mm^3 in 2001 and 445 Mm^3 in 2008. Additional 12.5% recharge has been taken as recharge from flooding.

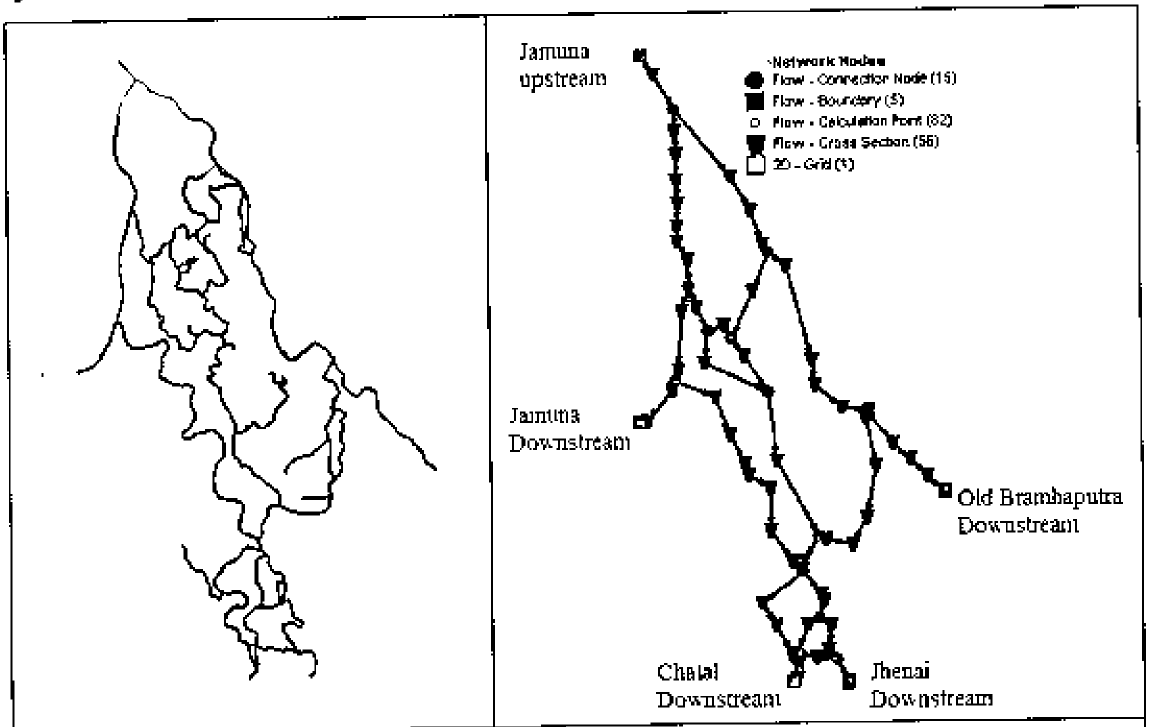
4.8.2 Hydrodynamic model

The 1DFlow module of Sobek is the hydrodynamic component. For the current research purpose this tool has been used to generate the river flows in the study area. In hydrodynamic model settings, the following data can be defined,

- The simulation period and the computational time step
- Initial data and restart data
- Output options includes parameters like water level, discharge, velocity etc. and time interval for output.

For model calibration, simulation period is taken as 1st April 1987 to 28th February 2005 and the computational time step is 24 hour. As the output option, water level and water depth has been selected and the output time interval is selected 24 hr.

For modeling the rivers in the study area, the whole river system in the area has been schematised in Sobek. During schematization. data related to cross section, flow boundary, friction etc. was given as input. Figure 4.23 is showing the complete river system and the schematized form.

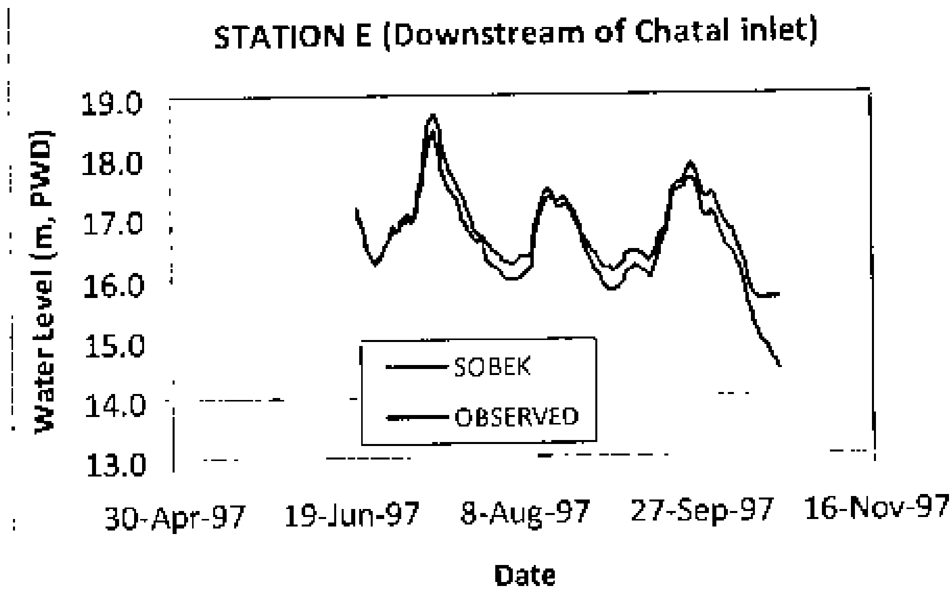


River network digitization | Schematized river network

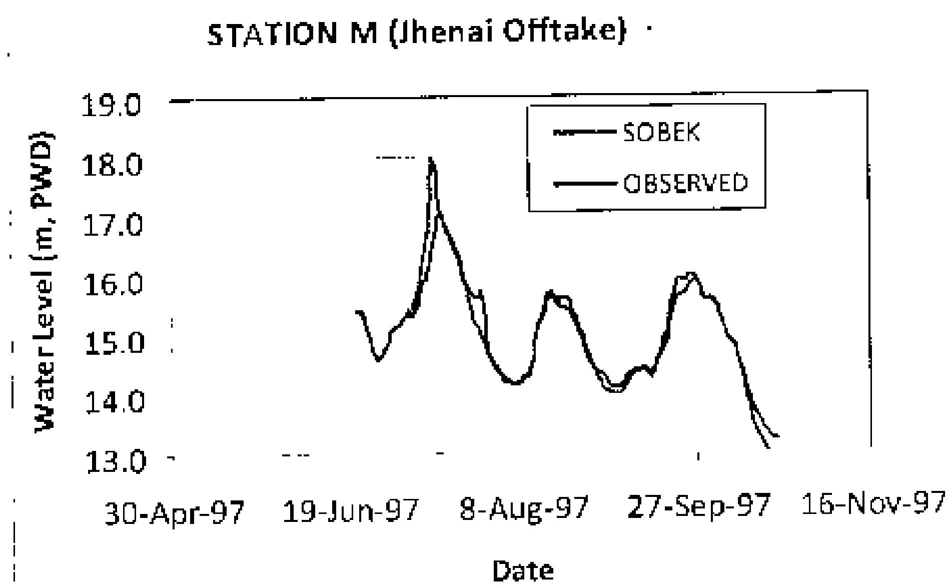
Figure 4.23: Schematization of river network in Sobek, 1979

Several boundary nodes were used in Sobek. The upstream boundary is placed at upstream of Jamuna river (chainage: 77700). The lower boundaries are placed at downstream of Jamuna (chainage: 123900), downstream of Old Bramhaputra (chainage: 63580), downstream of Jhenai (chainage. 48000) and downstream of Chatal (chainage: 58000). Discharge data is used as upstream boundary and water level data is used as the downstream boundaries. Sobek hydrodynamic model has also been calibrated in several other points in the smaller rivers in the study area for year 1997. For this, observed data has been used from FAP 3.1 study (FAP 3.1, 1997a and 1997b). Figure 4.24 illustrates the calibration results of Sobek for two locations.

The overland flow (2D) module of Sobek has been used for simulating 2 dimensional overland flow in the study area. The elevation reference value is the land height and DTM has been used in this research. The time step is taken 10 days for GIS output. The output parameters are: water depth and velocity in both directions. The friction factor for the floodplain has been taken as 0.03. Output hydrograph at each calculation node from the 1DFlow module has been used as the boundary data for the overland flow module.



(a) Station E (Downstream of Chatal Inlet)



(b) Station M (Jhenai Offtake)

Figure 4.24: Model calibration of internal rivers in the study area using Sobek

The overland flow pattern has been simulated in Sobek 2D overland flow module. For validation, the output result has been compared with flood maps generated from RADARSAT SCW images of different dates. Figure 4.25 shows three sets of flood maps generated for 26th August, 10th and 12th September 1998. From three pair of images it can be stated that Sobek 2D overland flow module is correctly simulating the flooding pattern.

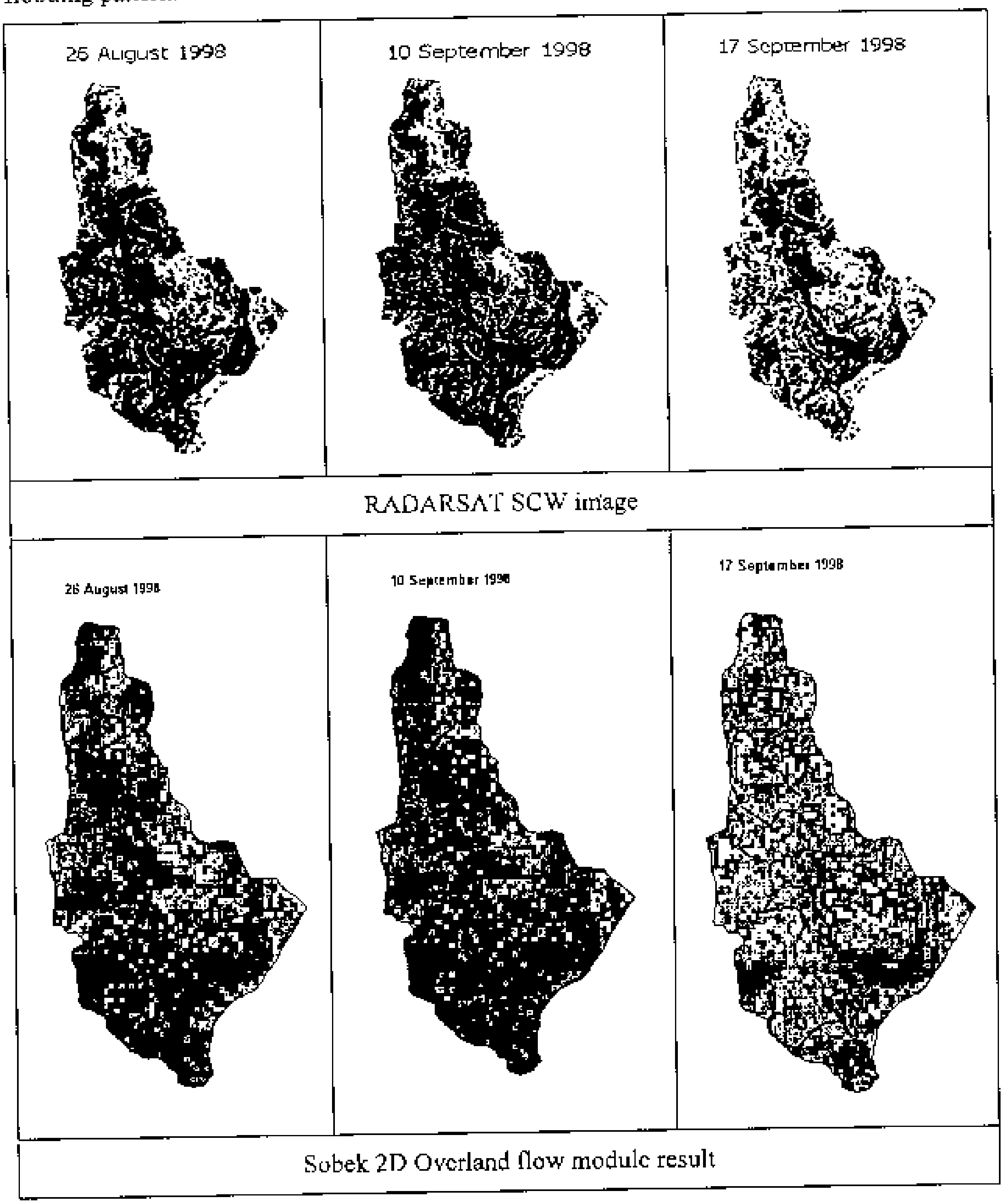


Figure 4.25: Model calibration for 2D overland flow

Flooded area has been estimated by overlaying interpolated water surface, generated from SOBEK HD model results and DEM. The model results have been compared with RS data. The RADARSAT SCW image has been classified into open water and others. The model results were compared against open flooding for 2001 monsoon water. There were classified images of five dates to compare the model results. Unfortunately, the developed model has underestimated flooded area than satellite image values. The results show that during monsoon peak the error is around 6%, whereas, during recession, error goes as high as 30% because some standing waters are picked up by satellite images but not by the model. These variations in results are shown in Figure 4.26.

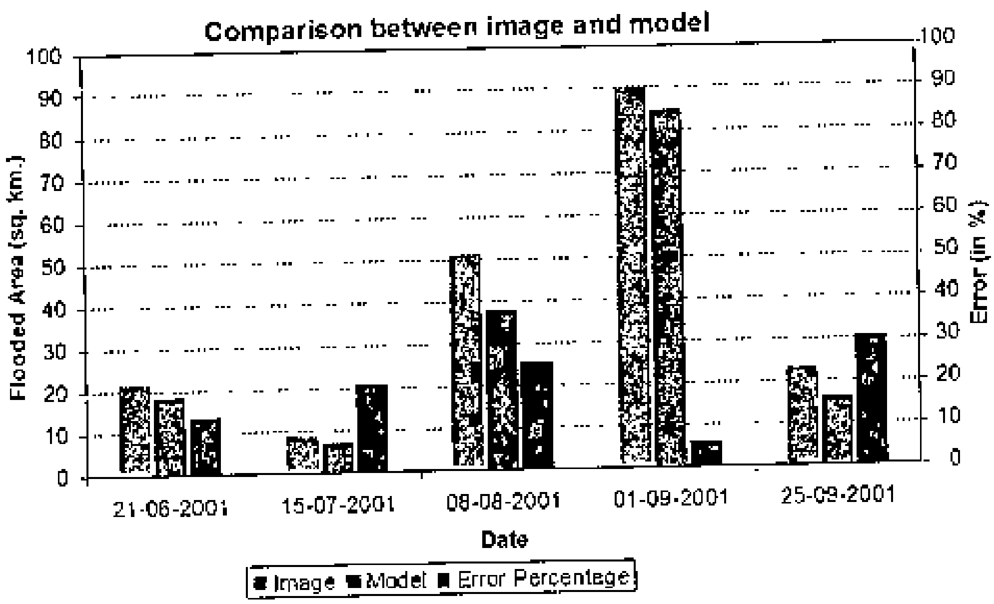


Figure 4.26: Flooded area estimation error with respect to classified RADARSAT image for different dates in 2001

Chapter 5

APPLICATION AND TESTING OF DECISION SUPPORT FRAMEWORK

5.1 Driving Factors: Needs and Requirements

As described in Chapter 3, the major driving factors that create pressure on land and water resources are social demand and needs, government plan and policy, opportunities for land and water use; and climate change and development scenarios. The magnitude and limits of driving factors are described in the following sections.

5.1.1 Social Demands and Needs

Social demand and needs are defined in terms of food, shelter employment, water supply and sanitation, forest cover and disaster risk reduction measures. These are estimated based on demographic projections as well as projection of public service and environmental development works. Each of the social demands and needs are discussed below.

The population projections in the study area had been done as an integral part of socio-economic assessment to know the future generation's needs and requirements. The estimates for the year 2010-50 are approximate in nature and the study followed the NWMP methodology for population projection as stated below. The steps are as follows:

1. Average growth rate (r) is calculated for the sub-class populations (urban, rural, male, female and households) separately as:

$$r = (Pop(t)-Pop(t-1))/(\,Pop(t)+Pop(t-1))/2 \quad \text{eq. 5.1}$$

with a minimum Pop(t) of zero, where Pop(t) is the most recently available data and Pop(t+1) is the projected population for the next interval.

2. Future population for the study area is calculated as:

$$Pop(t+1) = Pop(t)*(1+r*K) \quad \text{eq. 5.2}$$

r is calculated as above and K is a constant

It has been observed that total population in the study area in year 2001, as estimated by BBS was 0.625 million, which has been further estimated to 0.845 million for 2030 and one million for 2050 and for every 10 years the growth is around 72,000. Overall, male female ratio for the base case is 105: 100, and this proportion of male and female will not deviate much at the end of 2050. The total population from the year 2001 to year 2050 (10 years interval) is presented in Table 5.1.

Table 5.1: Total population from 2001 to 2050 (10 years interval)

Year	Population
2001	6,25, 314
2010	6, 96, 607
2020	7,69,748
2030	8,44,870
2040	9,22, 077
2050	10,01 455

The simulation exercise is very essential as it helps to assess the availability of human resources. In this regard, population by age and sex group has been projected from the base year (2001) to 2050 at 10 year interval. The time series data needed for the projection exercise was not available from nationally published sources. Hence, population data disaggregated by male, female and 5- year age group has been taken from the website of Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. The population pyramid has been constructed showing the male and female population, disaggregated by 5- year age group intervals. Overall, four age groups are derived for the analysis, which are:

- Child — Age ≤ 9
- Adolescent — Age > 9 to ≤19
- Middle age group — Age > 19 to < 60
- Old — Age ≥ 60

Results of the age group simulation showed that the shape of the population pyramid has been changing from pyramid to tomb shape over the projection period due to decreasing growth rate as well as decreasing death rate of the population (Fig. 5.1). Decreasing growth rate has reduced the width of the pyramid base and decreasing death rate increased the bluntness of the pyramid edge. Overall, it has been found from the age group simulation that over the projection period the population within the child age group and adolescent will be reduced from 25% to 13% and 22% to 14% of the total population respectively (Table 5.2). Other than this, the percentage of population who will join the labour force will increase by 11% (46% to 57%) and the proportion of senior citizen will be increased from 5% to 16% (Table 5.2).

Age-group simulation

The simulation exercise is very essential as it helps to assess the availability of human resources. In this regard, population disaggregated by 5- year age group and sex has been projected from the base year (2001) to 2050 at 10 year interval.

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- Child — Age ≤ 9
- Adolescent — Age > 9 to ≤19
- Middle age group — Age > 19 to < 60
- Old — Age ≥ 60

Results derived from the age group simulation has been presented through a series of population pyramids as shown in Table 6.11 and Figure 6.33 respectively. It is observed that the shape of the population pyramid has been changing from pyramid shape to tomb shape over the projection period due to decreasing growth rate as well as decreasing death rate of the population. Decreasing growth rate has reduced the width of the pyramid base and decreasing death rate increased the bluntness of the pyramid edge. Overall, it has been found from the age group simulation that over the projection period the population within the child age group and adolescent will be reduced from 25% to 13% and 22% to 14% of the total population respectively. Other than this, the percentage of population who will join the labour force will increase by 11% (46% to 57%) and the proportion of senior citizen will be increased from 5% to 16%.

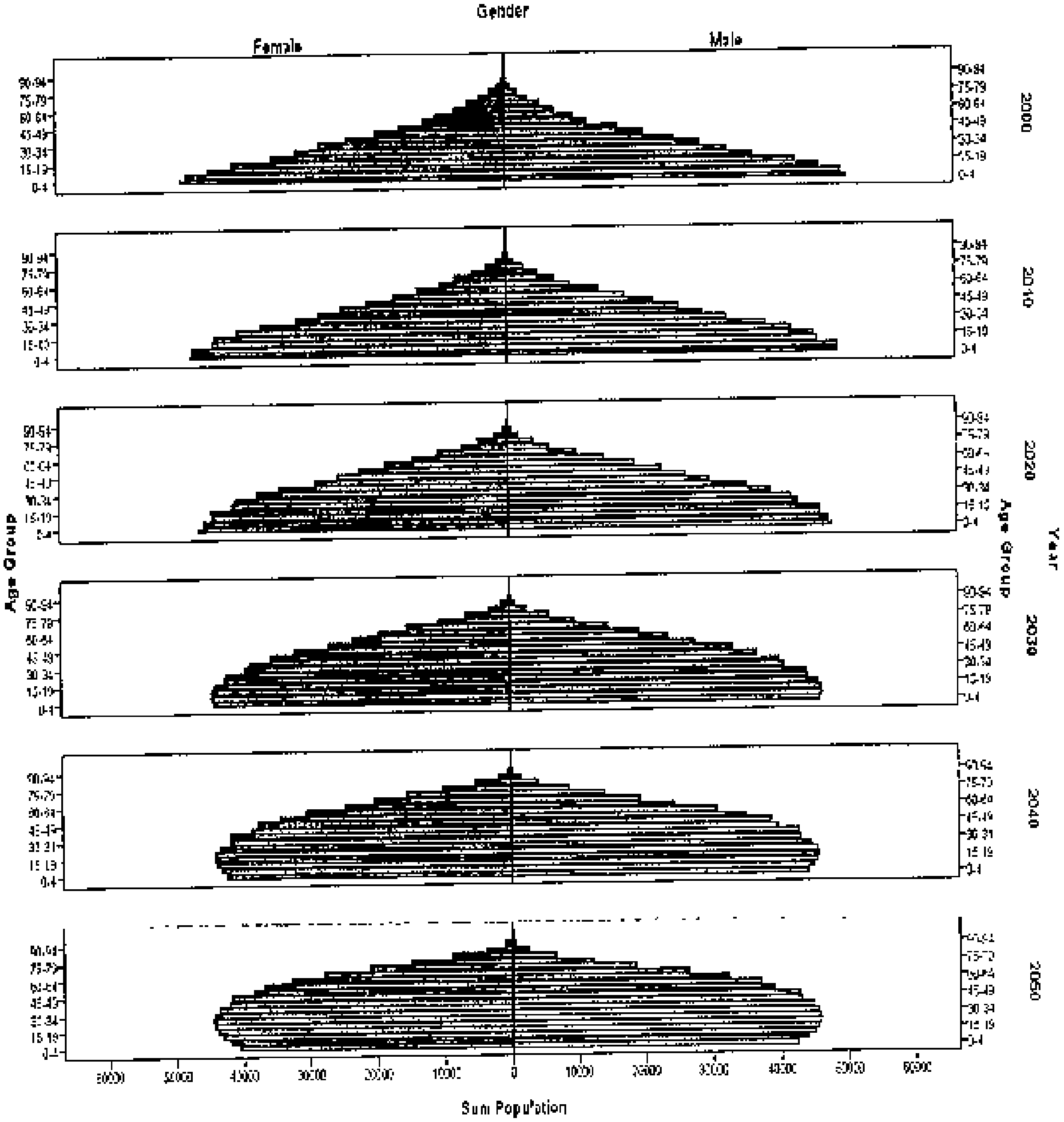


Figure 5.1: Population pyramid of study area

Table 5.2: Proportion of total population within different broad head age group

Age Class	Age Group	Yr 2000	Yr 2010	Yr 2020	Yr 2030	Yr 2040	Yr 2050
Child	≤ 9	25%	22%	19%	17%	15%	13%
Adolescent	> 9 to ≤19	22%	20%	19%	17%	15%	14%
Middle age group	> 19 to < 60	46%	50%	53%	54%	55%	57%
Old	≥ 60	5%	8%	9%	12%	15%	16%

Labour force has been projected taking into account the middle age group (20-59 years). The total labour force in 2001 was nearly 0.3 million. The male to female ratio of labour force is 105: 100. In the year 2030 and 2050 the total population will be around 0.45 million and 0.55 million. The male to female ratio of the labour force will be 103:100 and 102:100 in 2030 and 2050 respectively. It should be noted that 11% more middle age group (20-59) will join the labour force over the projection period.

The school-going children fall in the age group of 5-14 years. The rate of school going children will reduce with the reduction of number of children and adolescents in the future. The number of school going children will be 0.147 million in 2030 and will decline to 0.140 million in 2050 compared to 0.153 million in the base year 2001. The percentage decrease will be 10% (24%-14%). But the ratio of male to female of the school going children will remain almost same (104:100).

Several studies have estimated increasing trend of food grain demand for the study area. This impact assessment project has taken an attempt to project the food demand based on the calorie need projection, disaggregated by different income groups. It has been seen that the consumption of non-grain crops and animal products are increasing for the mid and upper income group. The NWMP team assumed the baseline calorie intake of around 2,200 calories per capita per day as a realistic estimate. NWMP also considered, even with real prosperity, calorie intake in Bangladesh would not increase more than 2500 calories per capita per day.

Table 5.3: Categories of food

Grains	Non-grains	Animal Products	Miscellaneous
Rice Wheat Maize Other cereals Pulses	Oil crop Potato Other roots Vegetables Fruits Sugar and sweeteners	Meat and poultry Eggs Fish Milk	Mainly stimulants and beverages have been covered

Based on types of food, the food demand has been divided into four major categories- grains, non-grains, animal products and miscellaneous (Table 5.3). The cereal crops category include rice and wheat (milled equivalent). Other cereals (such as barley, millet, sorghum etc.), mutton, beef, chicken, ducks, birds, and eggs fall under the meat and poultry category; fish means the consumption of sweet fish and dry fish. Oil crops can be treated as the non-grain crops mainly includes vegetable oils as oil crop equivalent and other non-grain crops are potato and other starchy roots, vegetables, fruits and sugar.

To calculate the total food demand for the base year, quantity demand for each food categories has been computed and converted to quantity demanded into calorie intake, the level of consumption of animal products has been assessed in terms of feed demand. The allocation for seeds and waste has been kept for the total demand computation as a percentage of total demand. The total demand for each crop is then estimated as:

> Total demand = (food demand + feed demand) / (1 - seeds and waste as a percentage of total demand)

For food demand projection up to year 2050, trends of energy intake of different food categories with respect to changes in different income groups have been computed. In most cases, annual growth rate has been computed on the basis of historical trend of per capita intake. Same methodology of total food demand calculation (as stated above) has been adopted for individual yearly demand calculation. Using the same methodology for converting the caloric demand to the gross population demand, consumption demand has been projected up to 2050 at 10 years interval.

In general, the cereal crops category include rice and wheat (milled equivalent). But this study considers only rice. Total rice demand in Jamalpur in 2050 can be increased by 189% from 0.125 Mmt in 2001 to 0.236 Mmt in 2050. Fish resource is defined as sweet fish and dry fish. Fish demand can be increased by 60% in 2050 compared to the base year. In 2050, the total demand can become 18,277 metric ton.

In PRSP target has been made to reduce the number of served population per tube-well from present 105 to 50. According to MDG data, the 2009 rate of population using safe drinking water and sanitation in Bangladesh is 86% and 54% respectively. By 2015, it can be 89% and 70% respectively (UNDP, 2010) Following the MDG data, it can be projected that the proportion of population using safe drinking water can be increased to 96% by 2030 and it will reach 100% before 2050. In case of sanitation, it can reach to 83% by 2030 and reach 100% before 2050.

MDG has targeted 100% net enrollment in primary schools by 2015 (UNDP, 2010). The number of school going children in study area can become 0.14 million in 2050. The male female ratio of school going children can be 104:100. PRSP has emphasized on leasing policy for land and water use for easy accessibility of the poor community. The current proportion of total water resource use is 6.6%. The proportion of terrestrial area currently protected is 1.78%, which has been targeted to increase to 5% by 2015 (UNDP, 2010). At present the total land area of the country under forest coverage is 19.2% (UNDP, 2010). Both PRSP and MDG have targeted to increase this forest coverage to 20% of the land area through social and participatory forestry. PRSP has also given importance to reduce flood vulnerability through various structural and non-structural measures. Prevention of river erosion and protection of forestry has also been focused.

5.1.2 Policies Plans and Strategies

National land use policy

In 2001, the Ministry of Land (MoL), Government of Bangladesh prepared the 'National Land Use Policy (NLUP)' to fill an important policy gap in the country. The NLUP deals with land uses for several purposes including agriculture (crop production, fishery and livestock), housing, forestry, industrialization, railways, roads, tea and rubber. The document basically identifies land use constraints in all these sectors. Some of the major ones include declining land productivity due to unplanned and improper uses of land and decreasing soil fertility, diminishing wetland and aquatic bio-diversity, dwindling natural forest and environment.

In Bangladesh, there are different types of government owned (Khas) land and Khas waterbodies. From a total of 10,075 square km khas land, about 3,251 sq. km. is agricultural khas land and remaining 6,824 sq. km. is non-agricultural land, which includes forests and urban areas (Barkat et. al, 2001). Distributed Khas land is about 1400 sq. km., which is 43.47% of the total agricultural khas land (Osman, 2009). Khas land is legally reserved for distribution to landless households, with priority being given as follows (Barkat et. al, 2001):

i) Diluviated tenant's family
ii) Martyred or crippled freedom fighter's family
iii) Widowed or divorced lady with working son
iv) Family without a homestead and agricultural land
v) Landless family with homestead land only
vi) Family with homestead land and less than 0.5 acres agricultural land

The quantity of khas land to be distributed to individual households varies by class as follows:

- Class 1: Triple-cropped with irrigation facilities -1.00 acre
- Class 2: Double cropped with irrigation facilities - 1.50 acres
- Class 3: Single cropped with no irrigation facilities - 2.00 acres

Issues in land use

The National land use policy (GoB, 2001) prioritises land zoning. This should be done in order to ensure sustainable land use. However, except policy directives, land zoning has not yet been done. Hence, the policy directions have not been implemented.

In Bangladesh, different concerned agencies have different land use policies. These policies often conflict with each other. So, harmonization of these policies is required.

The NLUP does not provide any policy guideline for preservation and protection of land resources. This is a major drawback of the policy. An authority should be established. to preserve, protect and manage the land resources.

The NLUP policy does not have any directions about resettlement of the low-income people, who are becoming landless due to land acquisition for various development works.

Further, in a deltaic country like Bangladesh, land in floodplain is greatly related to water. For ensuring sustainable management of land resources, an integrated approach of both land and water resources is required.

Water use policy

In the last decade, the water resources management has received worldwide attention and concentrated efforts were undertaken to formulate the World Water Vision and develop guidelines for future actions at international, national and local levels (Cosgrove and Rijsberman, 2000). The vision states that "*There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people and the environment suffer badly*". Bangladesh is no exception. They have to adopt a holistic, participatory, and integrated approach for water resource management. It has to take into account a variety of geographic, economic, social and environmental factors. Bangladesh is a lower riparian country. Most of the land is located within the floodplains of three larges rivers: the Ganges, the Brahmaputra, and the Meghna and their tributaries and distributaries. These alluvial rivers carries a huge annual discharge and sediment load, causing channel shifting and bank erosion and accretion. Withdrawals in upstream areas seriously affect socioeconomic growth, the environment, and the ecology. The habitat of fish is under threat from an increasing agriculture use and population pressure. Inland navigation is hindered by blockages of river siltation and need fresh water to push back the salinity of the coastal belt.

National water policy, 1999

In 1999, the water policy guided both public and private actions in the future to ensure optimal development and management of water, which will benefit both individuals and the society at large. The main theme of the national water policy is:

> *"The policies set forth herein are considered essential for addressing the objectives of improved water resources management and protection of the environment Every public agency, community and village, and each individual has an important role to play in ensuring that the water and associated natural resources of Bangladesh are used judiciously so that the future generation can be assured of at least the same, it not better, availability and quality of these resources"*

The Objectives of the National Water Policy (GoB, 1999) is:

- To address issues related to the harnessing and development of all forms of surface water and groundwater and management of these resources in an efficient and equitable manner
- To ensure the availability of water to all elements of the society including the poor and the underprivileged, and to take into account the particular needs of women and children
- To accelerate the development of sustainable public and private water delivery systems with appropriate legal and financial measures and incentives, including delineation of water rights and water pricing
- To bring institutional changes that will help decentralise the management of water resources and enhance the role of women in water management

- To develop a legal and regulatory environment that will help the process of decentralisation, sound environmental management, and improve the investment climate for the private sector in water development and management
- To develop a level of knowledge and capability that will enable the country to design future water resources management plans by itself with economic efficiency. gender equity, social justice and environmental awareness to facilitate achievement of the water management objectives through broad public participation

In the agriculture sector, paddy is the dominant land use in the floodplain. The goal of agriculture policy issued in 1999 is to maintain self-sufficiency in food. The policy also emphasizes on efficient irrigation, integrated pest management and more use of composite fertilizer. The fisheries policy is aimed at increasing fisheries production and give importance to capture fish to meet the need for animal protein and also gives emphasis on conserving fish habitats. In the forestry policy, it proposes about 20% area to be afforested. Environmental policy highlights the need to maintain an ecological balance and development through protecting and improving environment. The safe water supply and sanitation policy stated that all population should have access to safe drinking water and sanitation at an affordable cost. The policy emphasizes to reduce the number of served population per tube-well from 105 to 50 in near future and one sanitary latrine for each household. Labour intensive manufacturing industry should be core business and to create enough employment opportunity for future generation as mentioned in the industrial policy of 1999.

Poverty Reduction Strategies in Bangladesh

In 2003, Government has adopted the Poverty Reduction Strategy Paper (PRSP), as a development guideline for Bangladesh, which will assist in the eventual end of poverty. The major sectors to be challenged for PRSP with their strategies are discussed below.

To move agricultural production from a predominantly subsistence level to a more diversified commercial pursuit with appropriate attention to the challenges of productivity increase and environmental sustainability, PRSP focuses on four issues: intensification of major crops (i.e. cereals). diversification to high-value non-cereal crops (i.e. vegetables and fruits), development of non-crop agriculture (i.e. fishery, poultry, livestock), and promotion of rural non-farm activities (i.e. rural construction, transport and services).

In case of food security, action on two front will be taken: First, assure a continuous, hygienically sound low cost food supply. Second, aim an income distribution that provides adequate purchasing power in the hands of the low-income people. However, in attaining these changes both behavioral and developmental changes will be needed.

The overall strategy of PRSP in fishery sector development envisions intensification of aquaculture by species and ecosystems, addition of export-oriented species, ensuring bio-diversity and preserving natural breeding grounds, product diversification and value addition and development of appropriate marketing infrastructure. The underlying strategy will be to promote a dynamic rural aquaculture, involving the key actors among NGOs, private sector entrepreneurs and community-based fishing groups to ensure access of the low-income people and community groups to waterbodies.

The leasing policy of *jalmahals* seeks to optimize equity and ensure adequate opportunities for poor fishermen and community groups to be participant in the process. These steps will not only increase access of the low-income people to open water resources for fish culture but also increase productivity of inland capture fishery.

The PRSP target in the forestry sector is to bring at least 20 percent of the country's land under the afforestation program through a coordinated efforts of the government, NGOs, private sector and the local people. The major areas of intervention include expansion of forest in depleted hills and khas land, tree plantation in rural areas on private land and along the roadsides, railway tracks, embankment slopes and courtyards of rural organizations through community participation of the low-income people.

To minimize risk and vulnerability of natural disasters, among all, PRSP has given the topmost priority to flood protection. It will be implemented for zila and upazila towns in phases using both structural and non-structural measures. The programs emphasizes on distress/vulnerable pockets. It will reduce overdependence on groundwater. The main river systems will be developed and managed for multipurpose use through various structural and non-structural measures.

For environmental and natural resource conservation, PRSP has given attention mainly to five issues. These are: i) agricultural land degradation and salinity; (ii) biodiversity,

(iii) public commons; (iv) afforestation and tree plantation; and (v) urbanization-related environmental issues.

The suggested interventions of government include ensuring adequate water flow, legal and institutional measures for sustainable abstraction of wetland resources by the poor, introduction of public hearings, prepare Environmental Impact Assessment (EIA) documents, increase expenditure on environmental awareness and undertake environment-related projects and programs with a view to ensuring biodiversity, preventing land degradation, protecting forests and expanding social forestation. In this regard, enacting laws and regulatory frameworks and recognizing the rights of the ethnic minority and rural people to local common property resources are essential. Further, policies and actions of the Government must not cause marginalization of the low-income people and force them to intensify over utilization of the open access natural resource base, or make them more vulnerable to pollution hazards.

National Water Management Plan

In 2001, Bangladesh prepared a National Water Management Plan (NWMP). This plan is guided by six national goals, which has been developed under National Water Policy (NWPo). These goals are: i) Economic Development ii) Poverty Alleviation iii) Food Security iv)Public health and Safety v) Decent standard of living for the people and vi) Protection of the natural environment.

To achieve national goals, NWMP has three immediate objectives. They are inspired by a clause, which appears in both the DSNWMP and NWMPP ToR, which, says that the Plan is intended to contribute to national economic growth through rational management of water resources in a way that protects the natural environment and improves the quality of life for the people of Bangladesh. The Development and immediate objectives of the plan is shown in Figure 5.2.

In NWMP, the strategic planning framework began with an assessment of the needs arising within the human and physical environment, from the national goals and policy directives, and have been divided into six clusters based on capital needs and opportunities covering i) major rivers ii) towns and rural areas iii) major cities iv) disaster management v) agriculture and water management and vi) environment and aquatic resources.

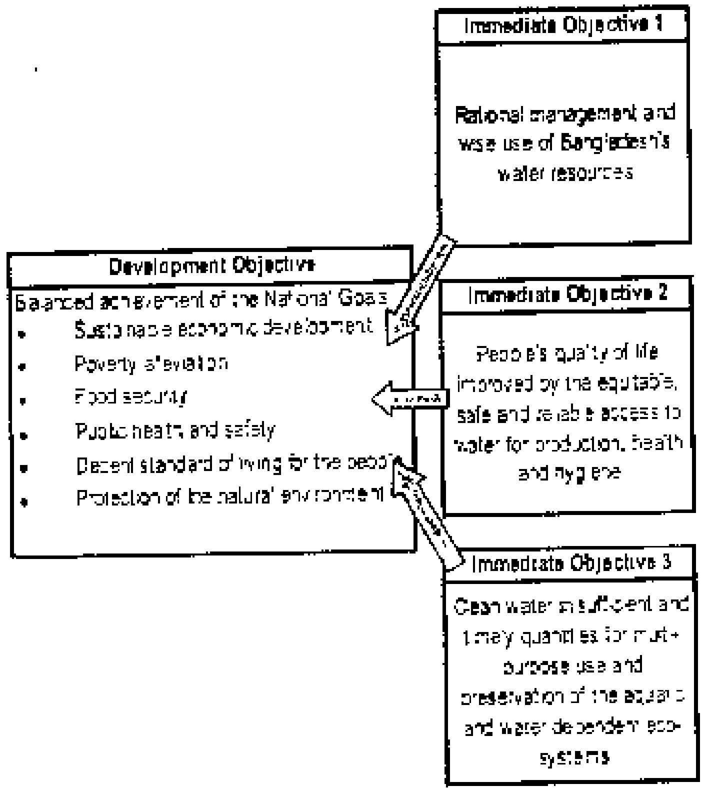


Figure 5.2: Overall objectives of national water management plan (WARPO, 2001)

Each of these clusters includes a range of program recommended for implementation under the NWMP. Each remaining programs where then considered in order to reflect various strategic prioritization of the national goals. These are: i) Balance development strategy- where in selecting Institutional Measures and development measures, equal importance is given to all six national goals. ii) Economic growth strategy: where priority is given to the national goals of – economic development, poverty alleviation, food security and standard of living. iii) Health and environment strategy: where priority is given to national goals of Public health and Safety and Protection of the natural environment.

Of the eight regional planning areas of NWMP, the study area is located in the North Central (NC) region. In association with some of the important areas including the Capital of the country, NC is the most urbanized and industrialized region in the country. A major challenge faced in the rural area of NC region is flooding and drainage problem. For the benefit of NC region, twenty-seven programs have been undertaken. Of which, the exclusive ones are flood protection and storm water drainage and flood proofing of key infrastructure. The program also includes involvement of some important institutions and agencies.

5.2 Opportunities for Land and Water Use

In this research, land and water use opportunities in the study area has been estimated for the year 2050. Opportunities are calculated based mainly on people's perception. However, some secondary projection data has also been used. Two types of opportunities are identified. First. horizontal expansion, which considers the current area of certain types of use will expand in future. Second, vertical expansion, which includes expansion other than area expansion such as, increase of agricultural production by cultivation of HYV, densification of settlement i.e. building more houses in the existing settlement etc.

Land use opportunity has been estimated in terms of land use for agriculture, settlement, wetlands and others which include, growth centres, industries, roads and health centres. Presently, agriculture is using its maximum suitable land for Aman and Boro because opportunity for horizontal areal expansion in agriculture is very limited. However, agricultural production will increase by increasing HYV rice cultivation Though there is not enough opportunity to increase Boro area but the dried up silted wetlands and improvement in areas of drainage congestion due to unplanned road construction, some additional area can be brought under HYV Boro cultivation. In case of Rabi, it is observed that almost 20 km^2 of land remains waterlogged in the monsoon due to drainage congestion. By improving the drainage system this additional land can be converted for Rabi cultivation. Moreover, flood control measure in the area will further give the opportunity to increase Aman production from present 250 km^2 to 280 km^2 in future The opportunities for horizontal expansion of agriculture are shown in Table 5.4 and Figure 5.3.

Table 5.4: Horizontal expansion of agriculture

Type of Crop	Present	Opportunity
Aman	250 km^2	280 km^2
Boro	281 km^2	285 km^2

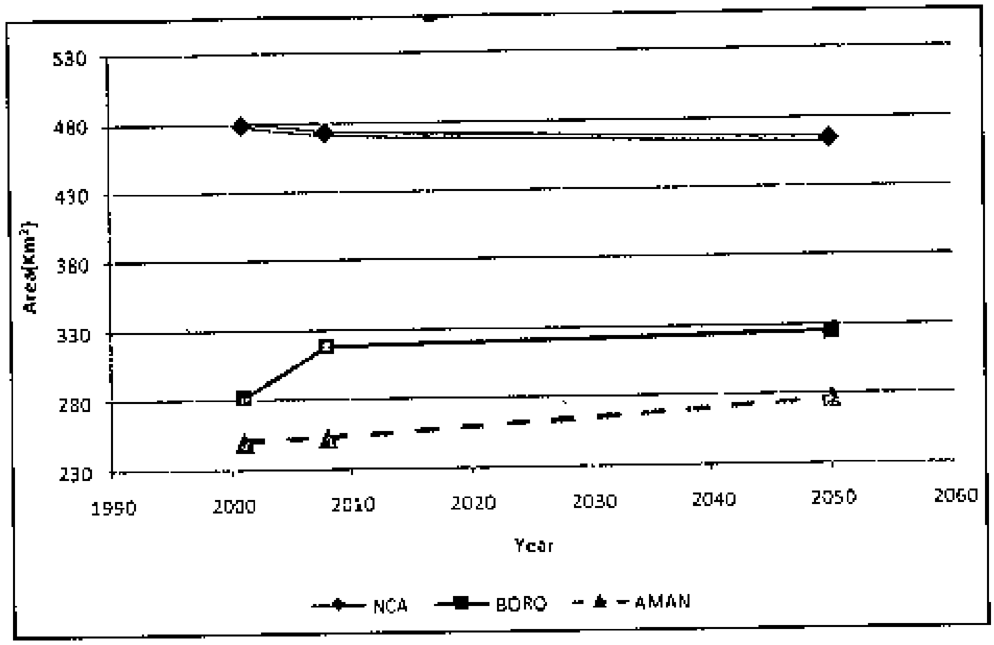


Figure 5.3: Horizontal expansion of agriculture

Through more cultivation of HYV and agriculture inputs, rice production can be increased. Presently.the ratio of HYV and local variety Aman in the area is 60:40. To increase production the HYV and local needs to be on a ratio of 90:10 For Boro, there will not be any remarkable change, because almost 100 percent of Boro cultivated is HYV. The opportunities for vertical expansion of agriculture are shown in Table 5.5.

Table 5.5: Vertical expansion of agriculture

Type of Crop	Present status of HYV		Opportunity for HYV	
	Area	%	Area	%
Aman	150 km^2	50	280km^2	90
Boro	281 km^2	96	285 km^2	100

With an increasing population in the future, more land will be needed to provide shelter for the increasing population. In addition, population growth will be more in urban areas than in the rural areas. For estimating the opportunity in settlement, local preferences have been considered, with a view to expand existing settlement, development of new settlement in highlands and fallow lands, less flood or erosion prone area and close proximity to the road. The opportunity for settlement expansion is calculated based on two assumptions. Presently, on average per households occupy 14 decimal of land both in urban and rural areas. First, opportunity of settlement expansion is calculated based on that in future per household will use the land area as present (13 decimal and 10 decimal of land in rural and urban areas respectively). It is observed that the opportunity for urban settlement will be almost double than the present situation. The rural settlement will be 92 km^2, which is 80 km^2 at present. Second, settlement expansion opportunity is calculated based on the concept of an ideal home. From the field survey, it is found that a family of four members needs a home of 540 sft lands (house size 420 sft and kitchen 120 sft). An additional 660 sft of land is needed for movement, gardening and raring cattle. Thus, an ideal house in a rural area needs 11 decimal (1200 sft) land and in urban areas it is assumed that per household will need 7 decimal of land. The opportunity for settlement for both the urban and the rural areas based on the concept of ideal house will be 22 km^2 and 80 km^2 respectively.

Over the years, wetland area has been decreasing. The beels are silted and it is being converted into other types of land. Wetlands are very important for nature because it supports wide range of biological species which helps to maintain ecological balance. The opportunity for wetlands has been calculated based on criteria like; restore of pre 1991 condition wetlands and maintaining environmental flow by dredging and other water management measures. For calculating the opportunities of wetlands, it is considered that the area of beel in the pre 2001 period can be regained. In 2001, the area of beel was 8.5 km^2 and current beel area is 7.9 km^2. Over the years, the area of the rivers remains almost same The opportunity of wetlands includes only the area of beel in the 1991. Therefore the opportunity of wetland area by 2050 is 29.35 km^2 (Figure 5.4).

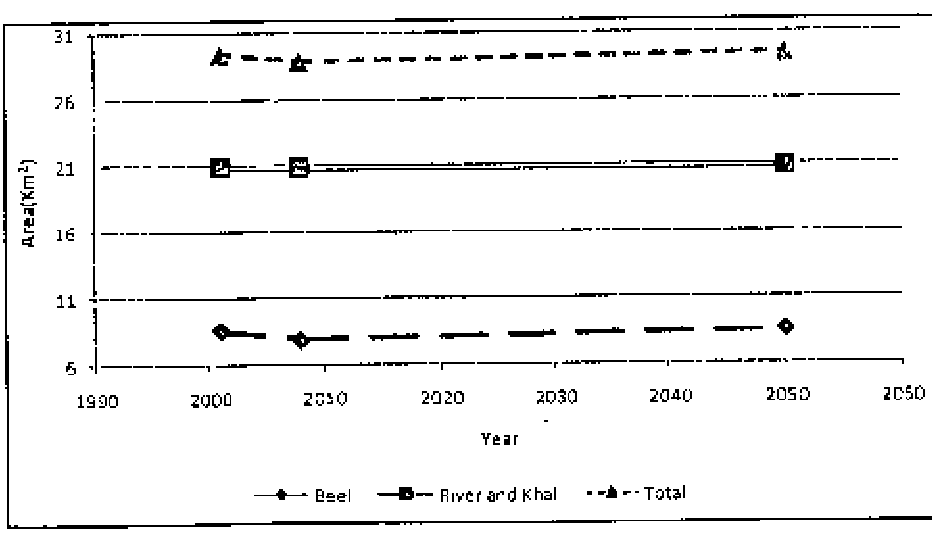


Figure 5.4: Expansion opportunity of wetlands

Opportunities for other land use include roads, growth centres, industries, health centres and schools. The criteria for estimating opportunity for road shows that there is no need to create new roads but the capacity of the roads should be increased by widening and raising the height of the roads to protect it from flooding. To calculate the opportunity for road, it is assumed that all feeder road will be converted to national road, feeder B type to feeder A and 50% of rural road will be converted to feeder B. and another 50% will remain as rural. It is observed that the opportunity for national road length is 95.6 km, where as, present length is only 0.85 km (Table 5.6) The opportunity for feeder A type of road length is 174.5 km, feeder B is 87.6 km and rural road is 180 km.

Table 5.6: Expansion opportunity of roads

Road Types	Present		Opportunity	
	Length (km)	Area (ha)	Length (km)	Area (ha)
National	0.85	1.2	95.6	133.8
Feeder A	79.82	55.5	174.5	122.15
Feeder B	138.14	96.7	87.6	61.3
Rural	194.26	97.1	180	90
Total	413.07	250.5	537.7	407.25

Both horizontal and vertical opportunities are calculated for growth centres. Based on the following criteria the opportunity of the growth centres is estimated on criteria like; it is assumed that the number of growth centres will not increase, in case of horizontal expansion only the area of the growth centre will increase and for vertical expansion only the number of shops will increase. Further, growth rate of upazila growth centres will be higher than other growth centres and markets. It is assumed that the upazila growth centres will increase at a rate of 2%, markets will increase at a rate of 1% and other growth centres will increase at a rate of 1.5%. Horizontal expansion considers only the area expansion of the existing growth centres and no new growth centres. And the growth rate for different types of growth centres will not be the same. Larger and urban growth centes will grow at a higher rate than others. It is estimated that the opportunity of upazila growth centres is 5 ha which is more than double than the current area (Table 5.7). The opportunity of other growth centres i. e the growth centres which is not located at the upazila and markets will be 4 ha and 19 ha respectively.

Table 5.7: Horizontal expansion opportunities of growth centres

Types of growth centre	Number	Area	
		Present (ha)	Opportunity (ha)
Upazila growth centres	5	5	11
Other growth centres	6	2	4
Markets	61	12	19
Total	72	20	34

For estimating vertical expansion, it is assumed that the area will remain same but the number of shops per growth centre will increase. In addition, this increment will follow the same growth rate. Table 5.8 shows that currently there are about 150 shops per upazila growth centre, whereas, the opportunity is for 330 shops/upazila growth centre and 130 shops/other growth centre.

Table 5.8: Vertical expansion opportunities of growth centres

Type	Number of Shops	
	Present	Opportunity
Upazila growth centre	150	330
Other growth centre	60	132
Markets	30	66

For calculating the opportunity for industrial expansion, it is assumed that all industrial growth rate will be doubled except the rice mill also the growth of rice mill is related to rice production. So opportunity for rice mill is calculated based on the rice production in the future. It is assumed that the rate of increment of rice mill will be higher in future than the present. The target of Government is to achieve foodgrain self-sufficiency. In this regard, there is no alternative to increase total rice production. It is also observed from field that currently about 50% of the total paddy produced in the study area is processed by rice mills and the rest of the paddy is sold. However, in future it is assumed that 80% of the paddy will be processed by the rice mills in the study area. Based on this assumption the opportunity for rice mill is calculated. It is found that presently there are 96 rice mills in the study area with area of about 43 ha and there is opportunity to grow up to about 107 ha (Table 5.9).

There are currently 13 brick fields operating in the study area and 6 brick fields are closed now as demand has declined. But the opportunity of brick field is calculated considering a growth rate of 2% per year (Table 5.9). Though this growth rate seems high, but it is assumed that in future due to development of infrastructure, communication, and the marketing will also be better. Therefore, the producers can sell the extra bricks outside the area after meeting the local demand.

Table 5.9: Expansion opportunity of Industries

Types of Industry	Present		Opportunity	
	Numbers	Total Area (ha)	Numbers	Total Area (ha)
Brick field	13	17.36	29	38.20
Rice mill	96	42.74	240	106.84
Poultry	12	1.60	26	3.53
Hatchery	3	1.82	7	4.01
Saw mill	72	11.66	158	25.64
Ice mill	14	0.68	31	1.50
Milk vita	1	0.06	2	0.13
Total	211	76	493	180

In addition to the industries given in table 5.9, there is one Sugar mill, one fish farm and small cottage industries such as pulse mill, flour mill. In future, there is opportunity to set up 3-5 jute binding industry in the area.

Based on the following criteria the opportunity for educational institutions and health centres are estimated. In the future, population between the age 5-14 will not increase and the present educational centres serves 80% of this population. Therefore, only vertical expansion will be sufficient to serve 100% of this population.

In the future, according to the government policy, every union will have at least one health centre to provide health services to its population. At present, there are only 6 health centres with an area of 0.7 ha. It is assumed that in future there will be a need for two health centres per union to serve the inhabitants of the area. So, the number of health centre will be 72 as there are 36 unions in the study area (Table 5.10). In this calculation, the unit area of each health centre has been assumed to be same in future.

Table 5.10: Expansion opportunity of health centres

Health Centre	Present (ha)	Opportunity (ha)
Hospital	0.7	4 4
NSDP clinic	0.0364	0.0364
Total	0.7649	4.9

Both groundwater and surface water are used in the study are. The major uses of water resources are domestic, irrigation, fisheries and other purposes like industrial and commercial use. All these uses, except for fisheries, are mainly dependant on groundwater. In the study area, the surface water is coming from Jamuna and Old Brahmaputra rivers through the small rivers Jhinai, Chatal. Dadbhanga. patharkata etc. and drains through Baushi Bridge point. The total amount of water coming through these rivers is 23 Mm^3 during dry season and 1140 Mm^3 during monsoon season, while 21.4 Mm^3 and 1128 Mm^3 of water drains during dry and monsoon season respectively through Baushi bridge point. The surface water use should ensure the environmental flow. Hence, the potential available surface water should be the excess water available after meeting the environmental flow considerations. At present, the available surface water volume does not meet the environmental flow criteria. So. there is no potential for surface water use unless the situation is improved through restoring and excavating the channels and khals by dredging and other measures.

Table 5.11: Groundwater use opportunity

Sub-catchment	Area (Km^2)	Recharge (Mm^3)	Present abstraction (Mm^3)			Abstraction opportunity (Mm^3)	
			STW	DTW	total	Suction mode	Force mode
Sub-1	148	119	50	4	54	65	89
Sub-2	169	129	57	4	62	86	97
Sub-3	82	81	28	2	30	54	61
Sub-4	63	36	21	2	23	37	27
Sub-5	64	38	22	2	23	37	29
Sub-6	76	48	26	2	28	28	36
Total	602	451	204	16	220	307	339

The major source of groundwater is mainly rainfall and flooding from rivers. For estimating groundwater, the study area has been divided into six sub-basins. Table 5.11 illustrates the area, abstraction from groundwater, recharge and potential abstraction opportunity in these sub-basins. Based on field survey, the maximum usable amount of groundwater is 75% of the total groundwater available. So, the maximum amount of groundwater available in the study area is 339 Mm^3. The total potential groundwater recharge in the area is about 450 Mm^3. From the potential available water resources, opportunities of water use in different sectors are estimated.

Domestic use

The present total population in the study area is 0.7 million and it will be 1 million in the year 2050. Of these, 18% live in urban areas, whereas 82% live in rural areas. According to Gleick (1996b), the basic water use requirement per capita per day is 50 litres. In this research, it has been assumed that the water use per capita per day is 80 litres for urban area and 50 litres for rural area. So, the water requirement for domestic purposes is 14.10 Mm^3 (present) and 21.68 Mm^3 (2050). The domestic water use is mainly dependent on groundwater. The available groundwater resources are enough to fulfill the domestic use requirements. The households are using hand tube-well (HTW) for pumping groundwater for domestic purposes. The hand tube-well abstracts water from main aquifers. The hand tube-well operates in suction mode and pumping in suction mode is possible upto 6.5 metres. So, the limiting depth for groundwater abstraction using hand tube-well is 6.5 metre. If the groundwater level falls below this level, pumping will not be possible using hand tube-well.

Irrigation use

Due to inadequate surface water in the river channels, irrigation in the study area mainly depends on groundwater. As the river flow is decreasing in the study area, the use of Low Lift Pump (LLP) is also declining. This situation can be improved by augmenting the flow of rivers by dredging and other measures. As the NWMP emphasizes depending more on surface water than on groundwater, the surface water availability in the rivers should be increased to fulfill the LLP requirements and environmental flow criteria while, present surface water availability is around 6% of the LLP requirement and 10% of environmental flow requirement.

The Jhinai river is dependent on Old Brahmaputra which is again dependent on Jamuna river flows. The connectivity of Old Brahmaputra and Jamuna is a very complex phenomena. According to FAP 3.1 study, dredging is not a feasible solution for Jhinai river (FAP 3.1, 1997a). Therefore, increasing intake is not possible in Jhinai river. As a result, to improve the situation, regulators should be placed in Jhinai offtake and Baushi Bridge point to increase the storage in the channel. Other rivers like Chatal should be dredged to increase flow and improve surface water availability during the dry season.

The shallow tube-wells (STW) and deep tube-wells (DTW) depend on groundwater for irrigation. The maximum potential available groundwater for irrigation is the volume available after meeting domestic use requirements. The shallow tube-wells operate in suction mode while deep tube-wells operate in force mode. As described earlier, pumping in suction mode is limited to 6.5 metres, shallow tube-wells are limited to pump groundwater available within 6.5 m. The deep tube-wells has no such limitations and it can pump even more than 12 m. But the drawdown due to deep tube-wells influences surrounding shallow tube-wells and hand tube-wells within a radius of 200 m. Thus, the water availability to shallow tube-wells and hand tube-well within this influence zone is reduced. The potential available groundwater to shallow tube-well is 417 Mm^3 and to deep tube-well is 453 Mm^3 (Table 5.12).

Table 5.12: Irrigation use opportunity

Irrigation mode	Present (Mm^3)	Opportunity (Mm^3)
LLP	5	11
STW	289	417
DTW	23	453
Traditional	15	20

Fisheries use

The capture fisheries production depends on good quality and quantity of water and also abundance of food in surface water habitat. The total water body (beel) area within the study area is 7.8 km^2, khal area is 6.85 km^2 and river area is 2.62 km^2. The water body condition is degrading in the study area as shown in Table 5.13.

Table 5.13: Present water use for fisheries and opportunities

Types of waterbody	Present		Opportunity	
	Area (km^2)	Volume (Mm^3)	Area (km^2)	Volume (Mm^3)
Beel	7.9	11.85	8.5	12.75
Khal	6.9	10.275	6.9	10.275
River	2.6	3.94	5.0	7.53
Total	17.4	26.06	20.4	30.56

The water body condition should be improved by re-excavating and restoring and improving connectivity by dredging. Through these interventions 30.56 Mm^3 water can be retained in the water bodies and rivers for fisheries resources.

Other use (Industrial/ commercial)

The number of industries in the study area and their water requirement for both present and future conditions is presented in Table 5.14.

Table 5.14: Present industrial water use and opportunities

	Groundwater (Mm^3)	Surface water (Mm^3)	Total (Mm^3)
Present	0.1192	0	0.1192
Opportunity	0.293	0	0.293

The industries mainly depend on groundwater except fish farms and sugar industry. The fish farms mainly depend on rain water harvesting and some small amount from groundwater. The sugar industries depend predominantly on surface water from river. In the study area, the annual rainfall is about 5500 mm. This amount can meet the requirement of fish farms. There are no Jute industries in the study area. If Jute industry is established in the area, standing water bodies will be required for jute retting during monsoon. Normally khals are used for this purpose. During monsoon there are available khals that are used for this purpose.

5.3 Scenarios

5.3.1 Upstream withdrawal

Water withdrawal due to development activities in the upstream areas, the flow of Jamuna river will be impacted. For assessment of the impacts of upstream water withdrawal on the flow of Jamuna river, several assumptions were made. Seventy percent of the Brahmaputra flow upstream of Bangladesh contributes to Jamuna flow. For assessment, it was assumed that 60% of dry season flow and 40% of wet season flow will be withdrawn from Upstream Brahmaputra while return flow through base flow and other means will be 50% of the net withdrawal. Finally, net reduction in Jamuna flow will be 20% during dry season and 15% during wet season.

Applying these assumptions, the Jamuna flow at Bahadurabad (Station 46.9L) is generated. Long term average values of Bahadurabad have been used as a base for this assessment. For generating other boundary point data for hydrodynamic analysis, correlations were established between the long term average discharge of Bahadurabad and average water level of corresponding boundary point. Table 5.15 represents these correlation equations. Figure 5.5 illustrates the hydrograph of Bahadurabad under upstream water withdrawal conditions.

Table 5.15: Relationship equations between Bahadurabad and boundary points

Boundary point	Correlation equation	R^2
Jamuna upstream	y=1.1x	-
Jamuna downstream (Station 15J)	y = {2.5769Ln(x) - 11.368} + 0.6	0.9886
Old Brahmaputra downstream (Station 225)	y = 1.685Ln(x) - 3.2238	0.897
Baushi bridge (Station 134A)	y = 1.84Ln(x) - 5.6882	0.898

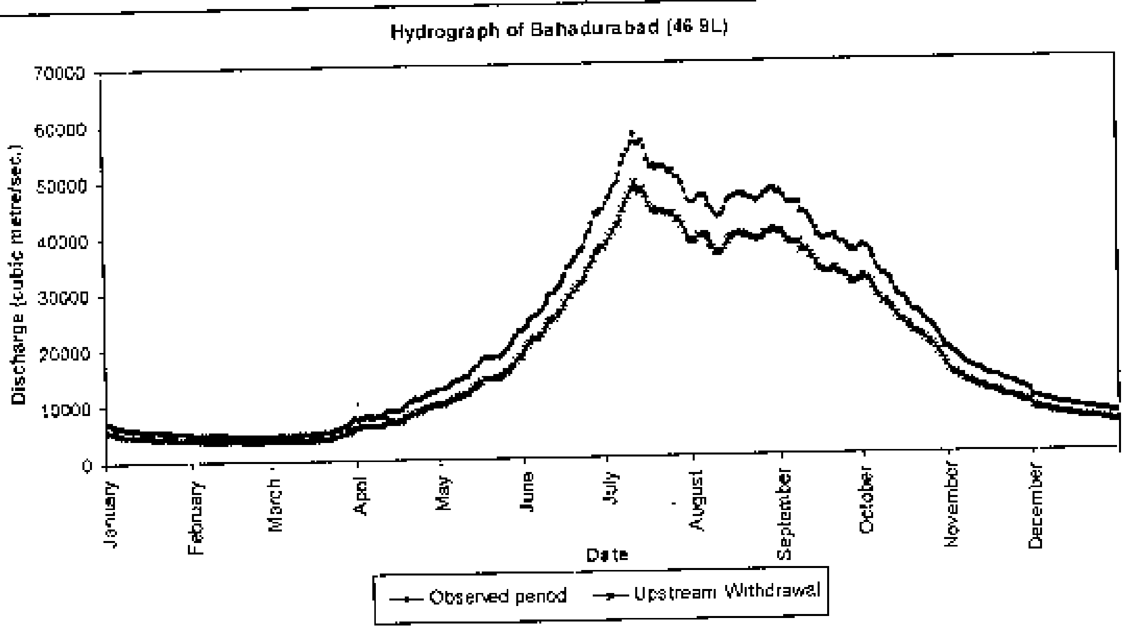


Figure 5.5: Hydrograph of Bahadurabad for upstream water withdrawals

5.3.2 Climate change scenarios

Several climate change related studies for Bangladesh have been published in recent years applying various models to predict the future scenarios. Among these studies the CLASIC project (Farquharson et al., 2007), ORCHID project (Tanner et al., 2007), and World Bank study on Climate Change Impacts on Food Security in Bangladesh (Yu et al., 2010) are remarkable. The present study adopts the most recent prediction done by Yu et al. (2010) as a part of the World Bank study. Yu et al. (2010) analyzed sixteen global climate models from the Inter-governmental Panel for Climate Change (IPCC) Program for Climate Model Diagnosis and Intercomparison (PCMDI) AR4 archive, each run for three emissions scenarios (A1B, A2 and B1) and a 20th-Century Experiment. The model output consists of monthly averages of simulated precipitation and temperature. Yu et al. (2010) used 64 scenario experiments. The resulting changes in various climatic parameters according to Yu et al. (2010) are projected temperature changes are following a positive trend for all months and seasons from the 2030s onwards. Median warming of 0.75°C, 1.55°C, and 2.4°C by the 2030s, 2050s and 2080s respectively is simulated from a range of plausible scenarios and greater uncertainty (in terms of magnitude and direction) exists with future precipitation than future temperature.

In this research, the impact of climate change in extreme flood monsoon has been analyzed. For this, the average hydrograph for 2050s of Bahadurabad station has been used from Yu et al. (2010). The dry season flow of 1981 and monsoon season flow of 1998 is used to prepare the base hydrograph of this research for Bahadurabad Station. Since the changes in dry season is not significant, only the percentage changes in monsoon season flow is applied to the base hydrograph. For generating other boundary point data for hydrodynamic analysis, correlations described in Table 5.15 have been used. Figure 5.6 illustrates the discharge hydrograph of Bahadurabad station for climate change condition as used in the current research.

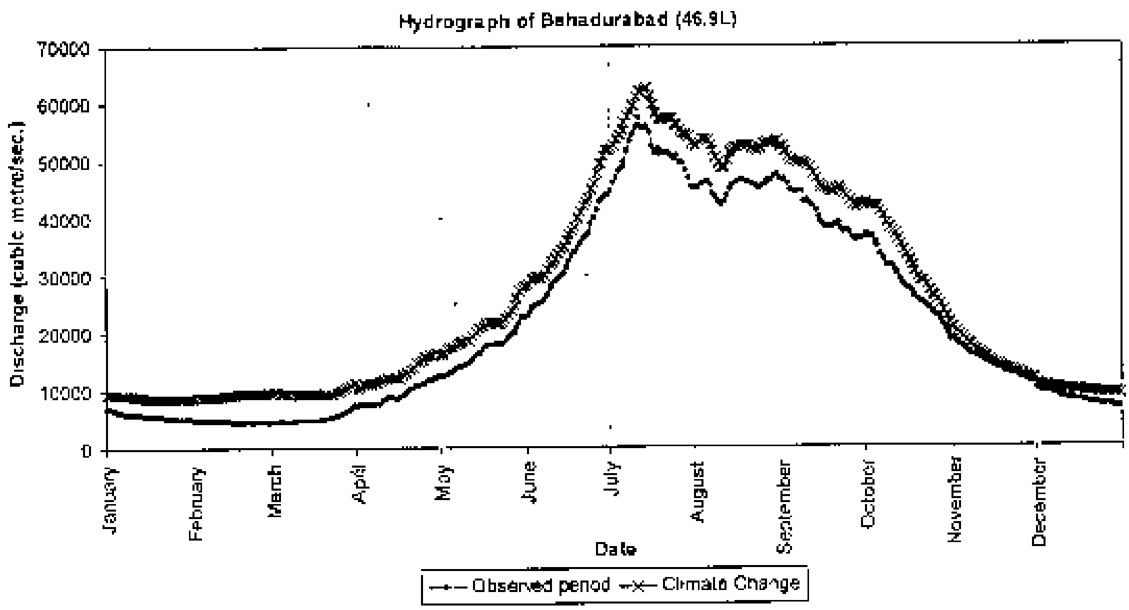


Figure 5.6: Hydrograph of Bahadurabad for climate change condition

5.4 Development of Options

By 2050, land and water use for the study area has been developed for three possibilities, which are Options A: Autonomous development (do nothing), Option B: Implementation of regional plan (Jamalpur priority project), and Option C: Sustainable land and water use (developed in this research).

5.4.1 Option A: Autonomous development

Autonomous development is referred to as the development that took place without any additional interventions. Autonomous development is projected following existing trend and social preferences of farmers and land use development. Sequencing of land use allocation has been done as settlement as first priority, then comes water and other uses (infrastructure and industries) and the remaining has been allocated as cultivable area. With existing trend, production of Boro is increased and Aman is reduced with the decrease of NCA.

5.4.2 Option B: Implementation of regional plan

In 1997, Flood Action Plan (FAP) started its Jamalpur Project Refinement study to alleviate poverty, improve social environment, provide flood protection along the river banks, improve natural areas where possible and improve quality of life of people in study area. These objectives were set to achieve by controlling flood waters on mainland to avoid catastrophic floods in wet years, flood proofing the poorest and most exposed char dwellings, enhance fish production and improving both natural and artificial fish habitats, creating short and long term employment opportunities especially for women and lower income groups, improving water transport facilities and agricultural production in the study area.

The study area is highly vulnerable to regular flood, which often cause damages to properties of the people living in the area. The main crops suffering damage are Aman, Jute and Sugar cane. In 1997, a public consultation with affected farmers revealed that uncontrolled floods were really felt as constraint (FAP 3.1, 1997a). The farmers wished to have more control of water during a normal monsoon As such, to reduce risks different options for embankment have been tested during feasibility and refinement study. Based on economic, social and environmental perspective the Controlled Flooding Embankment option has been accepted. The regional plan highlights different plans for development of agriculture and flood problems. Flooding and drainage are major concerns for agriculture life and livelihood in the area. To mitigate these concerns flood control and drainage improvement intervention will shift F2, F3 type of land to F0 and F1 type. As a result, more area will be brought under monsoon rice, mainly Aman (FAP 3.1, 1997b).

The embanked area comprises of five major hydraulic inflow and outflow structures: i) Jhenai inlet ii) Chatal inlet iii) Islampur inlet iv) Jhenai/ Chatal outlet and v) Bausi bridge outlet. All these structures will have standard double lifted gates of 3 m vent width. The number varies according to the overall width of the barrage, the height varies from 3m to 5 m (vent dimensions) according to hydromechanical and hydrostatic requirements. There will be one gate of 3.5 m width and 4.5/5 m height (vent dimensions) per structure for navigational requirements At Chatal inlet, Islampur inlet and Bausi bridge outlet, two gates per structure of 0.6 m width and 5 m height (vent dimensions) is located at the end of each structure with associated channels for fish migration requirements. At Jhenai/ Chatal outlet and Jhenai inlet, two fish gates per structure of 3m width and 5 m height. (vd) at the end of each structure have been proposed to reflect the much larger size of these structures. An implication of a 103 km embankment around the periphery of the study area will reduce the area of inundation (FAP 3 1, 1997a).

The proposed embankment and water control structures will have different effects on water bodies and fish production. Control of water level inside the protected area will decrease the extent, duration, and depth of the floodplain, as a result, it will affect the level of capture fisheries mainly among the subsistence fishermen. On the other hand, pond fish culture will be directly benefited from controlled flooding (FAP 3.1, 1997a). During normal flood years, the embankment and water structures will have no major effect, as the inlet/outlet structures will remain open during fish migration. Capture fishery will have a positive effect during the dry years. Induced flood will be possible to some extent by closing the outlet structures. In the study area, storage of water in the southern part of the perimeter will increase capture fisheries especially in the artificially inundated segments. Finally, the regional plan proposes to re-excavate beels, ponds, internal rivers and linking channels to fish and fisheries through restoration of habitat.

FAP has initiated regional plan for controlling flood by putting embankments and developing hydraulic inlet and outlet structures. The set target of Regional plan is to increase Aman production through flood control. In this regard, 2 outlet structures have been proposed at Chaatal-Jhinai outlet and Baushi bridge outlet for augmentation of water flow and fish production during dry season In addition with the outlet structures, rivers, khals and beels were proposed for dredging and excavation to increase productivity, connectivity to increase fish production. As a flood control measure, embankment was proposed to protect the land from 100 year flood. Other land use structures will follow similar projection of autonomous development.

5.4.3 Option C: Balanced land and water use activities

Balanced land and water use option focuses on the socio-economic improvement as well as protection of floodplain environment considering local preferences and government policies and strategies. In 2001. land use policy highlighted the need for land zoning for integrated planning and management. The policy also emphasized protection and maintenance of all existing wetlands. In 1999, National Water Policy addressed the need to harness, develop and manage all forms of surface and ground water in an efficient and equitable manner. It also emphasized ecosystem needs. The 1999 Agriculture policy emphasized on maintaining food self-sufficiency in conjunction with efficient irrigation, integrated pest management and increased use of composite fertilizer. The fisheries policy aimed at increasing fish production through capture fisheries and conserving fish habitat. Forestry policy is directed to maintain a minimum of 20% forest coverage. Environmental policy aimed at maintaining ecological balance and to protect and improve the environment. The safe water supply and sanitation policy stated that all population should have access to safe drinking water and sanitation at an affordable cost. The policy emphasized the reduction in the number of population served per tube-well from 105 to 50 in near future and one sanitary latrine for each household. Industrial policy emphasized on labour intensive manufacturing industry and create employment opportunity for future generation.

The Poverty Reduction Strategy Paper (PRSP) emphasized moving agricultural production from a predominantly subsistence level to a more diversified commercial pursuit. Regarding food security, PRSP strategies aimed at providing low cost food supply and an income distribution with adequate purchasing power for lower income population. In fishery sector, strategies have been initiated for intensification and promoting a dynamic rural aquaculture. The leasing policy of Jalmahal aims to provide adequate opportunities for poor fishermen and foster community participation. Forestry sector emphasized expansion of forest in depleted hills and khas lands and tree plantation in rural areas through community participation of lower income population. For environmental and natural resource conservation, PRSP gave attention to agricultural land degradation, biodiversity, access to common property, afforestation and tree plantation and urbanization-related environmental issues. Further, PRSP emphasized flood protection by implementing structural and non-structural measures aimed at reducing the loss of life and property.

In addition, Bangladesh developed a National Water Management Plan (NWMP) under National Water Policy (1999). The plan intended to contribute to national economic growth through rational management of water resources such that, it protects natural environment and improves the quality of life.

Balanced land and water use activity suggest to increase production through minimizing risks for monsoon rice. Area wise distribution of crops will help in reducing risks from flood and drought. As on social preference, 50m area on both sides of river is suggested for Jute and Rabi cultivation. 50m buffers around permanent water bodies have been suggested to safeguard the ecosystem. Cropping pattern will be chosen in a way that enhances spatial fair distribution of employment. Changing mindset of farmers, to provide supplementary irrigation to the Aus and Aman crop to reduce stress from drought. Presently, the farmers are heavily dependent on Boro cultivation. The mindset of farmers has to be changed from the heavy dependency on Boro to a diversified cropping pattern which includes T.Aus-T.Aman-valued Rabi crops in the high and medium high lands. The remaining area should cultivate Jute, Boro and other crops.

The above mentioned three projected options A, B and C will have four scenarios. First, no externality. Second, climate change in addition to long-term average hydrological condition. Third, upstream water withdrawal in addition to long term average hydrological condition. Fourth, climate change is super imposed on extreme flood events. Thus, the projected options along with the scenarios, that is, twelve situations are shown in Table 5.16. To simulate these twelve situations, hydrologic, hydrodynamic and land and water use projections are used under a deltaic floodplain environment.

Table 5.16: Possible options with scenarios

	A. Autonomous Development	B. Implementation of Regional Plans	C. Balanced land and water use activities
1.No externality	A1	B1	C1
2.Climate change	A2	B2	C2
3.Upstream water withdrawal	A3	B3	C3
4. Climate change with extreme event	A4	B4	C4

Scenario A1 is autonomous development with no externalities A2 and A3 are the autonomous development with influence of climate change and upstream water withdrawal respectively. A4 is the autonomous development with Climate change strengthened by extreme event. Similarly, scenario B1, B2, B3 and B4 represents implementation of the regional plans scenarios while C1, C2 and C3 are the scenarios showing the Sustainable land and water use options for the future.

5.5 Land and Water Use for Different Options

In the future, increased population demand for economic and social necessities like food, shelter, communication etc. will create additional pressure on land and water resources. Presently, the total population in the study area is more than half million and by 2050 it will be almost double. Population in urban areas will be higher compared to that of rural areas and this increasing urban pressure will end up with more land and water use. 2050 projection on land and water use for the study area has been derived on the basis of the above three options and these are analyzed in the following section.

Based on the constraints, opportunities and driving factors, four types of land use had been estimated for the study area (shown in Table 5.17). From the projection, it is assumed that in future, agriculture and wetland area will decrease where as, settlement and other land uses will increase.

Agriculture: Ten types of cropping patterns have been identified covering total 47,171ha of NCA. Table 5.18 and Figure 5.7, 5.8 and 5.9 show cropping patterns with future NCA. Among them the major crops are Aman and Boro In future, due to increased settlement and industrial areas, NCA will decrease. According to option A, production of Boro will increase but Aman will decrease. Option B suggests that Aman production will increase as there will be flood protections and less risk of loss.

Table 5.17: Four types of land use for 2001, 2008 and options A, B and C

Land use (ha)	2001	2008	A	B	C
Agriculture	47,819	47,171	44,448	44,300	46,348
Settlement	9,141	9,766	12,367	12,367	10,296
Wetland	2,935	2,875	2,805	2,875	2,935
Others	405	488	680	758	721
Total	60.300	60,300	60,300	60,300	60,300

Option C suggested an agricultural land zoning based on crop suitability. flood depth and its vulnerability to the crops. As a result, it is suggested a new cropping pattern T.Aus-T.Aman-Valued Rabi crop in the high land area where the flood depth does not exceed 30 cm. Another cropping pattern Aman-Rabi-Jute is suggested where the flood does not exceed 60 cm. Aman and Boro is suggested to be cultivated where the flood depth level is between 60-90 cm. Whereas, Boro and Jute has been suggested where the depth of inundation is between 90-135cm. Jute and Rabi are preferred on sandy soils along the periphery of the river. Further, existing cultivation of sugarcane will be unchanged.

Table 5.18: Cropping pattern for 2001, 2008 and options A, B and C

Crop area (ha)	2001	2008	A	B	C
Sugarcane	3005	2330	2327	2338	2442
Others (Fruits, Vegetable)	3668	3709	3301	3262	670
Boro-Mustard/ Valued Crop	1993	1899	1781	1718	7414
Boro-Aman	18414	18778	18369	24905	6195
Boro-Jute	529	524	506	507	4559
Boro	7245	10574	11812	5296	9422
Aman-Rabi-Jute	3073	3008	0	2734	6261
Aman-Rabi	3495	3472	2423	0	0
Rabi-Jute	4734	1526	2753	2992	548
T.Aman-T.Aus-Rabi	0	0	0	0	7969
Fallow	1663	1351	1175	550	868
Total Aman	24981	25258	20792	27639	20425
Total Boro	28181	31775	32468	32425	27590
Total	47819	47171	44448	44300	46348

Land type analysis for the years 2001, 2008 and 2050 for different land use option (A, B and C) has been carried out based on the results of HDM and DEM. The land type distribution is shown in Table 5 19. In 2001, there was 72% of F0 land, which is in a declining state. In future, flood control measures will increase this percentage. In option B, a full control, with embankments in both Jamuna and Old Brahmaputra will increase F0 land up to 88%. Hence, additional 12,000 ha of flood free land will be added to increase Aman cultivation in option B against option A, where no flood control measures will be applied. Option C, partial control (embankment only in Jamuna), will increase flood free area up to 74%.

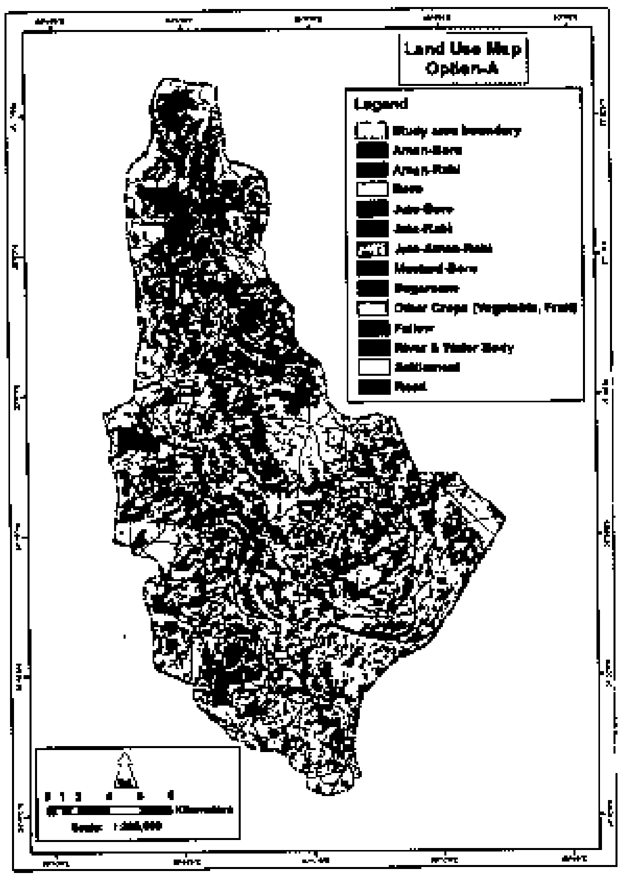


Figure 5.7: Land use map showing different cropping pattern for option A

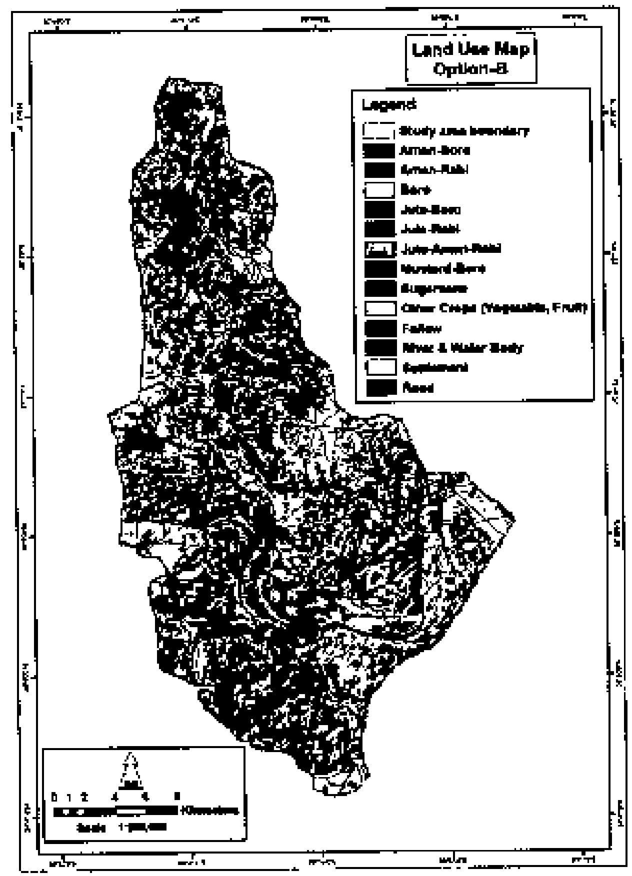


Figure 5.8: Land use map showing different cropping pattern for option B

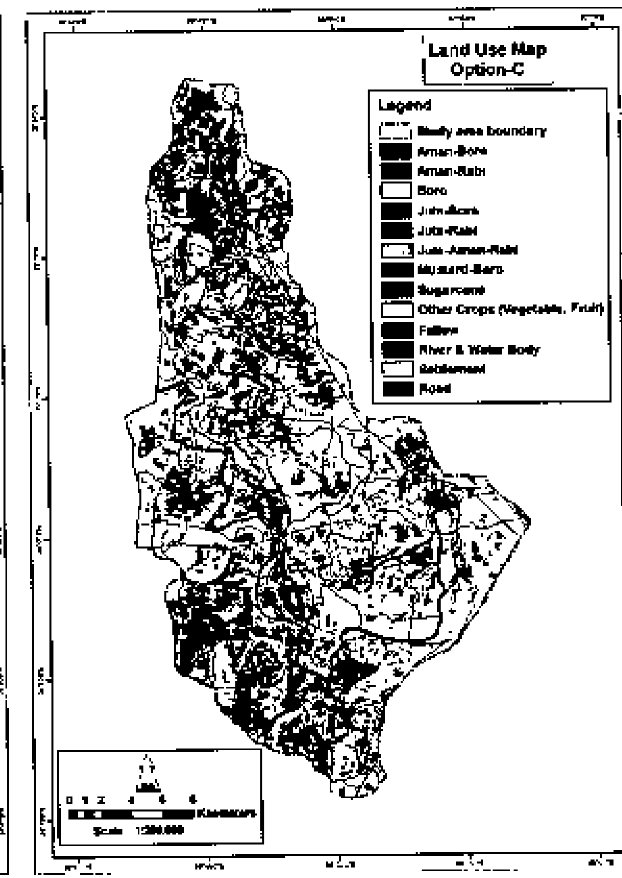


Figure 5.9: Land use map showing different cropping pattern for option C

Table 5.19: Land type distribution (in percentage) for 2001, 2008 and the options

Land Type	2001	2008	A	B	C
F0	72	48	67	88	74
F1	13	26	12	5	11
F2	8	18	13	2	8
F3	2	6	3	2	3
F4	5	2	5	3	4

Settlement: Urban area is expected to increase more rapidly due to available facilities and modernization of urban sector, but rural areas will not expand at the same rate. In 2001, only 16% of the population in the study area lived in urban areas, whereas in 2050, 31% of the total population is projected to live in urban areas. In option A, it is assumed to follow the current trends of both urban and rural settlements. By 2050, per capita area will be 3.3dec and 2.5dec for rural and urban areas respectively. On the other hand, option B, the regional plan does not indicate the expansion of the settlement area for future generations (population in year 2050). Therefore, option B assumes same projections as option A. The projected settlement area is shown in Table 5.20.

Table 5.20: Settlement area for 2001, 2008 and the options

Type (hectare)	2001	2008	A	B	C
Urban settlement	1,463	1,737	3,149	3,149	2,267
Rural settlement	7,678	8,029	9,218	9,218	8,029
Total settlement	9,141	9.766	12,367	12,367	10,296

Option C has been projected considering ideal house of 1,200 sft for four people (assuming an average household size in year 2050) and 30-50% area has been included for road and other utility services. As such, per capita settlement area for urban and rural have been fixed at 1.8d and 2.9d respectively.

Wetland: From 2001-2008, wetlands have been declining from 850 ha to 790 ha, mainly due to encroachment of farmlands and sedimentation. In option A, by following the declining trend, the beel area has been projected to be 720 ha. However, due to partial restoration and maintaining existing beel area under option B, by 2050, the beel area will be 790 ha. Whereas, with full restoration under option C, the beel area will be restored to the 2001 level as shown in Table 5.21.

Table 5.21: Wetland area for 2001, 2008 and the options

Wetland types (hectare)	2001	2008	A	B	C
Beels	850	790	720	790	850
Jhinai (dry season)	382	262	100	382	502
Rivers	2085	2085	2085	2085	2085
Total	2935	2875	2805	2875	2935

As the data demonstrates, without any intervention and with the current trend, the beel area will continue to decline by 2050 as shown in Figure 5.10. Some beels are still existing because of water demand for fish production and the depth of water in these beels are not conducive for rice production. Regional plan will increase the amount to 790 ha and a full restoration will increase the water up to 2001 level of 850 ha.

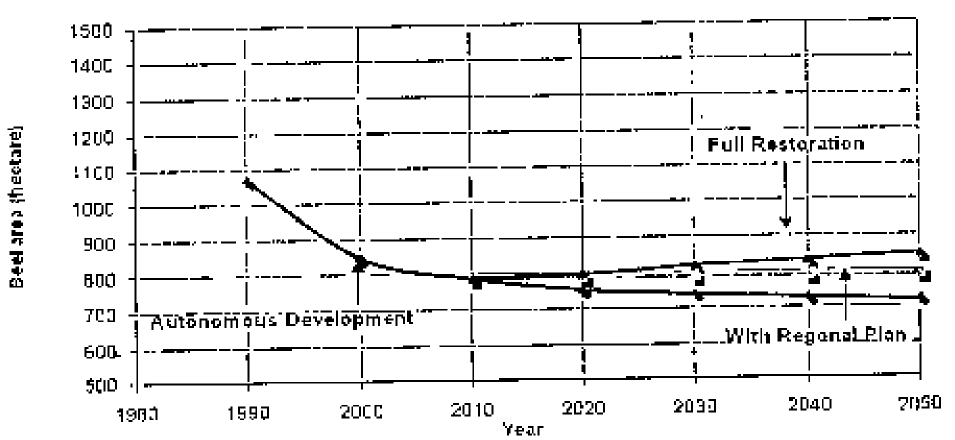


Figure 5.10: Change and restoration plan for Beels

The considered criteria for productive fisheries, the inundation should be at least one meter for three months. Using hydrodynamic model and using the criteria as stated, the fisheries productive area has been delineated for different options and scenarios. Since 2001, Chatal and Dadbhanga has been dry during the dry season. In 2008, Jhinai covers 262 ha which has a possibility of further decline to 100 ha by 2050, if followed by the present trend in option A. Partial restoration through dredging and other water flow improvement measures for Chatal and Jhinai and full restoration considering all the rivers will increase the area up to 502 ha in option C. Option B, targets to achieve 382 ha of land. Restoration plans for all three rivers are shown in Figure 5.11.

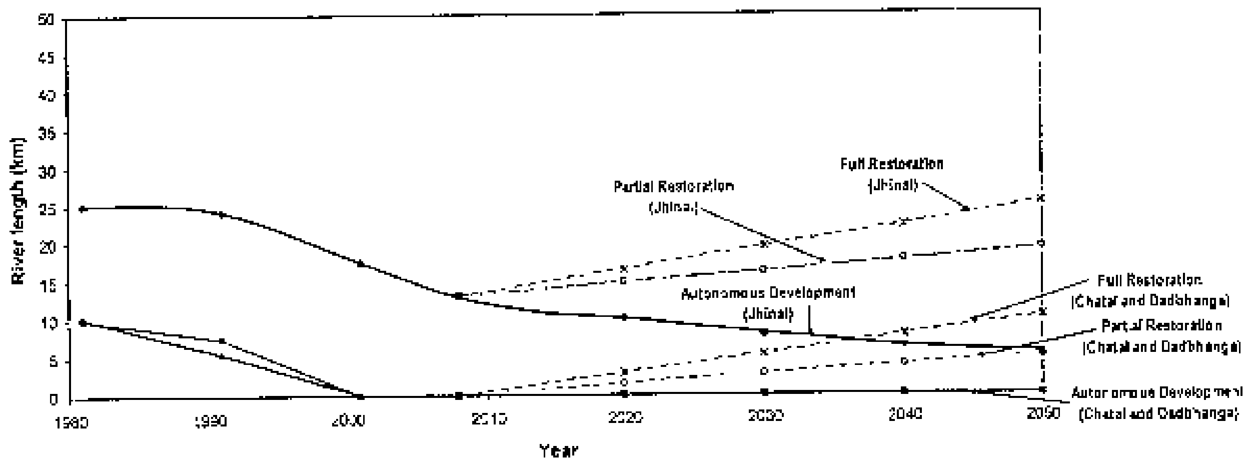


Figure 5.11: Change and restoration plan for rivers

Other land use: Road length is projected for all three options, which emphasize on increasing capacity and functionality of existing roads rather than create new ones and protection of roads from flood. In this regard, the existing roads either were widened or increased the road height. Widening roads will require more land. Hence, total area of roads will increase in future. For all options, every upazilas will be connected to district headquarter by regional roads to improve the connectivity. According to government policy, all upazilas will be connected and every union will be connected to its respective upazila Such as, Chukaibari union of Dewanganj upazila and Satpoa union of Sarishabari upazila were not connected to any union or upazila. Based on the government policy it is assumed that in future, these unions will be connected by feeder road B to the nearest upazila or union. In addition, to improve the connectivity, the road between Islampur and Madarganj will be converted to feeder road A. Option A considers only existing flood control measures, but option B includes new measures and regulators for all rivers. Option C includes flood control measures only for Jamuna river. The embankment along the Jamuna river will be used as embankment cum feeder road A to protect the loss of agricultural land for both options B and C, and this road will be connected to nearest upazila or feeder road A by feeder road A. In option B, the embankment along the Brahmaputra river starting from Islampur and ending at

Melandaha, will be converted to regional roads. The projected road length for different options are shown in Figure 5.12.

Industries, education and health centers will be utilized as mentioned in chapter four. It is assumed that government intervention for industries in upazilas, creation of employment opportunities by constructing jute and garment industries by 2050. Option A assumes to have 5 garment industries, option B assumes 10 and option C assumes 25 garment industries. More than 60% employment in the garment industries are women. Under option C, jute cultivation is proposed to be doubled. To take advantage of this additional production, two jute mills have been proposed, which will create market for the farmers and additional employment opportunities for the labour force. On the other hand, to adhere to the environmental condition, it is proposed to reduce brick fields. Table 5.22 shows the distribution of other land uses for different options. The land use maps have been prepared for the options A, B and C. Figures 5.7 to 5.9 illustrates the land use pattern for options A, B and C respectively.

Table 5.22: Other land use for 2001, 2008 and the options

Type	Area (ha)				
	2001	2008	A	B	C
Road & Others	262	324	387	465	446
Brick fields	13	17	38	38	20
Rice mills	32	43	107	107	107
Other Industry	13	16	35	35	35
Health Center	1	1	5	5	5
Growth Center	16	20	34	34	34
Education center	68	68	75	75	75
Total	405	489	680	758	721

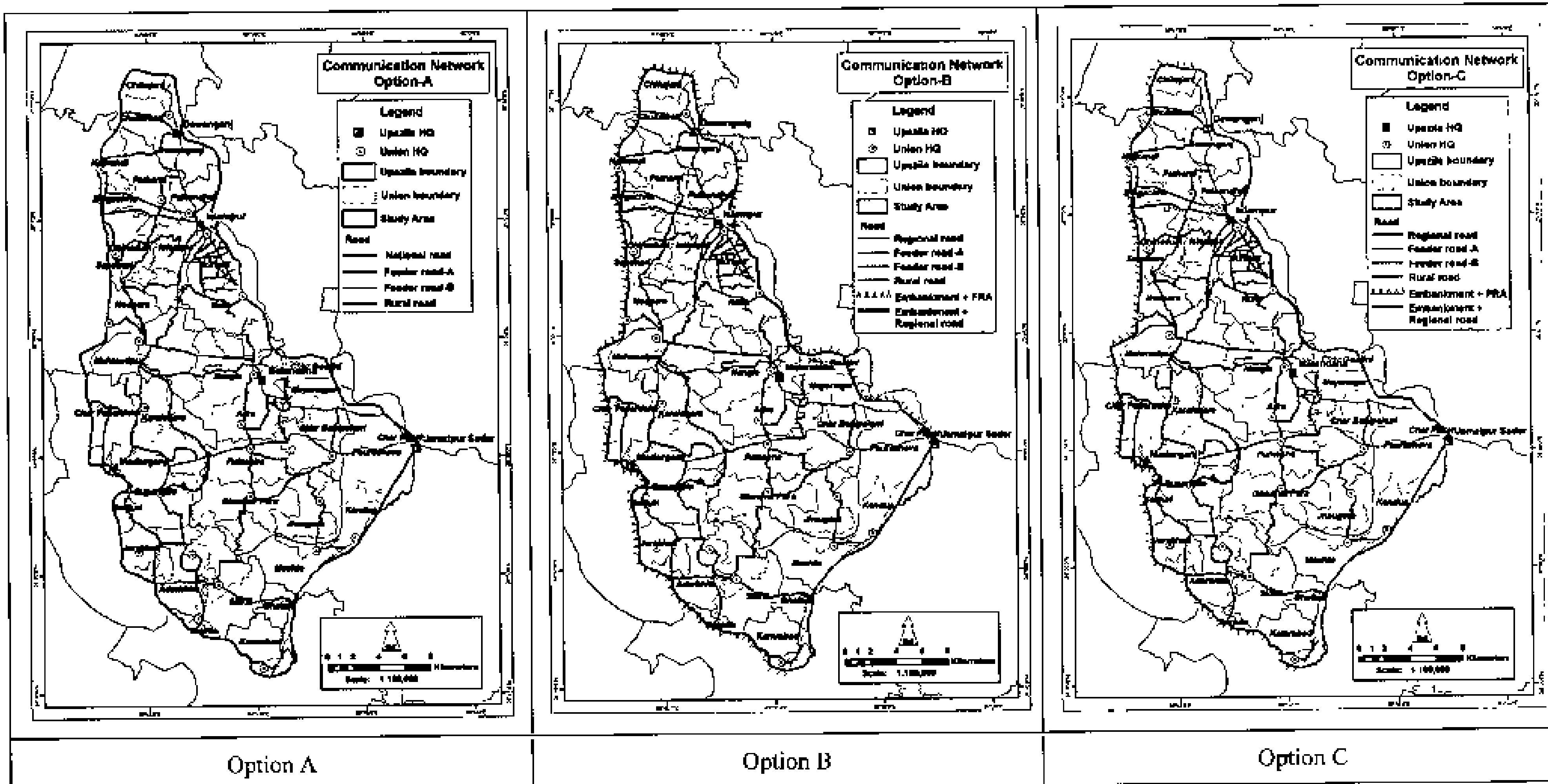


Figure 5.12: Road length by road type for different options

Water use for year 2050 has been projected based on the three options A, B and C. Four major water use categories have been identified which are shown in Table 5.23.

Table 5.23: Four types of water use for 2001, 2008 and the options

Type	2001	2008	A	B	C
Irrigation use	300.26	340.23	347.71	347	296.00
Domestic use	12.49	14.10	21.68	21.68	21.68
Fisheries/ wetland	15.37	12.85	14.62	15.67	17.77
Other use	0.34	0.38	0.65	0.65	0.65
Total	328.45	367.56	384.67	385	336.11

Irrigation: Groundwater and surface water sources are used for irrigation. Normally, the pumps are required to run12 hours per day, but in extreme dry spell it is expected to be 16 hours. Both operational times has been taken into account for the projection (shown in Table 5.24). Following the present trend. option A will increase the use of groundwater for irrigation but surface water use will decline due to drying of river water. Dredging, fixing regulators and augmentation of rivers in the dry season will increase the surface water flow in option B. As such, in option B. total water use per day will be 347 Mm^3 for 12 hrs and 463 Mm^3 for 16 hrs. With the use of deep tube-wells and shallow tube-wells for irrigation, the water table lowers. As a result. it affects the use of hand pumps for domestic use.

To protect the domestic users to get safe drinking water through hand pumps, a 50 meter buffer around the settlement has been proposed to restrict groundwater extraction under option C. In addition, the irrigation efficiency is also very low. Currently 2000-2400 mm of irrigation is used in per ha of boro field, whereas, requirement is 1000-1400 mm of water. By using 'Optimal Water Use' technology developed by CEGIS, this additional use of water can be saved which will reduce energy use by 25%-30% (EGIS, 2001b)

Table 5.24: Surface and Ground water irrigation (Mm^3) for 2001, 2008 and the options

	2001		2008		A		B		C	
	12 hr	16 hr	12 hr	16 hr	12 hr	16 hr	12 hr	16 hr	12 hr	16 hr
Deep tube-well	17	22	23	30	27	36	23	31	22	29
Shallow tube-well	213	283	289	385	313	417	295	394	274	366
Total Ground water use	**229**	**306**	**311**	**415**	**340**	**453**	**318**	**425**	**296**	**395**
Low lift pump	10	14	5	6	2	2	5	6	0	0
Khal	21	28	9	12	2	3	9	12	0	0
Traditional	40	53	15	20	4	5	15	20	0	0
Total Surface water use	**71**	**95**	**29**	**38**	**8**	**11**	**29**	**38**	**0**	**0**
Total water use	**300**	**400**	**340**	**454**	**348**	**464**	**347**	**463**	**296**	**395**

Domestic use: In future, population pressure will increase the demand for domestic water use in both urban and rural areas. The domestic water use has been projected (as shown in Table 5.25) is based on the assumption of per day demand of water is 80 liters for urban and 50 liters for rural areas. Urban society is completely dependent on groundwater source for its use. For all three options, water use will have no change being 9.09 Mm^3 for urban and 12.60 Mm^3 for rural use.

Table 5.25: Domestic water use (Mm^3) for 2001, 2008 and the options

Type	2001	2008	A	B	C
Urban	2.87	3.70	9.09	9.09	9.09
Rural	9.62	10.40	12.60	12.60	12.60
Total	12.49	14.10	21.68	21.68	21.68

Fisheries/ wetland: In the context of above discussion, in the land use section 5.3.3. re-excavation of beels and rivers will increase from 15.67 to 17.77 Mm^3 water, which will support more fish habitats. The waterbody use is shown in Table 5.26.

Table 5.26: Fisheries/wetland use (Mm^3) for 2001, 2008 and the options

Type	2001	2008	A	B	C
Beel	12.75	11.85	10.80	11.85	12.75
Dry River	3.82	2.621	1.00	3.82	5.02
Total	15.37	12.85	14.62	15.67	17.77

Other uses: In the future because of increased population and changes in land use due to growth in industries, markets, education and health care facilities will result in higher water usage. In all three situations, amount of water use will be same. Industries will be the major user, using water up to 293,043 m3 in 2050. The uses are shown in Table 5.27.

Table 5.27: Other water uses (Mm^3) for 2001, 2008 and the options

Type	2001	2008	A	B	C
Industry	88,797	119,188	293,043	293,043	293,043
Growth center & market	73,500	89,775	163,800	163,800	163,800
Education center	173,160	173,160	190,985	190,985	190,985
Health Center	920	1,117	7,143	7,143	7,143
Total	336,377	383,240	654,972	654,972	654.972

5.6 Compliance to Constraints

From both field survey and literature review, it has been found that affordability of basic needs are related with income of the population of the study area (Figure 5.13). As the income of the population increases, percentage of population below poverty standard also starts to decline. The figure shows that in a society with an average income of 3000 Tk/month, 25% of the population consumes rice below the standard. 58% of the population cannot afford required amount of fish and 82% of the population cannot maintain the standard living space.

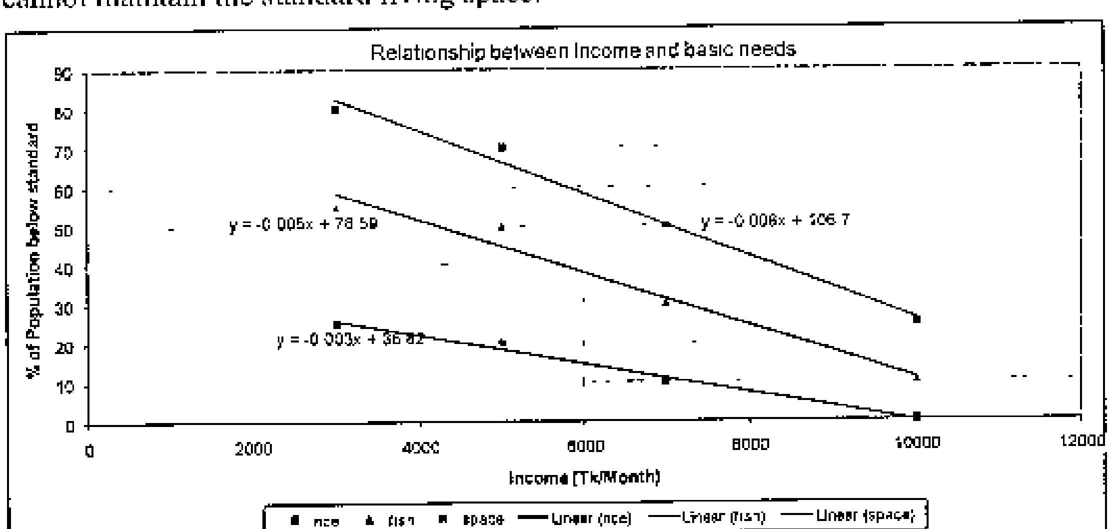


Figure 5.13: Relationship between income and affordability of basic needs

Table 5.28: Estimated values of indicators of equitable resource distribution

Criteria	Sub-criteria	Indicator		Unit	2001	2008	Options for 2050		
							A	B	C
Fulfilling basic needs	Safe drinking water	% of people have access to safe drinking water		%		90	100	100	100
	Housing space	% of household meet the living space requirement	Average household	%	25	20	28	31	30
			Farmer (LL)	%	17	18	43	50	45
			Fisherman	%	37	21	21	18	37
	Cereal (Rice)	% of household meet the cereal (rice) requirement	Average household	%	78	76	79	81	80
			Farmer (LL)	%	74	75	86	90	87
			Fisherman	%	83	76	76	75	83
	Animal protein (fish)	% of household meet the fish requirement	Average household	%	48	44	50	54	52
			Farmer (LL)	%	41	42	63	69	65
			Fisherman	%	58	45	45	42	58
Fairness in resource distribution	Accessibility to flooded area for subsistence fishing	% of settlement area within 1/2 km of the flooded area		%	45	48	42	35	40
	Temporal distribution of occupation (Agriculture)	More than 9 months employment opportunity in agriculture		Man-year	14,645	14617	10,223	15,500	32,164

The average household income and income of land less farmer (LL) and fisherman are calculated for the study area under different options. Using the above mentioned method, the population below the standard are calculated for different options. However, it might be changed with preferences, societal changes etc., but these things are considered as constant in this research. The results are presented in Table 5.28. From the table it is observed that the status of equitable resource distribution indicators are better in option C compared to the other two options (A and B). In case of basic needs, the consumption status is almost same for the average household and the selected two different income group. Among the four selected indicators of basic needs, only the value of safe drinking water is satisfactory, which shows 100% people will get access to safe drinking water which currently is about 90%. In addition, among the other three, the value of housing space is very poor for all.

In case of fairness in resource distribution, the access to common property situation is worsening with time, but temporal distribution of employment (more than 9 months) shows significant improvement in option C. It is assumed that to attain fairness in resource distribution (subsistence fishing), at least 50% of the households have to get access to the floodplain fisheries. However, none of the option can provide 50% of the household's should have access to flooded floodplain area for subsistence fishing (Figure 5.14)

For 2001, 2008, option A, and option B, it is observed that employment opportunity are mostly available in the first five months of the year. This is mainly due to the greater dependency on Boro cultivation. But in June, July, September, October and November, the employment opportunity in agriculture is very low. But under option C, where a sustainable cropping pattern has been suggested, which emphasizes cultivation of more jute, Aus and Aman rice. As a result, employment opportunity is better distributed throughout the year. It is observed that in option C, more than 9 months employment opportunity is available for 32,164 people, whereas, this number is about 10,223 and 15,500 in option A and B respectively (Figure 5.15).

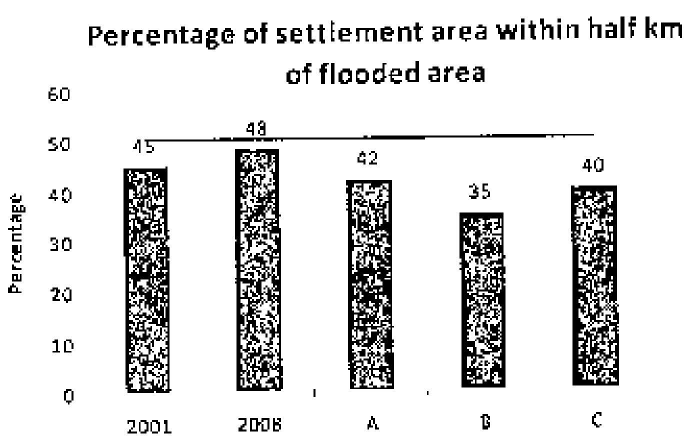


Figure 5.14: Percentage of settlement area within half km of flooded area

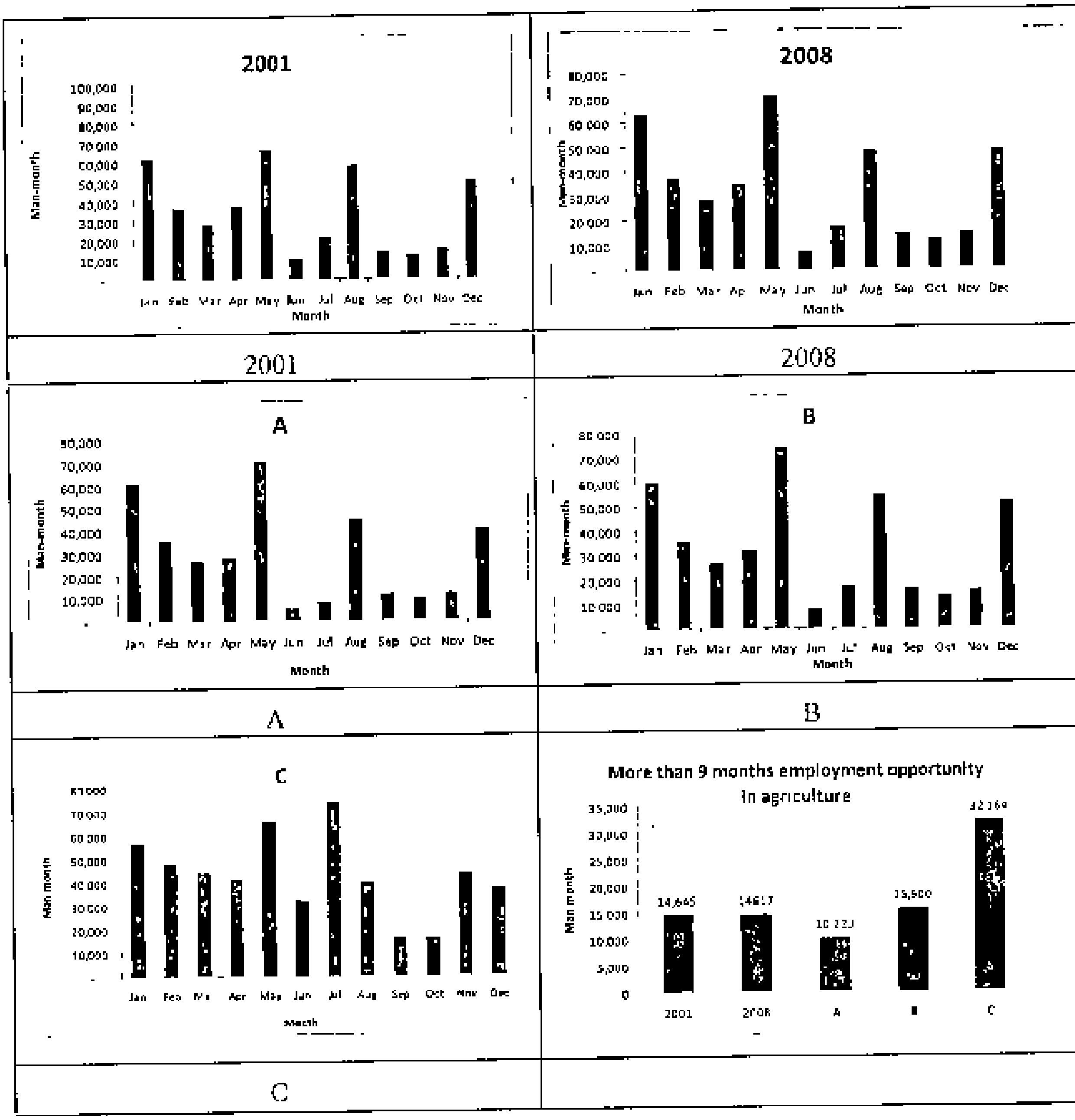


Figure 5.15: Distribution of employment opportunity throughout the year under different options

Figure 5.16 shows the performance of the indicator of safeguarding the ecosystem against the requirements. The indicators dry season water area and floodplain vegetation area are important for ensuring the natural condition in the floodplain and supporting the ecosystem. The dry season water area should be at least 5% of the gross area. But this requirement could not be met by any of the options. Option C achieved 2.3% which is less than the requirement, but is slightly better than 2001. Options A and B shows degradation from 2008 value. The floodplain vegetation area is performing well in all options against the requirement of 65% of the gross area. This requirement ensures the protection of ecosystem from urbanization that can damage the ecosystem. The aquatic species biodiversity indicator illustrates the aquatic habitat condition in the study area. From Figure 5.16 (d) it is seen that, in 2001, the habitat quality was good which degraded in 2008. Option A and B have reached lower limits of moderate quality. Option C tried to improve this condition through protective measures and is able to attain the good quality habitat.

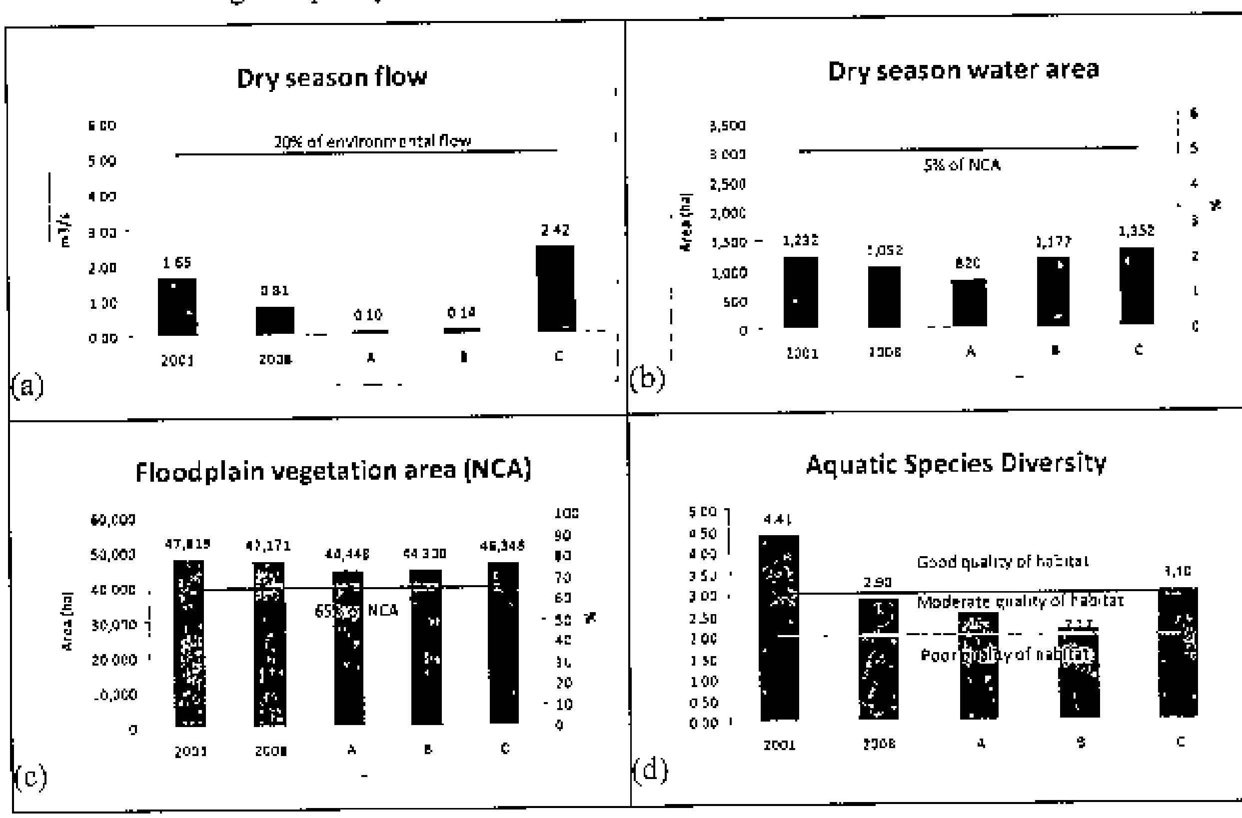


Figure 5 16: Indicators of safeguarding ecosystem for options A, B and C compared to 2001 and 2008

5.7 Change in state: Floodplain Functions

One of the objectives of this study is to maintain and improve or at least stop further degradation of the floodplain functions. In order to evaluate, two time periods. 2001 and 2008 was selected to see the changes in the floodplain functions due to land and water use interventions (such as option A, B and C). The floodplain functions (maintaining hydrology, protecting environment, maintaining ecosystem and facilitating socio-economy) are evaluated by indicators developed in section 3.1.

The hydrological function indicators show better performance in option C than in A and B. In general, the indicator values show degradation in 2008 from 2001 values. In most of the cases, option C shows improvement or stopped further degradation from 2008. In terms of connectivity of waterbodies to rivers or khals shown in Figure 5.17 (c) shows degradation in 2008 compared to 2001 and it continued in option A and B. However, option C shows it has managed to stop further degradation and shows slight improvement over 2008. Figure 5.17 (b) shows that change in dry season water level indicators show similar trend for option A and B against 2001 and 2008. On the other hand, option C shows significant improvement, even compared to 2001.

The flooded area percentage values in Figure 5.17 (c) shows a slightly increasing value in option A, while in option B flooding is minimum. In option C, flooded area is slightly less than 2001, but higher than option B, because option B is full flood control project, whereas, option C is partially controlled that is, only controls overland flow from Jamuna.

The estimated base flow indicator as shown in Figure 5.17 (g) shows a significant drop from 2001 to 2008 and further declined in option A, but in option B. it has stopped declining, whereas, in option C, not only it has stopped the decline, but it has improved the regeneration functionality of the floodplain. The groundwater table indicator as shown in Figure 5.17 (h) has declined below the suction limit (7 meter) from the ground level in both option A and B. However, in option C, it has stopped to decline and it is within the suction level of seven meter to protect the usage of domestic hand tube-wells.

The values of indicators of environmental function have been computed utilizing methodology described in section 3.1.2. Figure 5.18 illustrates the results of the indicators under different options.

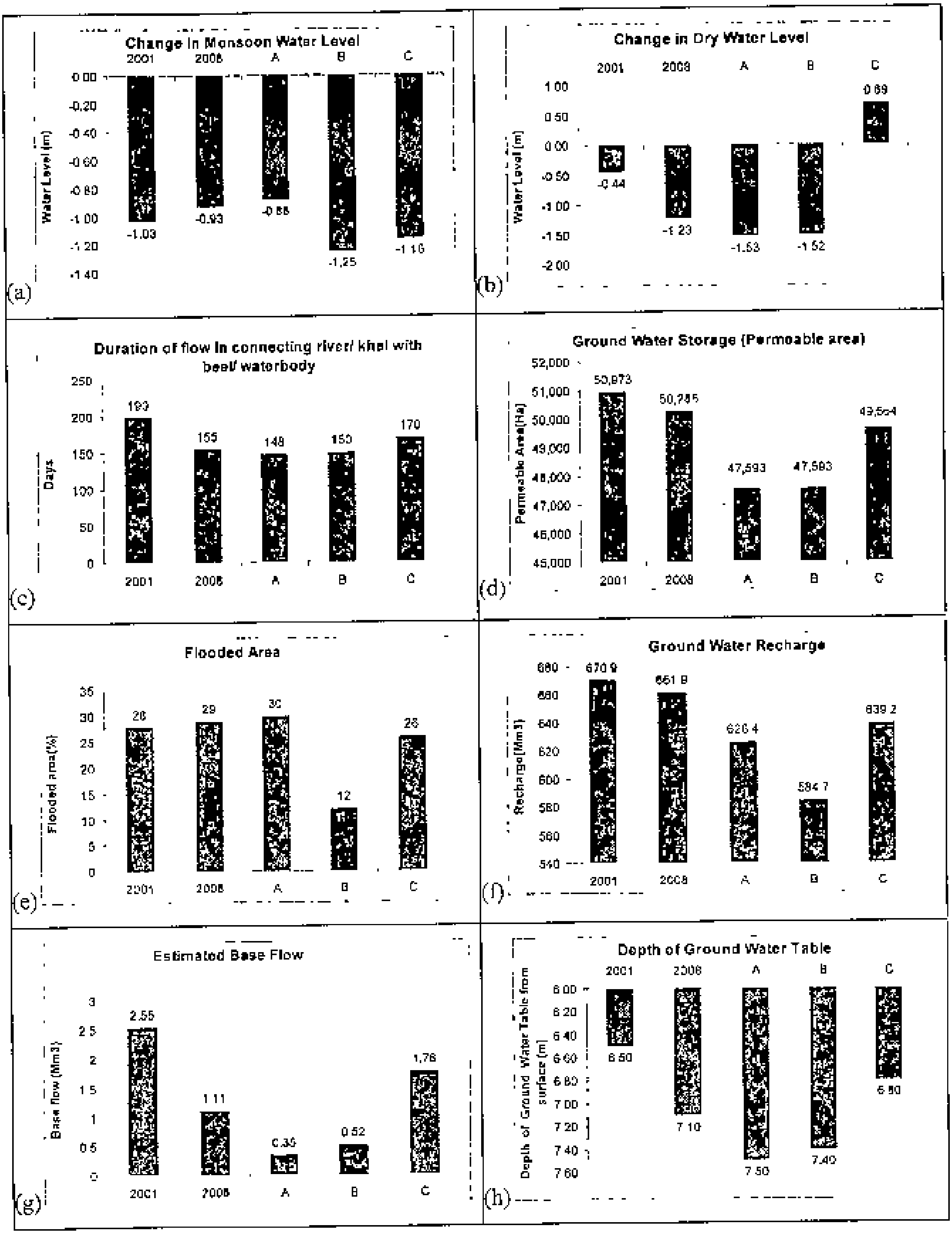


Figure 5.17: Hydrological function indicators for options A, B and C compared to 2001 and 2008

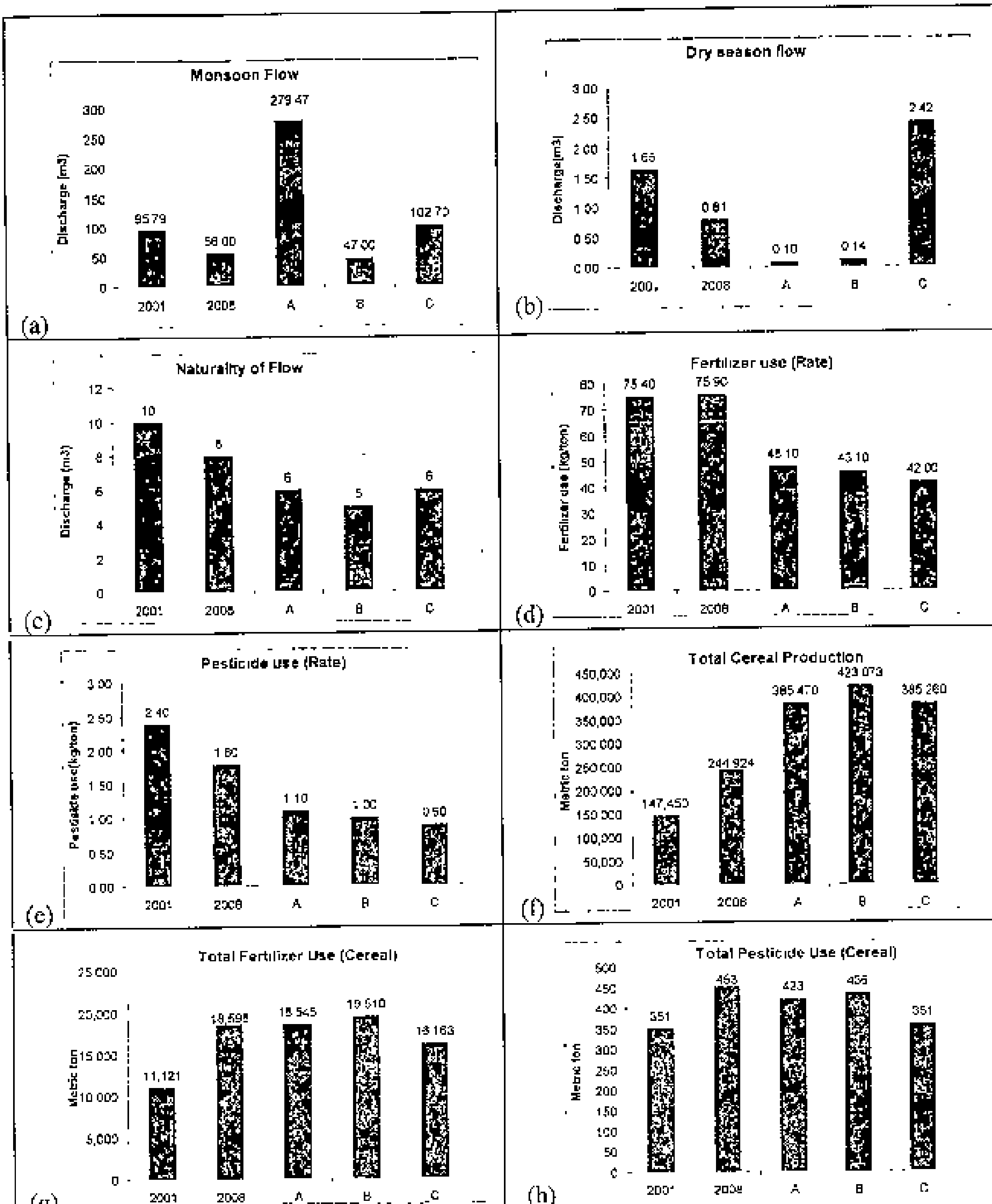


Figure 5.18: Environmental function indicators for options A, B and C compared to 2001 and 2008

The environmental flow requirement for these rivers in total is 5.08 m3/s as stated in section 3.1.2. The dry season flow has declined from 2001 to 2008 and it continues to decline in both option A and B. All these numbers indicate that they are well below the above environmental requirement. However, option C shows a significant improvement from both option A and B (Fig. 5.18 (b). This is largely due to two measures. First, in option C, surface water withdrawal through LLP was assumed. Second, less groundwater abstraction, which increases the base flow, and which in turn increases the surface flow. Dry season flow in option C is 2.42 m3/s, which is approximately 10 percent of the mean annual flow. According to the Tenant method stated in section 3.2.2 at least 10 percent flow is required during dry season to avoid severe degradation, which is attained in option C. Figure 5.18 (a,b,c) also shows that combined water flow in monsoon and dry season for option C is well in the fair category of Tenant method. The naturality of flow indicator shows a declining condition in options A, B and C.

The land and water quality indicators shows that presently fertilizer and pesticide use rate is highest. The condition is going to improve in future in all three options. Among the options, A is worst for environment, B is moderate and C is most environment friendly (Fig. 5.18 (d,e.g,h)).

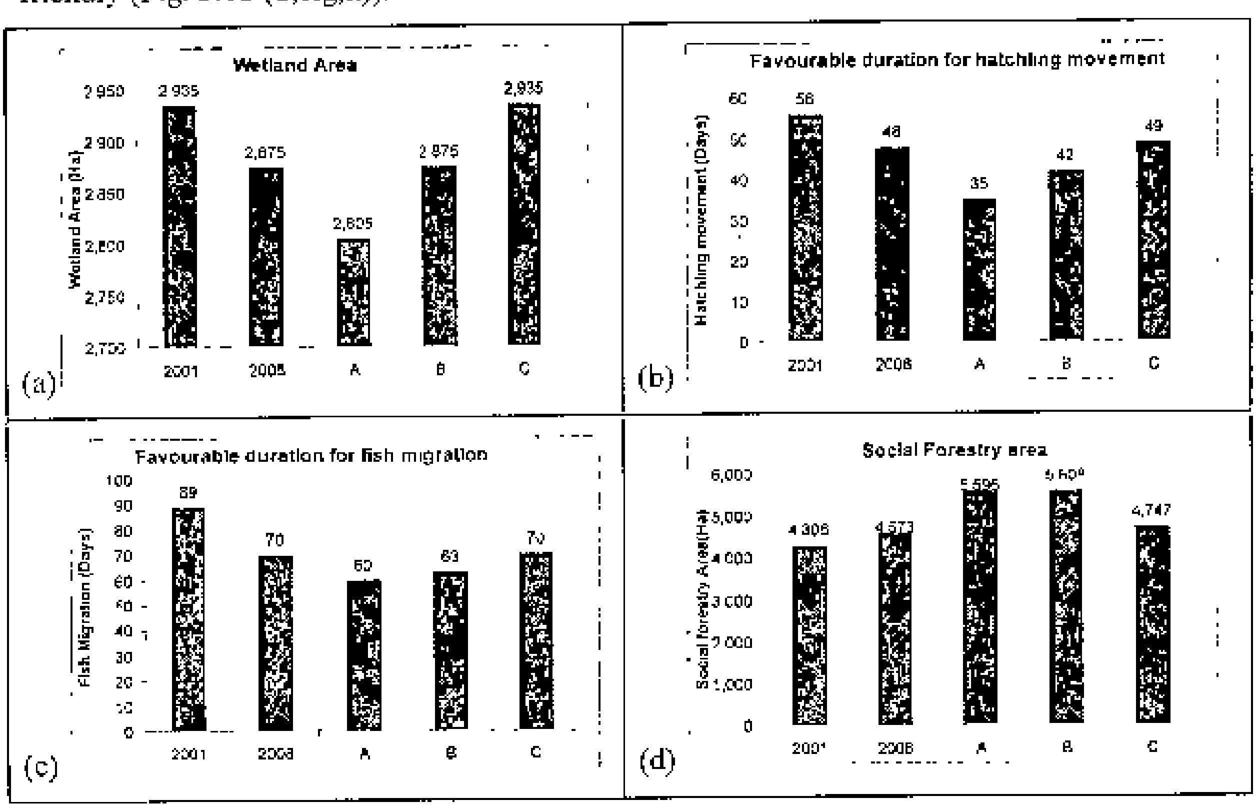


Figure 5.19: Ecosystem function indicators for options A, B and C compared to 2001 and 2008

The values of ecological function indicators have been estimated by the procedure described in section 3.1.3. The estimated results are presented in Figure 5.19. The results show that wetland area has decreased in option A, but increased in both options B and C because of restoration of wetland (beels) (Fig. 5.19(a)).The declining trend of fish migration can be improved under option B and C (Fig. 5.19 (c)). Hatchling movement follows similar trends as fish migration (Fig. 519 (b)). The amount of social forestry area has increased in all three options but the increment in option C is less than option A and B (Fig. 5.19 (d)).

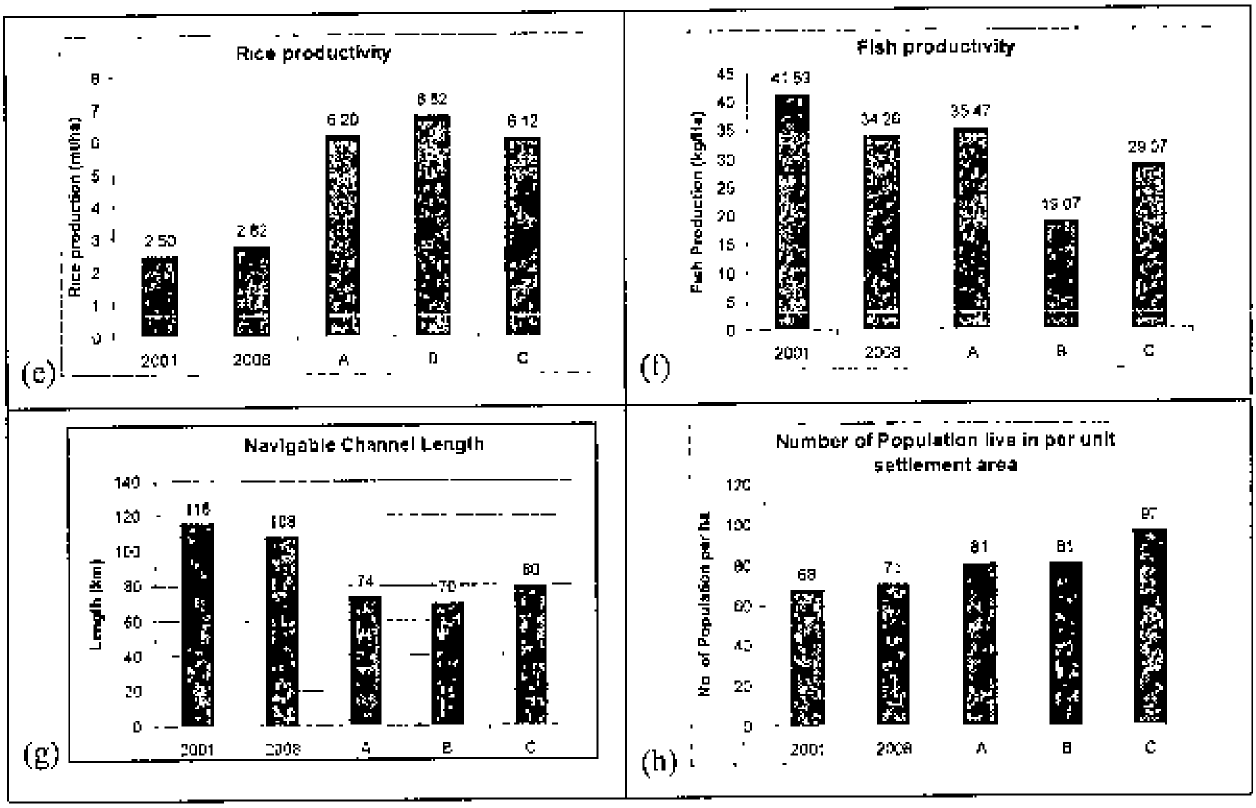


Figure 5.20: Socio-economic function indicators for options A, B and C compared to 2001 and 2008

The indicators of socio-economic function as shown in Figure 5.20 shows mixed results. For rice productivity, option B is best [Figure 5.20 (a)], while for capture fish productivity, option A is better than B and C. The navigability of socio economic goods, represented by navigation channel length as shown in Figure 5.20 (c), shows improvement in option C, compared to A and B, but it is still below 2001 and 2008 level.

5.8 Assessment of Impacts on Socio-economic Conditions

One of the objective is to improve socio-economic condition of the present and future generations in year 2050 by meeting the demands of both these generations. Indicators of socio-economic improvement are graphically shown in Figures 5.21, 5.22 and 5.23.

As there will not be major change in infrastructures, the scopes of earning from these sectors will change a little. Majority of the increased income will come from agriculture and fishery sectors. It is observed that gross income is highest in option B, followed by option C and then A (Fig. 5.21(a)). Agricultural production will be highest in option B because of increased cultivation of Boro and lower risk of flood on Aman, which will help to increase gross income. Landless farmers income is highest in option B because agricultural income is highest (Fig. 5.21(c)). Option B, will have the highest production because both Aman and Boro production will increase. Option A has the lowest income because of lowest agricultural income. Though option C has lower agricultural income as well as gross income also compared to B. however suggests less risky.

environment friendly cropping pattern which emphasizes cultivation of Aus and Jute. Annual income of landless farmer will increase for all three options and it is highest in option B as agricultural income is highest in option B. Annual income of fishermen will be highest in option C (Fig. 5.21(d)), as it does not support leasing of waterbody and full access of the farmers to the open water fishery.

Increase of Boro production and other land uses side by side with risk minimization and more safety has increased income of people. Thus, people will be able to save more. The savings of landless farmer in both option A and C is almost equal but higher in option B because farmers income is highest in option B due to highest agricultural production (Fig. 5.21(e)). But in case of fisherman, savings will be almost nine times higher in option C than in option A (Fig.5.21(f)).

In option B, fisherman would not able to save money, rather, they have to borrow money to run his family. This is mainly due to reduced floodplain and open water body and increasing leasing activity of the wetlands, restricts fisherman access to open water fishery. Better distribution of cropping pattern, and increased production of jute along with establishment of more industries and encouragement of women employment, employment rate will increase in option B and C In option C, employment will be double of A and 1.5 times higher than B (Fig. 5.21(b)).

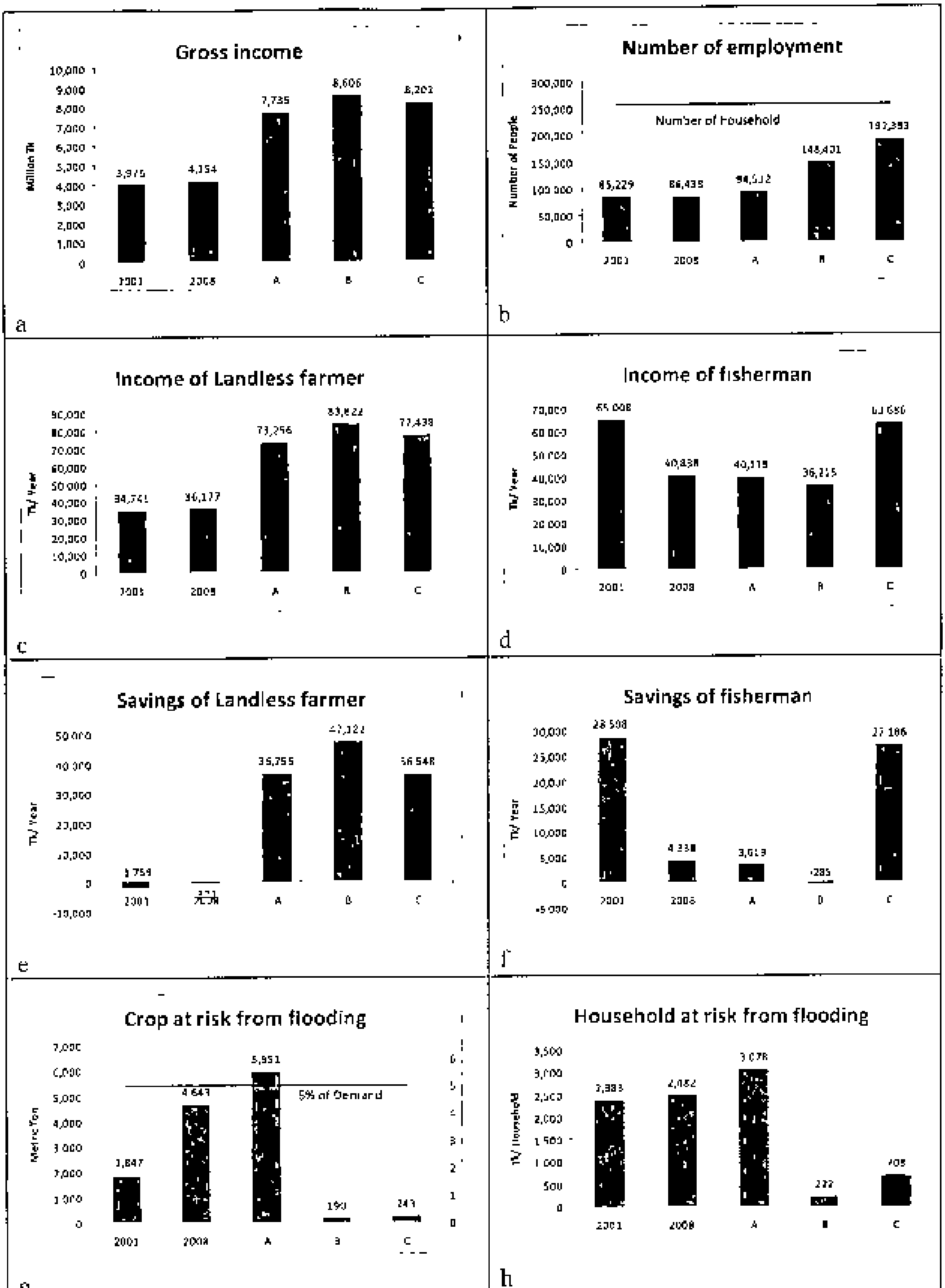


Figure 5.21: Indicators of socio-economic improvement for options A, B and C compared to 2001 and 2008 (criteria: economic sustenance)

Risk has been identified for crops and households. In Option A, risk of crop loss will increase nearly 5,950 mt and per household loss will be Tk 3,078. Flood control measures will minimize the risk for both option B and C. Based on the methodology described in section 3.3.4, the household asset values at risk have been estimated. For this analysis, the average household asset values for different options and flood frequency are presented in Table 5.29. Damage percentages have been assumed as 10% (urban) and 20% (rural) as described in section 3.3.4. Using these asset values, damage percents and flood frequency, the household asset values at risk has been estimated. Table 5.30 presents the estimated household asset values at risk. It is estimated that household asset value at risk is increasing in 2008 and option A (2050) (Table 5.30 and Fig. 5.21(h)). In option B and C the risks are very much lower than option A. Option B has the lowest asset value risk as it will protect the study area with embankments. While in option C, asset value at risk is higher than option B as it partially implements flood control.

Table 5.29: Average household asset value (in Taka) and flood frequency

	HH Type	2001	2008	Option A	Option B	Option C
Average household asset value (in Taka)	Urban	79,423	82,732	102,588	110,861	177,046
	Rural	39,711	41,366	51,294	55,430	88,523
Flood frequency (x times in 100 year)	Urban	10	10	10	1	2
	Rural	20	20	20	1	2

Table 5.30: Estimated household asset at risk (in Taka)

HH Type	2001	2008	Option A	Option B	Option C
Urban	79.423	82,732	102,588	11,086	35,409
Rural	158,845	165,464	205,175	11,086	35,409
Cumulative loss in 100 year	238,268	248,196	307,763	22,172	70,819
Loss per year	2,383	2,482	3,078	222	708

Based on the methodology described in section 3.3.4, the crop production at risk has been estimated. The assumed crop damage percentages for different land types are presented in Table 5.31. The values used in the regional plan (FAP 3.1,1997a) are also included in this table. Over the period, the study area has faced several floods. In the last 30 years, there were seven major floods causing damages to Aman production. This means, floods are occurring once in every five year. So, the possibility of flooding is 20 times in a 100 year period under normal condition without intervention. Based on these circumstances, flood frequency for the area is taken as 20 times in 100 year as presented in Table 5.32. The total Aman production and the distribution of land types used for different options are presented in Tables 5.33 and 5.34 respectively.

Table 5.31: Damage percentages for crop production

	Damage Percentage			
Land type	F0	F1	F2	F3 & F4
Study assumption	10	30	60	100
FAP 3.1 (for 1 in 10 year return period)	20	40	50	60
FAP 3.1 (for 1 in 30 year return period)	60	90	100	100

Table 5.32: Flood frequency (x times in 100 year) for crop production risk

	2001	2008	Option A	Option B	Option C
Frequency	20	20	20	1	2

Table 5.33: Aman crop production (in metric ton)

	2001	2008	Option A	Option B	Option C
Production	45,512	75,774	110,198	146,487	108,253

Table 5.34: Land type distribution for Aman

Land Type	2001	2008	Option A	Option B	Option C
F0	0.7154	0.4522	0.6072	0.9074	0.9618
F1	0.1643	0.3156	0.1555	0.0641	0.0283
F2	0.0956	0.1644	0.1865	0.0219	0.0061
F3	0.0204	0.0626	0.0438	0.0041	0.0003
F4	0.0044	0.0052	0.0069	0.0025	0.0034

Using the production and land type distribution, damage percentages and flood frequency, the crop production at flood risk have been estimated. Table 5.35 and Figure 5 21(g) shows that, Aman production at risk will be increasing in option A, while in both options B and C risks will be much lower. This occurs due to the implementation of embankments in options B and C.

Table 5.35: Crop production at risk (in metric ton) from flooding

Land Type	2001	2008	Option A	Option B	Option C
F0	65,116	68,527	133,832	13,292	20.824
F1	44,872	143,488	102,825	2,817	1,840
F2	52,213	149,496	246,686	1,929	796
F3	18,525	94,855	96,475	595	70
F4	3,964	7.910	15,264	367	733
Cumulative loss in 100 year	184,689	464,277	595.082	19,000	24,263
Loss per year	1,847	4,643	5,951	190	243

It is estimated that rice production is highest in option B followed by option A and then Option C (Fig. 5.22(a)). Rice production is the highest in option B because of increasing Boro production and lower risk to Aman crops from flooding as option B adopts full protective measures from flooding. Fish availability in option B is almost half to that of option A due to the degradation of beels and reduction of floodplains (Fig. 5.22(b). as embankments will protect more land to be flooded. However, in option C, restoration of wetlands will increase the natural productivity of the fish.

It is observed that per day per capita calorie availability from rice and fish is increasing over time. This is mainly achieved by increasing rice production. Though fish productivity is lower in option B compared to option A and C But per capita rice availability is highest in option B. As a result, calorie availability will be highest in option B (Fig. 5.22(c)). However, all three options will achieve per capita calorie availability than the requirement (2112 calorie/person/day).

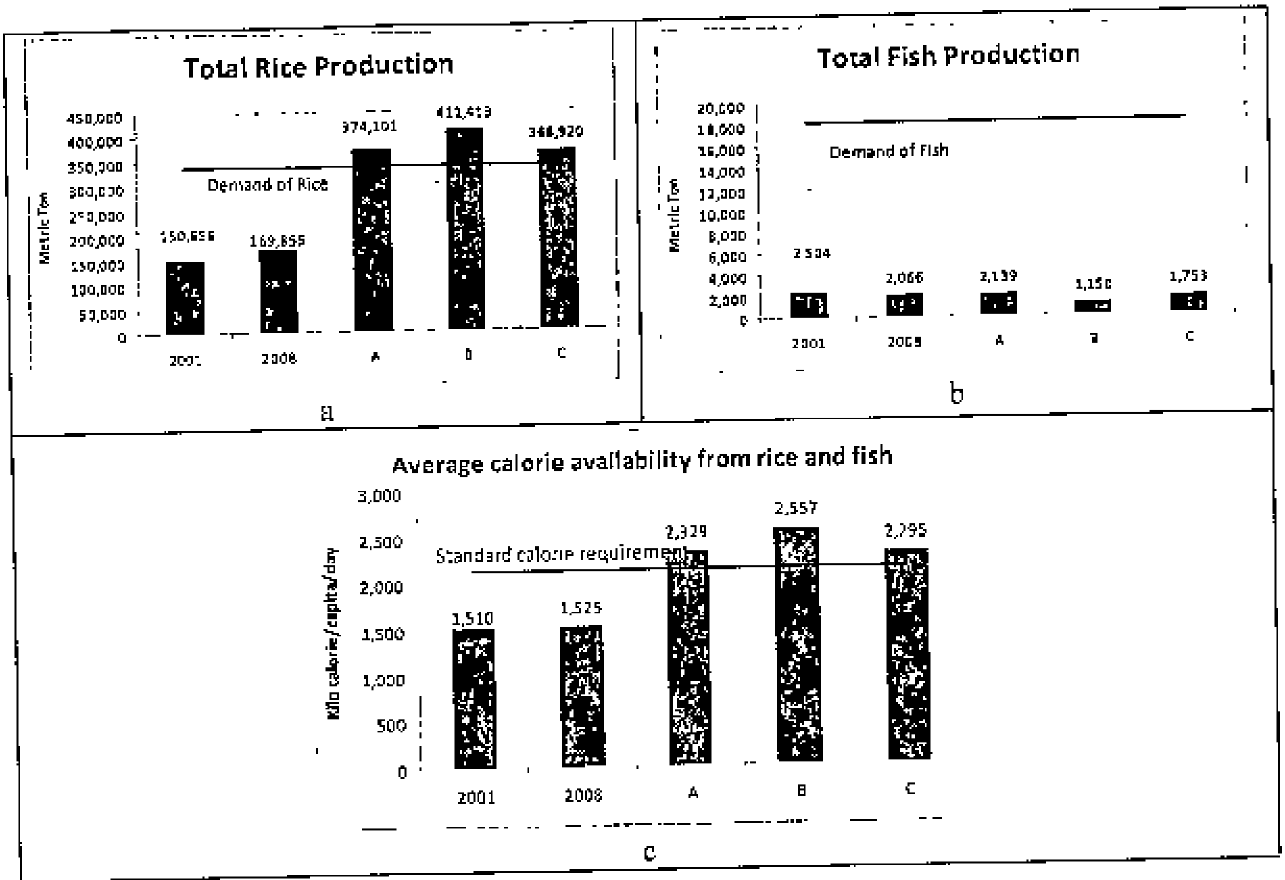


Figure 5.22: Indicators of socio-economic improvement for options A, B and C compared to 2001 and 2008 (criteria: food availability)

The status of public services is shown in Figure 5.23. Access to public service condition is better in option C for two selected indicators: number of population served/km of road and number of population served/health centre. In option A, every health centre has to serve 27,000 people on average, but in option B and C, it shows quite improvement (about 24,400 people/health centre).

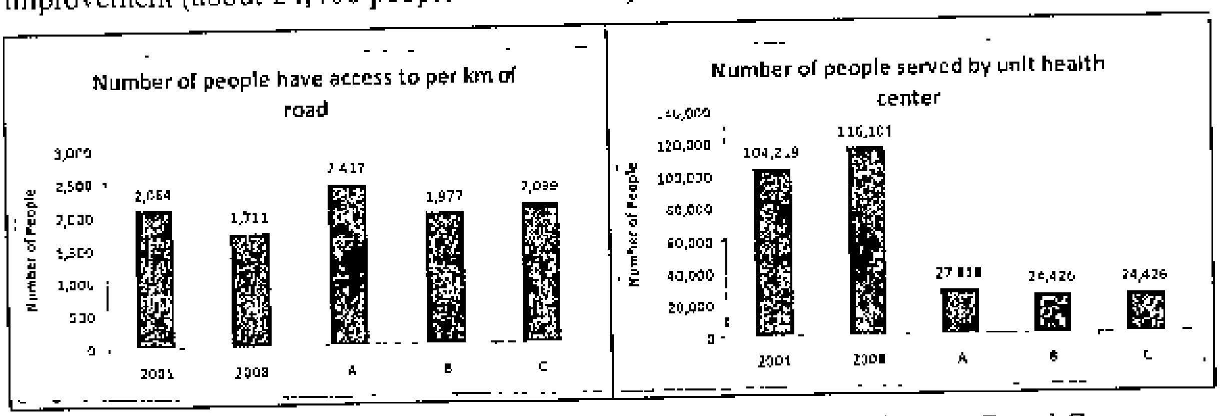


Figure 5.23: Indicators of socio-economic improvement for options A, B and C compared to 2001 and 2008 (criteria: public services)

5.9 Interdependency of land and water use in deltaic floodplain

The use of land and water resources in the deltaic floodplain are interdependent and interrelated. For sustainable land and water use, the understanding of interdependences of these resources is crucial for integrated planning. The sustainable resource management framework established an interdependency relationship between indicators with land and water use activities (Figure 5.24). The figure shows the projected land and water use under three developed options (option A: autonomous development, option B: implementation of regional plans and option C: sustainable land and water use). In rural areas, agriculture is the dominant landuse. Boro being a major agricultural crop in the study area was selected as an example to demonstrate the interdependencies between land and water use activities and the indicators. Boro production changes due to changes in Boro area under different options. The figure shows the contribution of Boro in terms of total rice production. Boro cultivation creates employment and in turn generates income. For option A and B, more than 55% of agricultural employment is obtained from Boro, but it is almost 40% in option C. Farmers (landless) income is increasing with increasing production It is observed that Boro contributes more than 2-5% of total income in all three options and it is highest in option A (31% of total income). Increasing income of the farmers will lead to better affordability to fulfill their basic needs (minimum cereal (rice), fish and living space).

Boro requires irrigation and with increase or decrease of Boro area, irrigation requirement also changes which is shown in figure. Further it is observed that irrigation water requirement is lowest in option C and almost equal in both option A and B (because area is also equal) Groundwater is the principal source of irrigation and the figure shows that depth of ground water table is lowest in option C, because of less withdrawal of ground water. Lowering of groundwater table will reduce ground water availability for drinking. It is observed that only in option C, 100% of the population will get access to safe drinking water. Option C prohibited surface water withdrawal for irrigation resulting in better dry season stream flow. Fertilizer and pesticide uses also increases with increasing area and it is observed that more than 70% of total fertilizer use is applied in Boro field. Whereas, in case of pesticides, Boro usages is about 60% of total use. Increasing usages of fertilizer will ultimately result in increasing concentration of nitrogen, phosphates etc. in water body. Excess concentration of these nutrients is very harmful for the aquatic species and thereby, degrade the quality of habitat. From the figure it is observed that aquatic species diversity is highest in option C because of its lowest usage of fertilizer. Though, there are other factors which affect aquatic species diversity, such as connectivity and NCA. But this figure presents only the indicator related to Boro cultivation.

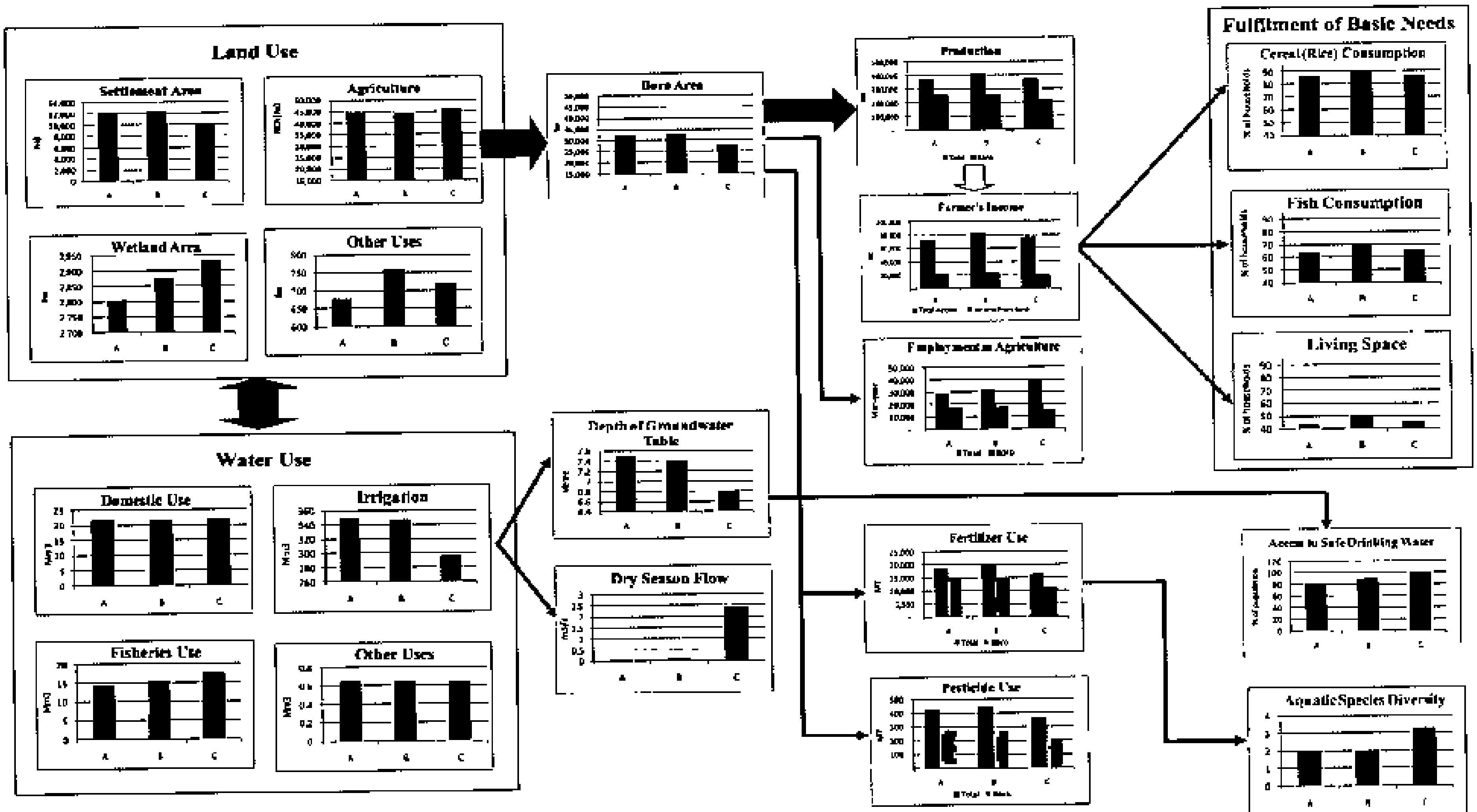
5.10 Scenario Analysis

The analysis have been carried out for three different future options. To analyze the sensitivity, four different scenarios have been used for each of the three options. Details of these options and scenarios have been described previously. To look at the sensitivity of the results to these scenarios, impacts on hydrology and flooded area has been analyzed and are presented in the following sections.

Hydrology

The impact and sensitivity on hydrology have been evaluated on five boundary nodes.

Chatal River: For Chatal river the long term average peak flow is 82 m^3/s in option B and C. It will decline by 28 percent because of upstream water withdrawal. Due to climate change events the peak flow will increase by 24 percent than the long term average peak value. The flow of Chatal river will be regulated in both option B and C. Even during the extreme event flood along with climate change, it will not be allowed to discharge more than $200m^3/s$. On the other hand, in option A, the river is closed so there is no flow in any of the scenario. Figures 5.25 to 5.27 illustrates the hydrographs of Jhinai river under different scenarios. Different rivers under different scenario are shown in annex-A.



A= Autonomous development

B= Implementation of regional plan mainly FAP 3.1

C= Sustainable land and water use

Figure 5.24: Interdependence of land and water use in deltaic floodplain

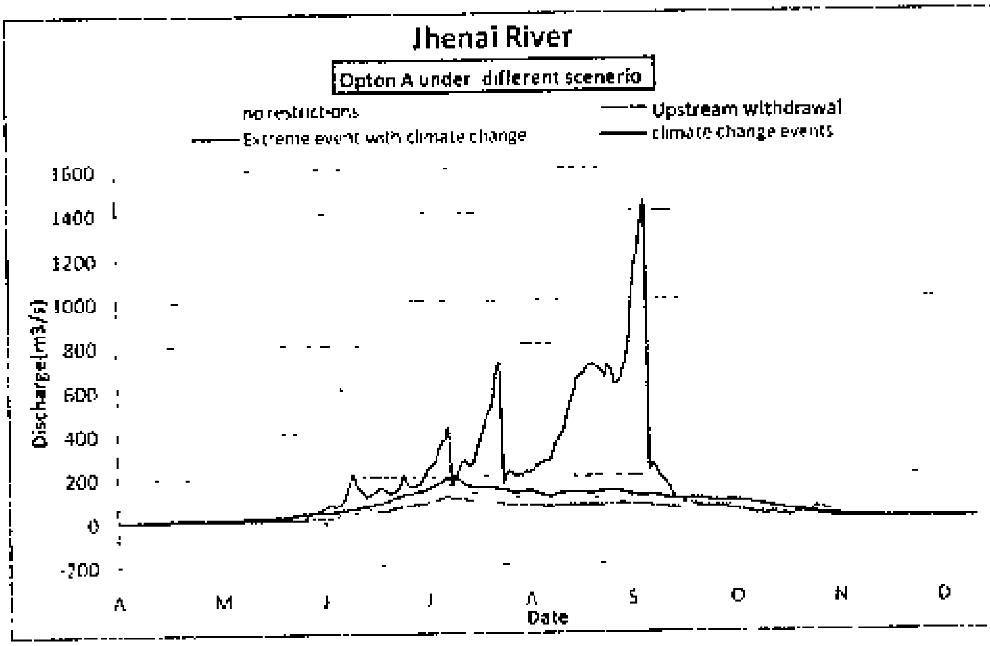


Figure 5.25: Hydrograph influenced by externalities for option A (Example: Jhinai)

Jhenai river: For Jhenai river, the long term average peak flow is 165 m^3/s, which will decline by 35 percent because of upstream water withdrawal. Due to climate change events the peak flow will increase by 18 percent than the long term average peak value. As in option A and C, the flow of Jhenai river will be unregulated so as to maintain its natural flow. In the extreme event of flood along with climate change will be as high as 1,429m^3/s. However, in option B, the flow will be regulated and will not be allowed to discharge more than 400m^3/s during extreme event

Hidagari river: For Hidaagri river, in option A and C, the long term average peak flow is 188 m3/s .In these options, the long term average peak flow will decline to 147m^3/s because of upstream water withdrawal. Due to climate change events, the peak flow will be to 283m^3/s in option A. Due to the regulation of the river flow it will not be allowed to exceed 200m^3/s in option C. In option B, Hidagari river will be regulated to allow discharge not more than 2m^3/s. Hence, in all scenarios of option B, the flow will not be above 2m^3/s.

Patharkata: As Patharkata river has been closed due to siltation so there will be no flow in any scenario of option A and C. However, in option B this river will be regulated to allow discharge not more than 20m^3/s. In this case, the long term average peak flow will be $1.47m^3/s$, which will dry up because of the upstream water withdrawal. However, it will increase by threc times with climate change.

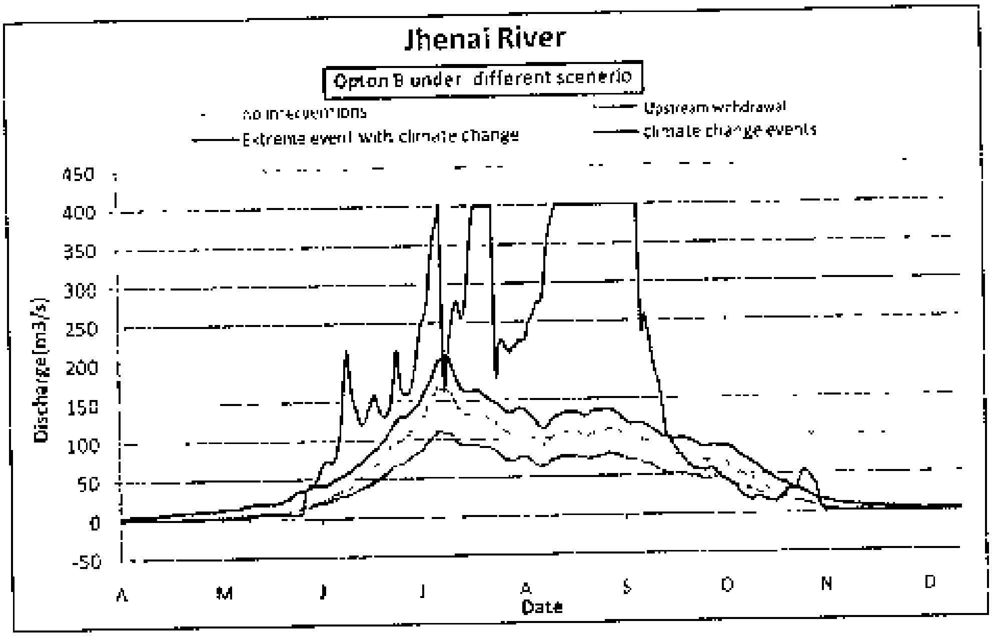


Figure 5.26: Hydrograph influenced by externalities for option B (Example: Jhinai)

Baushi Bridge: The flow beneath the Baushi Bridge is the combined flow of Jhenai Chatal and Hidagari river. In option A, the flow at this section for the long term average peak flow is $342m^3/s$, which will reduce by 1.3 times due to upstream water withdrawal. Due to climate change events the peak flow will increase by 1.4 times than the long term average peak value. In extreme event of flood along with climate change, the flow will be as high as $2120m^3/s$. In option B, the flow at this section for the long term average peak flow is $238m^3/s$. which will reduce by 1.3 times because of upstream water withdrawal. Due to climate change events the peak flow will increase by 1.3 times than the long term average peak value. In extreme event of flood along with climate change, the flow will be as high as $645m^3/s$. In option C, the flow at this section for the long term average peak flow is $414m^3/s$, which will reduce by 1.4 times because of the upstream water withdrawal. Due to climate change events the peak flow will increase by 1.2 times than the long term average peak value. In extreme event along with climate change, the flow will be as high as $1800m^3/s$.

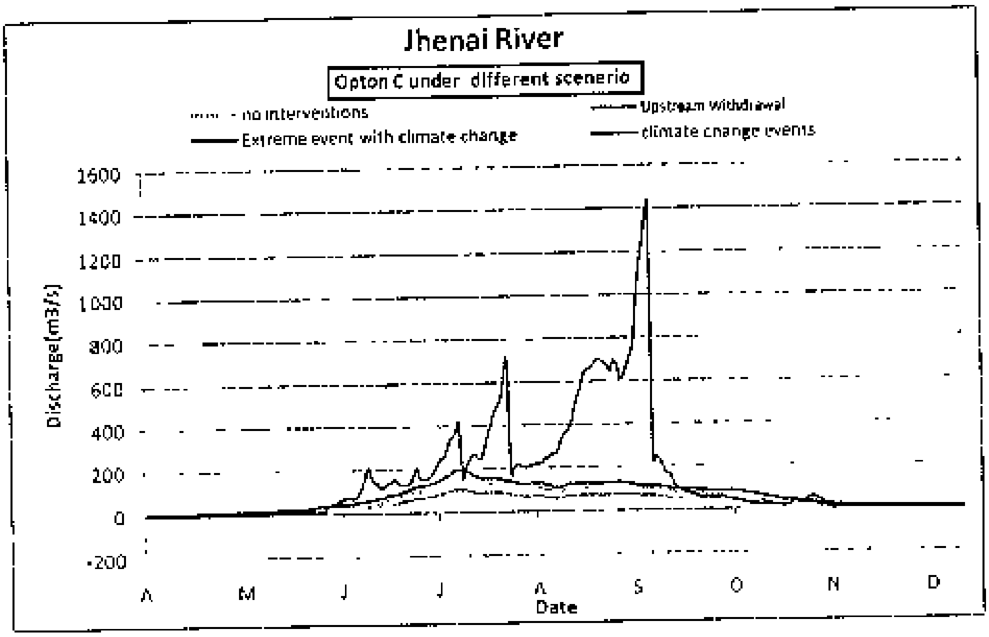


Figure 5.27: Hydrograph influenced by externalities for option C (Example: Jhinai)

Flooded area

Flooded area in option A for average flooding will be 33.4 percent of the gross study area (Figure 5.28). With climate change, it will increase by 2 percent but will decline by 12 percent due to upstream water withdrawal. As there are no externalities in option A, so extreme event of flooding like 1998 will cause enormous inundation. This inundation is about 89 percent of the total study area and will increase by 1 percent with climate change.

On the other hand, flooded area in option B for average flooding will be 11.3 percent in the study area (Figure 5.28). With climate change it will go up to 11.8 percent and due to upstream water withdrawal, the average flooding will decline to 7.6 percent.

All the inlets in the study area are regulated, therefore, in the event of extreme flooding like 1998; it will not cause enormous inundation like in option A. Even with regulated intervention, the inundation area will be 53 percent and it will increase by 4 percent with climate change.

In option C, flooded area for average flooding will be 27 percent in the study area (Figure 5.28). With climate change it will increase by 1 percent and will decline by 4 percent due to upstream water withdrawal. As Chatal and Hidagari rivers are regulated and Jhenai river is unregulated, therefore, in the event of extreme flooding like 1998, will cause higher inundation in option B but much lower than in option A. Even with partial intervention, the inundation area will be 64 percent and it will increase by 3 percent with climate change.

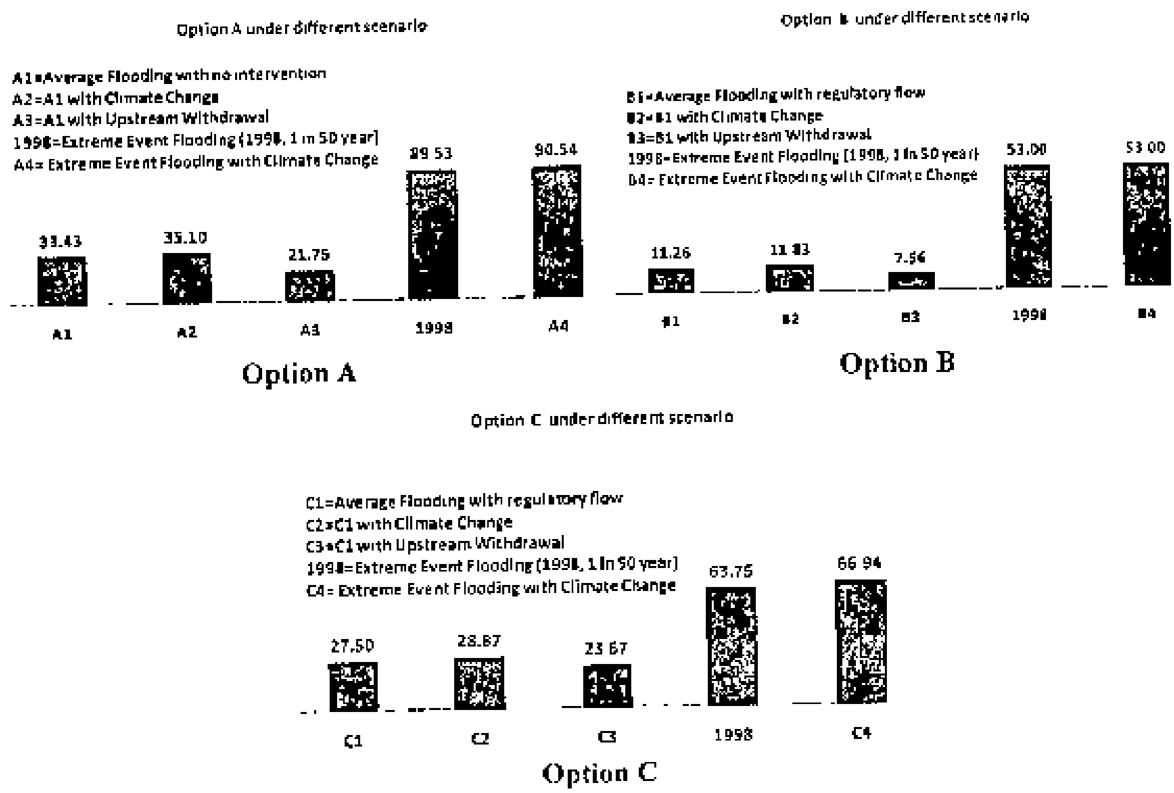


Figure 5.28: Flooded area (in percentage) under different scenarios for three option

Recharge

Groundwater recharge has been estimated for three options. The climate change scenarios for these three options have been generated based on long term average rainfall along with percentage change in rainfall due to climate change. The analysis show that for option C, the recharge is more than A and B. The recharge should be the same for all three options as the gross area is same. However, option C has lesser impermeable area than the other two and therefore, recharge is more for C. The estimated recharges for all these three options are tabulated in Table 5.36. The figure shows that for 2-4% increase in rainfall due to climate change, the recharge in the study area increases by 10-15 million m^3, which is 2-3% of the long term average recharge.

Table 5.36: Groundwater recharge (Mm^3) estimation for different options

Parameter	2001	2008	Option A	Option B	Option C
Impermeable area (ha)	9,327	10,014	12,707	12,707	10,636
Recharge area (ha)	50,973	50,286	47,593	47,593	49,664
Recharge from rainfall (mm)	1,170	1,170	1,170	1,170	1,170
Recharge from rainfall (Mm^3)	596.4	588.3	556.8	556.8	581.1
Flooding contribution to recharge (Mm^3)	74.5	73.5	69.6	27.8	58.1
Total potential recharge (Mm^3)	670.9	661.9	626.4	584.7	639.2
Usable recharge (Mm^3)	503.2	496.4	469.8	438.5	479.4
Climate change induced rainfall recharge (mm)	1,200	1,200	1,200	1,200	1,200
Climate change induced rainfall recharge (Mm^3)	611.7	603.4	571.1	571.1	596.0
Climate change induced flood recharge (Mm^3)	76.5	75.4	71.4	28.6	59.6
Total potential recharge with climate change (Mm^3)	688.1	678.9	642.5	599.7	655.6
Usable recharge with climate change (Mm^3)	516.1	509.1	481.9	449.8	491.7
Groundwater use (Mm^3) for 12 hr pumping	241.5	325 5	362	308	317.7

5.11 Option Evaluation and Selection by Multi Criteria Analysis

A Decision Support System (DSS) focuses on the interactive analysis and evaluation of management options/strategies for planning (EGIS, 2001a). Decision support systems (DSSs) can be described as analytical tools, which can be used to assist planners and decision makers in developing and comparing alternative courses of action and preparing preferred interventions for subsequent decision-making. Major attention is given to a user-friendly interface, which allows an interactive exploration and specification of alternatives, and a comparison of their performance under different assumptions. In an elaborate form, a DSS would include tools to give preferences or weights to different objectives and criteria to obtain a priority ranking of alternatives. DSS is a software instrument, that is truly interactive, and to some extent improves communication among factors related to a complex project.

It is necessary to consider the technical, environmental and social implications of land and water resource projects, in addition to the economic criteria to ensure sustainable decisions and favourable decision outcomes. It also engage stakeholders and interest groups in decision making process, which requires the use of multi criteria decision making (MCDM). Multi criteria evaluation approaches utilising GIS have received considerable attention in literatures (Janssen and Rietveld 1990, Carver 1991, Eastman et al 1993). The most widely used GIS based approach to multi criteria decision-making is the weighted linear combination methods of boolean overlay (Hopkins 1977, Tomlin 1990, Berry 1993). Within the Arc/Info GIS environment, Carver has integrated, two multi criteria evaluation methods: Hierarchical optimization and concordance-dis-cordance analysis. An alternative approach to multi-criteria evaluation was suggested by Banai (1993). He proposed an integration of the Analytical Hierarchy Process (AHP) with GIS-based techniques.

Analytical Hierarchy Procedure (AHP) is used to evaluate the criteria, sub-criteria and objectives in order to attain the goal. The AHP is a comprehensive methodology that provides groups and individuals with the ability to incorporate both qualitative and quantitative factors in the decision making process. The AHP uses a hierarchical model comprised of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken into sub-criteria, sub sub-criteria, and so on, into as many levels as the problem requires. In the present research, a MCA program to evaluate the decision support framework has been developed as described in annex-D. This program utilizes AHP and generates scores at different levels using weighted standerdization at each level. This program evaluates the different options based on weights at indicator, criteria, sub objective and objective level.

5.11.1 Evaluation of projected land and water use options

The MCA model (Figure 5.29) used in the study simultaneously assesses two objectives: protect floodplain environment and improvement of socio-economic condition. Equal weight is given to both objectives and they are evaluated together. Protect floodplain environment has three sub objectives, such as, maintain hydrological condition, protect environment and safeguard ecosystem. Fulfilling basic needs, fairness in resource distribution, economic sustenance, access to public services and food availability are the sub objectives of improvement of socio-economic condition. Each of the sub objectives contain several criteria and a number of indicators. The protect floodplain environment objective include 3 sub objective, 9 criteria and 15 indicators while improvement of socio-economic condition objective include 5 sub objective, 13 criteria and 21 indicators. In total there are 8 sub objective, 22 criteria and 36 indicators.

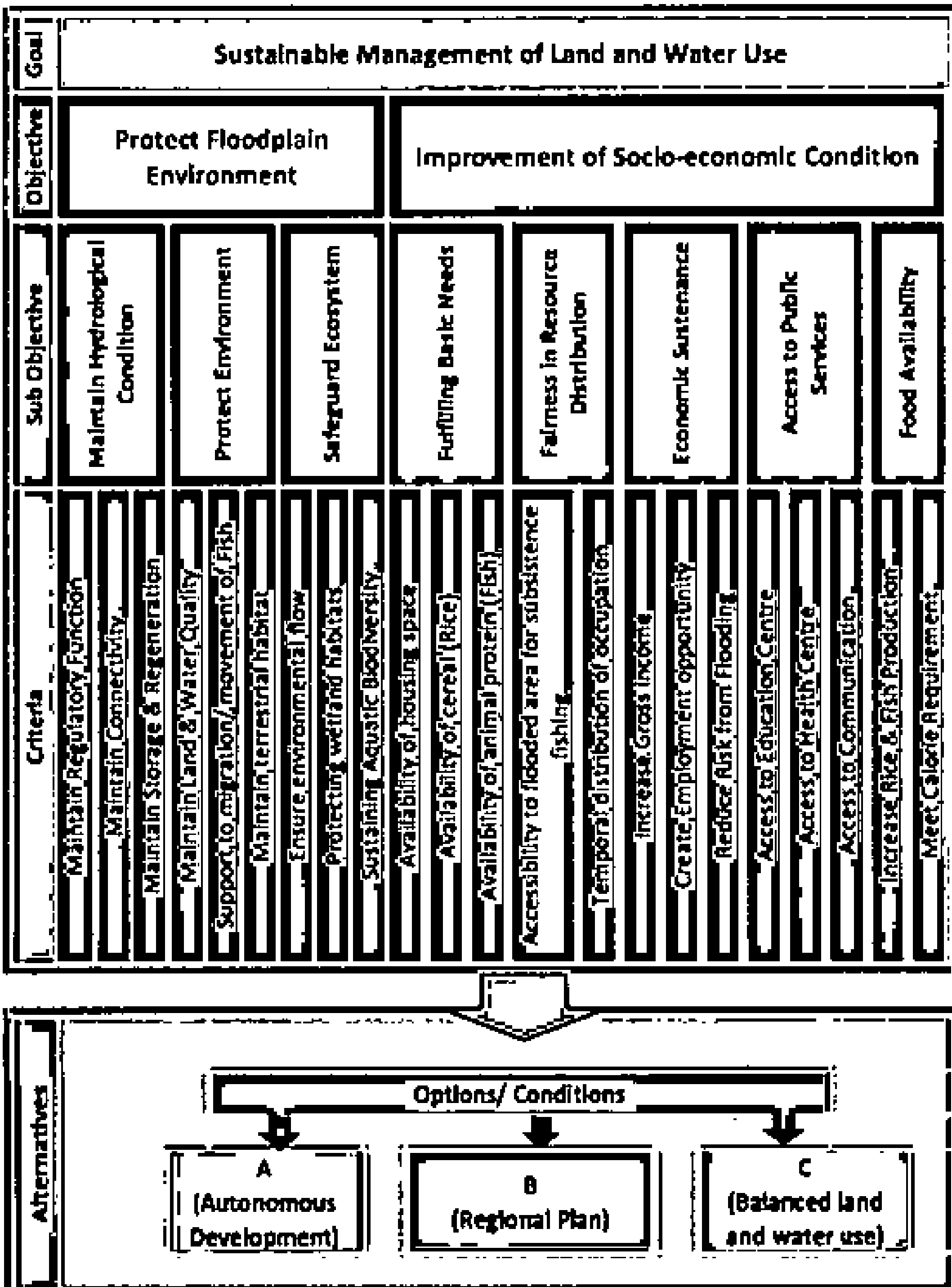


Figure 5.29: The MCA model

The evaluation of projected land and water use have been carried out at objective, sub objective, criteria and indicator level. The abbreviations used for different objectives, sub objectives, criteria and indicators are presented in Tables 5.37 and 5.38. The indicators are evaluated on either benefit or cost criteria. There are eight indicators evaluated on cost criteria which have been shaded in green colour in Table 5.38

Table 5.37: Abbreviations for criteria/ sub-criteria used in MCA

Objective	Sub-objective		Criteria	
	Abb.	Description	Abb.	Description
Protect Floodplain Environment	MHC	Maintain Hydrological Condition	HR	Maintain Regulatory Function
			HC	Maintain Connectivity
			HSR	Maintain Storage & Regeneration
	PEN	Protect Environment	EQ	Maintain Land & Water Quality
			CM	Support of migration/ movement of Fish
			CT	Maintain terrestrial habitat
	SEC	Safeguard Ecosystem	PE	Ensure environmental flow
			PH	Protecting wetland habitats
			PD	Sustaining Aquatic Biodiversity
Improvement of Socio-economic Condition	FBN	Fulfilling Basic Needs	HP	Availability of housing space
			CR	Availability of cereal (Rice)
			AN	Availability of animal protein (Fish)
	FRD	Fairness in Resource Distribution	RP	Accessibility to flooded area for subsistence fishing
			RO	Temporal distribution of occupation
	ESU	Economic Sustenance	IG	Increase Gross income
			EM	Create Employment opportunity
			RK	Reduce Risk from Flooding
	APS	Access to Public Services	EC	Access to Education Centre
			HE	Access to Health Centre
			CO	Access to Communication
	FAV	Food Availability	PR	Increase Rice & Fish Production
			NT	Meet Calorie Requirement

Table 5.38: Abbreviations for indicators used in MCA

Sub Objective	Criteria	Indicators	Abbreviation	2001	2008	Option A	Option B	Option C
MHC	HR	Change in monsoon water level (m)	HR-01	-1.03	-0.93	-0.88	-1.25	-1.16
		Change in dry season water level (m)	HR-02	-0.44	-1.23	-1.53	-0.6	-0.6
	HC	Duration of flow in connecting river/ khal with beel/ waterbody (days)	HC-01	199	155	148	150	170
	HSR	Ground water storage (Permeable area) (ha)	HSR-01	50,973	50,286	47,593	47,593	49,664
		Flooded area (%)	HSR-02	28	29	30	12	26
		Recharge (Mm^3)	HSR-03	671	662	626	585	639
		Depth of ground water table (m)	HSR-05	6.5	7.1	7.5	7.4	6.8
PEN	EQ	Fertilizer use for producing per ton of cereal (kg/ton)	EQ-01	75.4	75.9	48.1	46.1	42
	CM	Favourable duration for hatchling movement (days)	CM-01	56	48	35	42	49
		Favourable duration for fish migration (days)	CM-02	89	70	60	63	70
	CT	Social forestry area (ha)	CT-01	4,306	4,573	5,596	5.608	4,747
SEC	PE	Dry season flow (m^3/s)	PE-01	1.65	0.81	0.1	0.14	2.42
	PH	Dry season water area (ha)	PH-01	1,232	1,052	820	1,172	1,352
		Floodplain vegetation area (NCA) (ha)	PH-02	47,819	47,171	44,448	44,300	46,348
	PD	Aquatic species diversity	PD-01	4.27	2.42	2	2.03	3.28
FBN	HP	Percentage of average households meet the living space requirement	HP-01	25	20	28	31	30
		Percentage of landless farmer household meet the living space requirement	HP-02	17	18	43	50	45
		Percentage of fisherman household meet the living space requirement	HP-03	37	21	21	18	37
	CR	Percentage of average household meet the cereal (rice) requirement	CR-01	78	76	79	81	80
		Percentage of landless farmer household meet the cereal (rice) requirement	CR-02	74	75	86	90	87
		Percentage of fisherman household meet the cereal (rice) requirement	CR-03	83	76	76	75	83

Sub Objective	Criteria	Indicators	Abbreviation	2001	2008	Option A	Option B	Option C
	AN	Percentage of average household meet the animal protein (fish) requirement	AN-01	48	44	50	54	52
		Percentage of landless farmer household meet the animal protein (fish) requirement	AN-02	41	42	63	69	65
		Percentage of fisherman household meet the animal protein (fish) requirement	AN-03	58	45	45	42	58
FRD	RP	Percentage of settlement area within half km of the flooded area	RP-01	45	48	42	35	40
	RO	More than 9 months employment opportunity in agriculture (man-year)	RO-01	10,031	8,788	7,344	9,559	31,395
ESU	IG	Income from land use (Tk./ year)	IG-01	3,976	4,154	7,735	8,606	8,202
	EM	Percentage of employment (%)	EM-01	29	25	17	27	35
	RK	Crop at risk from flooding (metric ton/ year)	RK-01	1,847	4,643	5,951	190	243
		Household at risk from flooding (Tk./HH)	RK-02	2,383	2,482	3,078	222	708
APS	EC	No. of population served by unit education center	EC-01	459	428	336	336	336
	HE	No. of population served by unit health center	HE-01	104,219	116,101	27,818	24,426	24,426
	CO	No. of population have access to per km road	CO-01	2,064	1,711	2,417	1,977	2,099
FAV	PR	Total rice production (metric ton)	PR-01	150,656	169,855	374,101	411,413	368,920
		Total fish production (metric ton)	PR-02	2,504	2,066	2,139	1,150	1,753
	NT	Average calorie availability per day from rice and fish (kilo calorie)	NT-01	1,510	1,525	2,329	2,557	2,295

Note:

Cost criteria represent the inverse relationship

Benefit criteria represent the positive relationship

The MCA based evaluation of the sub objectives, criteria and indicators have been carried out based on the weights given to every level. Detail description of the indicators along with their weights and scores at each level are presented in Table 5.39.

Table 5.39: Scores at different level for MCA model

Objective				Sub-Objective					Criteria					Indicator				
	A	B	C		Wt	A	B	C		Wt	A	B	C		Wt	A	B	C
Protect Floodplain Environment	0.293	0.305	0.402	MHC	33.33	0.319	0.306	0.375	HR	20	0.25	0.322	0.427	HR-01	70	0.276	0.378	0.345
														HR-02	30	0.191	0.193	0.616
									HC	30	0.316	0.32	0.364	HC-01	100	0.316	0.32	0.364
									HSR	50	0.348	0.29	0.362	HSR-01	25	0.314	0.314	0.372
														HSR-02	20	0.441	0.176	0.382
														HSR-03	25	0.339	0.317	0.344
														HSR-04	0	0.131	0.195	0.674
														HSR-05	30	0.321	0.325	0.354
				PEN	33.33	0.313	0.333	0.354	EQ	30	0.313	0.327	0.359	EQ-01	100	0.313	0.327	0.359
									CM	50	0.297	0.33	0.373	CM-01	40	0.277	0.334	0.389
														CM-02	60	0.31	0.327	0.363
									CT	20	0.35	0.351	0.299	CT-01	100	0.35	0.351	0.299
				SEC	33.33	0.249	0.276	0.476	PE	33.33	0.193	0.207	0.6	PE-01	100	0.193	0.207	0.6
									PH	33.33	0.279	0.342	0.379	PH-01	60	0.246	0.35	0.404
														PH-02	40	0.329	0.329	0.342
									PO	33.33	0.274	0.278	0.448	PD-01	100	0.274	0.278	0.448
Improvement of Socio-economic Condition	0.279	0.367	0.354	FBN	25	0.32	0.333	0.347	HP	30	0.306	0.33	0.364	HP-01	50	0.315	0.348	0.337
														HP-02	30	0.312	0.362	0.326
														HP-03	20	0.277	0.236	0.487
									CR	50	0.328	0.335	0.337	CR-01	50	0.33	0.337	0.333
														CR-02	30	0.328	0.342	0.331
														CR-03	20	0.324	0.32	0.356
									AN	20	0.318	0.335	0.347	AN-01	50	0.321	0.345	0.334
														AN-02	30	0.32	0.349	0.331
														AN-03	20	0.309	0.289	0.402
				FRD	10	0.297	0.27	0.434	RP	70	0.359	0.3	0.341	RP-01	100	0.359	0.3	0.341
									RO	30	0.152	0.199	0.65	RO-01	100	0.152	0.199	0.65
				ESU	40	0.221	0.424	0.355	IG	50	0.316	0.35	0.334	IG-01	100	0.316	0.35	0.334
									EM	25	0.215	0.342	0.443	EM-01	100	0.215	0.342	0.443
									RK	25	0.038	0.654	0.308	RK-01	40	0.017	0.552	0.431
														RK-02	60	0.052	0.722	0.226
				APS	10	0.315	0.345	0.341	EC	40	0.333	0.333	0.333	EC-01	100	0.333	0.333	0.333
									HE	40	0.305	0.348	0.348	HE-01	100	0.305	0.348	0.348
									CO	20	0.297	0.362	0.341	CO-01	100	0.297	0.362	0.341
				FAV	15	0.329	0.35	0.321	PR	50	0.335	0.344	0.322	PR-01	90	0.324	0.356	0.319
														PR-02	10	0.426	0.229	0.345
									NT	50	0.324	0.356	0.32	NT-01	100	0.324	0.356	0.32

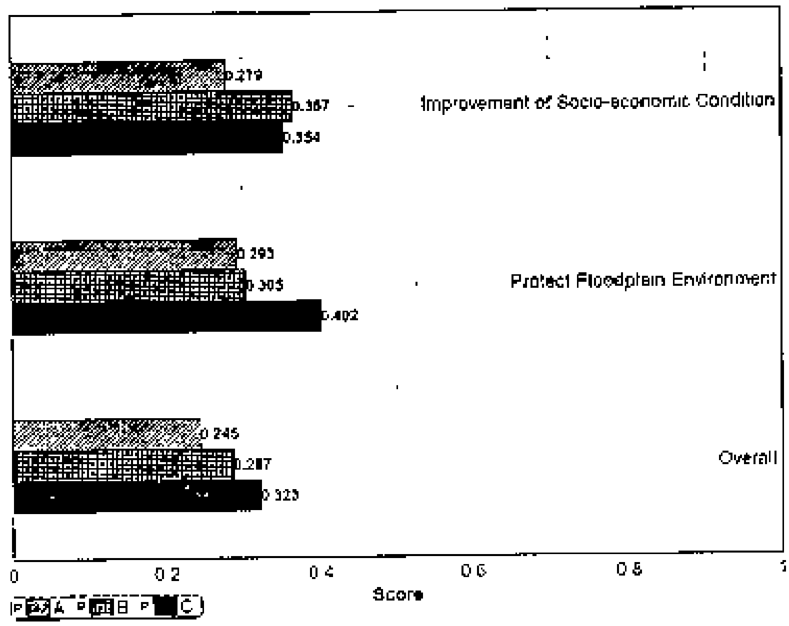


Figure 5.30: Performance of objectives

The performance evaluation of objectives and sub objectives level are presented in Figures 5.30 and 5.31. Figure 5.30 shows that, at the objective level, option C performs better in protecting floodplain environment while option B shows better results in socio economic improvement. Table 5.40 represents the overall score and ranking for MCA. Based on the scores, option C is ranked first followed by option B and option A.

Table 5.40: Overall score and ranking for MCA

Objectives	Weight	A	B	C
Protect Floodplain Environment	0.5	0.171	0.178	0.23
Improvement of Socio-economic Condition	0.5	0.2	0.258	0.245
Score		0.185	0.218	0.238
Rank		3	2	1

All sub objectives under protect floodplain environment show better results in option C followed by options B and A (Figure 5.31a). The sub objectives of socio-economic improvement shows better results in option B for economic sustenance, food availability and access to public services while option C is better in fulfilling basic needs and fairness in resource distribution (Figure 5.31b). All three options show closely packed results for most of the sub objectives except for safeguard ecosystem, economic sustenance and fairness in resource distribution where variations are wider.

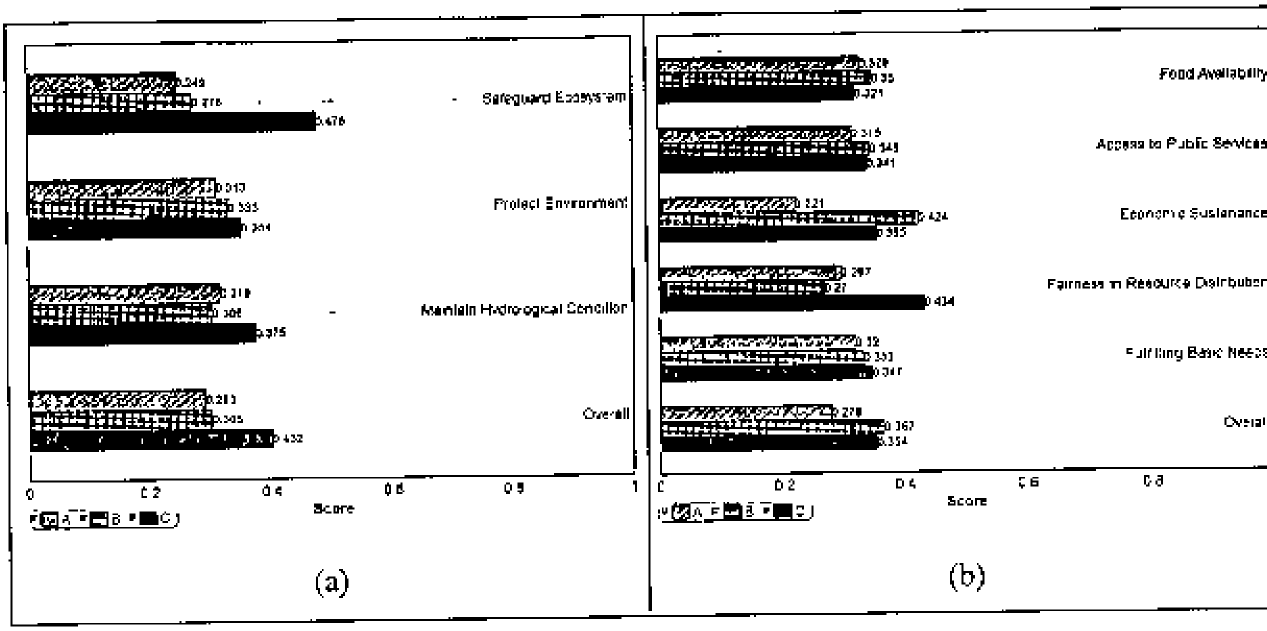


Figure 5.31: Performance at sub objectives level, (a) protect floodplain environment and (b) improvement of socio-economic condition

The performance evaluation at criteria level for individual sub objectives under protect floodplain environment are presented in Figure 5.32 while those under socio-economic improvement are presented in Figure 5.33. All criteria for maintain hydrological condition (Figure 5.32a) performs better in option C followed by option B while for maintain storage and regeneration option A is better than B though C is the best. In protect environment sub objective (Figure 5.32b), the results of criteria are closely packed showing option C as the better one except for maintain terrestrial habitat. It shows worser results in potion C than the other two. The criteria for safeguard ecosystem (Figure 5.32c) shows wide variation between option C and the other two specifically in sustaining aquatic biodiversity and ensure environmental flow. In overall, option C is clearly ahead than B and A in safeguard ecoisystem.

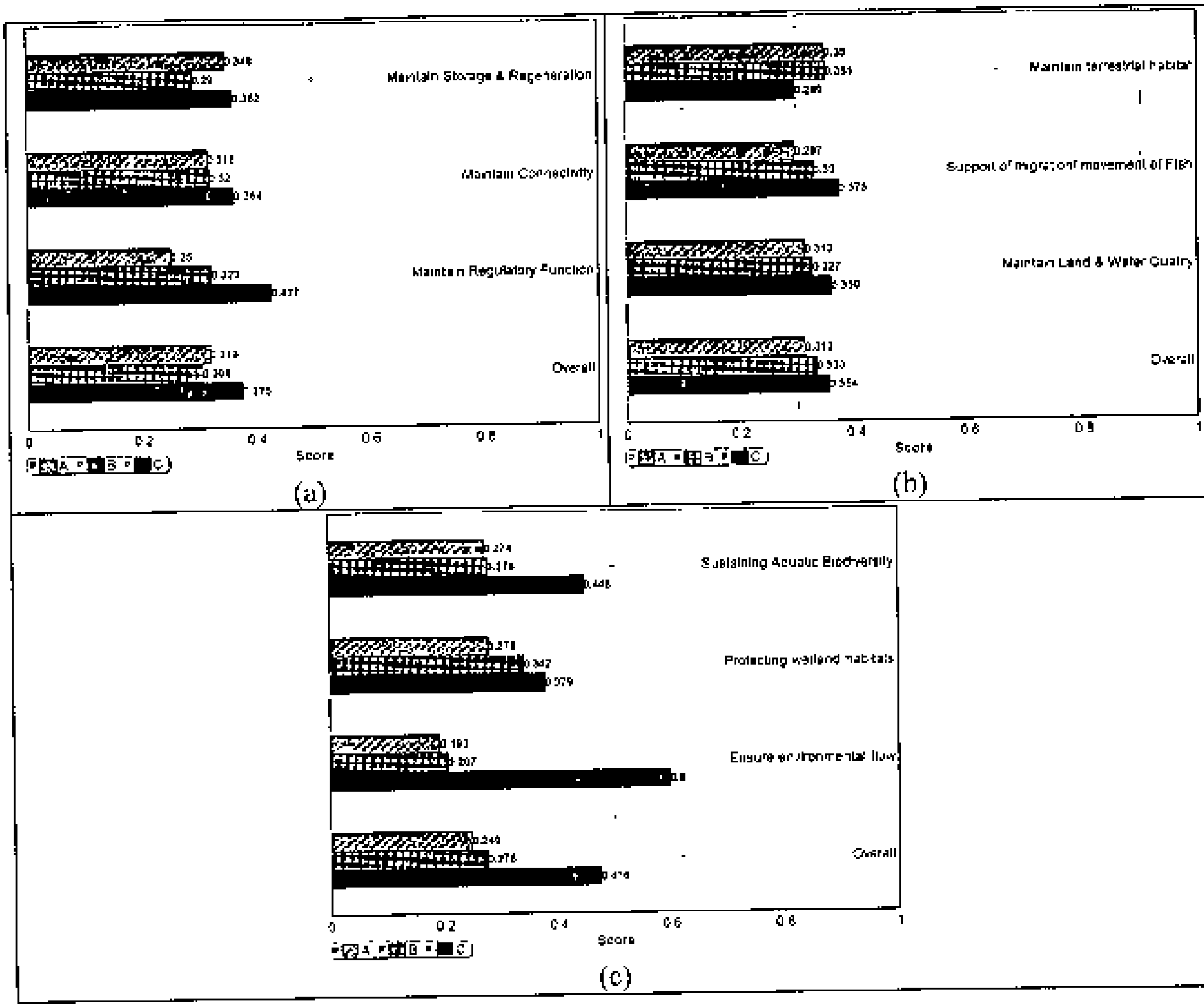


Figure 5.32: Performance at criteria level, (a) maintain hydrological condition, (b) protect environment and (c) safeguard ecosystem

The criteria under fulfilling basic needs (Figure 5.33a) show slight variation between the three options. Cereal availability is almost same for all options while animal protein and housing space availability perform better in option C. Figure 5.33b illustrate two criteria for fairness in resource distribution. Temporal distribution of occupation show huge variation between option C and the other two. But accessibility to flooded area for subsistence fishing shows better results in option A, then C and A. In overall, Option C is better in fairness in resource distribution.

Economic sustenance sub objective show that option B is better than C and A (Figure 5.33c). Option C perform better in create employment opportunity and close to option B in increase gross income while in reduce risk from flooding option B clearly outperform other two options. Performance of option A is considerablely worse than B and C.

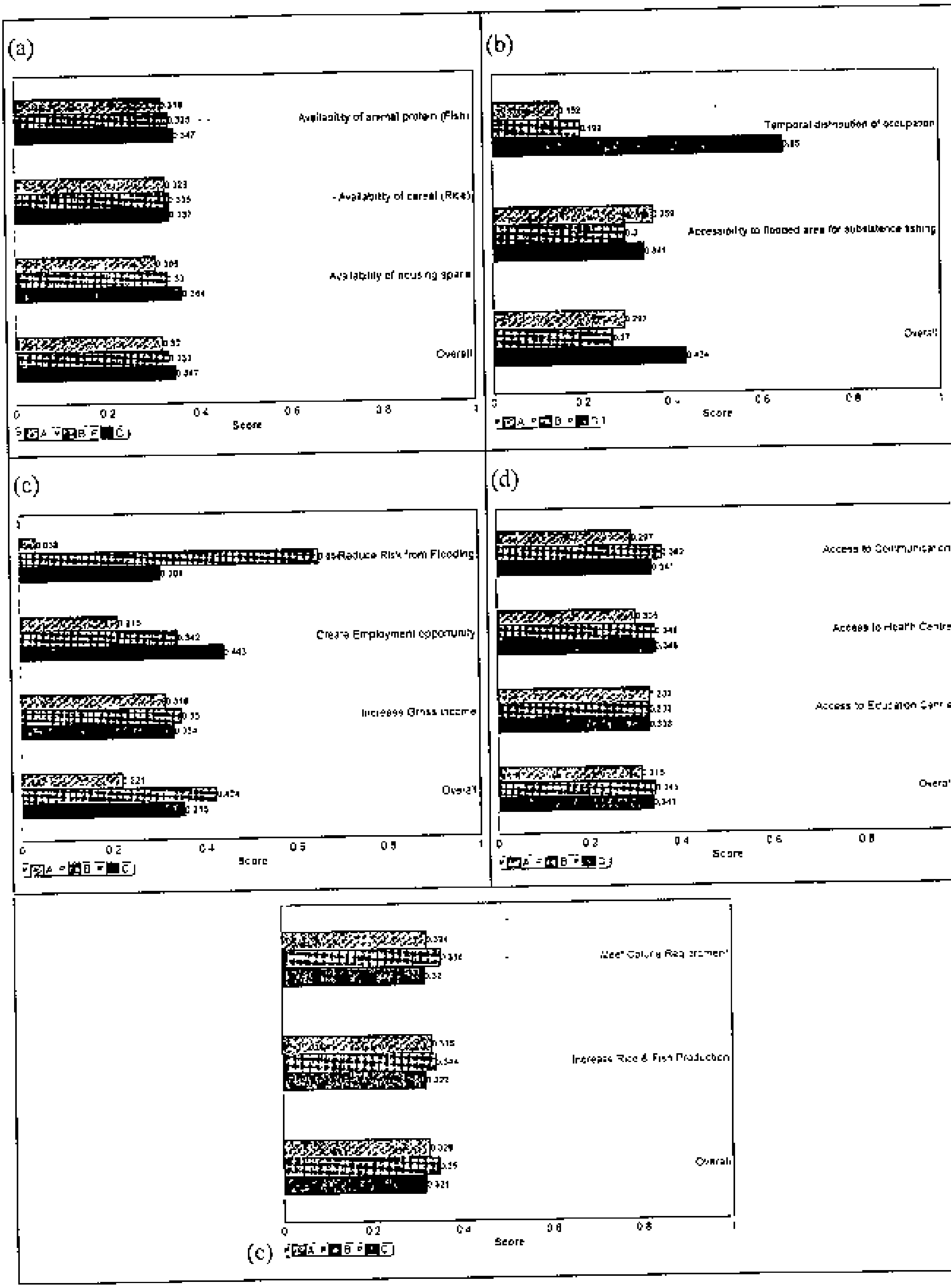


Figure 5.33: Performance at criteria level, (a) fulfill basic needs, (b) fairness in resource distribution (c) economic sustenance, (d) access to public services and (e) food availability

The access to public services (Figure 5.33d) shows similar results in option B and C and poorer results in option A. Access to education centre and health centre show same results for option B and C while access to communication shows better results in option B. For food availability option C shows inferior results than the other two (Figure 5.33e). Option B performs better in this sub objective followed by option A and C. In respect of meeting calorie requirement option A and C show almost similar results while option B is substantially better. For increase rice and fish production option B is perform well than option A followed by option C.

5.11.2 Selection of options

Socio-economic improvement is the ultimate goal of sustainable resources management. However, to be sustainable, development should maintain floodplain functions. At the same time, sustainable landuse must be compliant with the constraint: equitable resource distribution and safeguard ecosystem. Analysis using MCA shows that option C is compliant with the constraint. Actually, option C incorporates all measures necessary to comply the constraints. For example, to fulfill basic needs, it is necessary to increase rice and fish production To increase rice production several measures have been suggested such as, less risky, climate resilient and environment friendly cropping patterns, which incorporates Aus and emphasizes Aman and jute production. This option recommended that Aman production should be restricted to high and medium high lands to save crop damages from floods and supplementary irrigation must be provided to reduce damage from droughts. Dependency on Boro should be reduced because it demands more inputs (fertilizer, water, etc) and it is highly vulnerable to climate change effect (Yu et al, 2010). The suggested cropping pattern also support a better distribution of employment opportunity throughout the year as shown in Figure 5.33b. The most important point is that this cropping pattern will increase productivity but demand less fertilizer as Boro area is reduced The suggested cropping pattern will reduce Boro cultivation but it will increase Rabi/valued crops.

To restore floodplain habitat and to protect the environment, option C has improved the connectivity by dredging and installing fish friendly structures. It also reclaimed the wetland from Boro cultivation. Improvement of capture fisheries production and the aquatic environment have been achieved in option C due to the implementation of fish migration routes and facilitate hatchling movement between river and floodplain. A buffer zone is identified encircling every permanent waterbody (beel), where boro cultivation is restricted. As the suggested cropping pattern will demand less fertilizer, so less pollutant will go to the waterbody. Under option C, the flooded area of the floodplain is higher than in option B, which ensures accessibility of the subsistence farmer to fishing (common property), as shown in Figure 5.33b.

Option C suggests that no tube-wells should be installed for providing irrigation within 50 metre of the periphery of settlement area to prevent the drying of hand tube-wells used for drinking and domestic purpose. To maintain base flow as well as environmental flow, no low lift pumps will be used for irrigation under option C. Option C also provides better safeguard to the ecosystem than the other options as shown in Figure 5.32c. Restoration and protection of wetlands helps to maintain dry season water area. which is important for aquatic habitat. The floodplain vegetation area will improve in option C than both options A and B. This is achieved mainly by not expanding the settlement area under option C.

Overall, floodplain environment has been improved under option C. Several measures have been taken to improve the floodplain functions. Suppose in case of hydrological function, dry season flow has been improved by putting regulators and dry season flow augmentation. Even though, there is a huge population pressure who will demand more settlement, the rural settlement area has been suggested not to expand in order to restrain decline in cultivable land. Option C suggested compaction or zoning of settlement area. As a result, settlement area is less in comparison to both option B and A. Less settlement area will lead to more permeable area. This will have dual effects. First, it will increase the recharge of groundwater. Secondly, more agricultural land will be available for agricultural production. Groundwater storage is also higher under option C compared to the other two options. Substantial improvement has been observed in environmental flow which is mainly due to impediments of surface water withdrawal.

In improving socio-economic condition, option B has higher values than option C but lower than option A. Rice production is higher in option B and A due to more cultivation of Boro. But option C incorporates Aus and emphasizes Aman and reduce Boro cultivation as it demands more inputs. But all these three options are able to meet the cereal demand in 2050. Fish production has increased substantially in option A.

Option C has the second highest values because wetland has been restored, improvement in water quality due to less usage of fertilizer in agricultural land. Option C shows the overall improvement of socio-economic condition than A but lower than option B (Figure 5.33). Occupation wise income (farmer, fisherman) shows a substantial improvement. This research considers only landuse related incomes and as rice and fish production will increase, the gross income from landuse will also increase. As the income of different occupation group is derived from different landuse activities, so increased gross income increases the income of different occupants (landless farmer and fisherman).

Option C provides comparatively better protection to crops and household assets than option A. Option B provides the highest degree of protection as it suggests full protection from flooding by constructing embankments. But full protection by means of embankment creates many environmental problems such as drainage congestion, lack of flushing of impurities, etc.

In overall, for improvement of socio-economic condition option B is the best as it implement several structural measures like construction of embankments. promote and protect agricultural production through maximum cropping intensity and reducing risk from flooding. But it lacks in fairness in resource distribution. Option C is far lot better than option B for fairness in resource distribution. Option B also falls behind option C in fulfilling basic needs. Though option B is better than option C in overall results for socio-economic improvement, option C provides a efficient and balanced resource use considering protection of floodplain environment, equitable resource distribution and fulfilling basic needs.

5.11.3 Findings and discussions

This research has developed a decision support framework for sustainable land and water management in a floodplain After performing sensitivity tests against land and water use activities, this study adopted a practical approach in developing 8 sub objectives, 22 criteria and 36 indicators to evaluate the objectives of sustainable resources management framework. Based on the available outputs developed from hydrodynamic model, hydrological model and field investigations, the indicators for different functions in the framework were chosen.

To evaluate the sustainable resources management goal, multi criteria analysis model has been developed. In this analysis the constraints (safeguard ecosystem and ensuring equitable resource distribution) has been included as criteria to effectively represent the sustainable resources management framework.

Protection of floodplain environment is the base for improving socio-economic condition in terms of equitable resource distribution and safeguarding the ecosystem. To assess the state of floodplain, three criteria maintain hydrology, protect environment and safeguard ecosystem has been considered. At the objective level, protect floodplain environment shows that option C is able to improve the degrading condition, whereas, option B can restrain degradation beyond present status. However, option A degrades further than the present status. In option C, several measures have been taken to improve the condition. Settlement area and irrigation from groundwater has been limited to protect groundwater recharge area and to reduce groundwater use respectively. Dredging of river channels have been done to increase the connectivity in khals and small rivers. Similarly, to maintain environmental and ecological functions, the fertilizer and pesticide use has been minimized by increasing efficiency. The naturality of flow has been maintained to allow interchange of food between rivers and floodplain as well as movement of fish species. To ensure safeguarding ecosystem, protection to wetland habitat, sustain aquatic biodiversity and improving environmental flow condition were targeted. Substantial improvements were achieved in option through various environment friendly measures. Despite the efforts, some of the indicators could not be improved. For example, dry season flow is already degraded to maintain environmental flow, which could not be improved to meet the environmental flow requirements.

To ensure equitable resource distribution two criteria: fulfill basic needs and fairness in resource distribution has been considered. The criteria to fulfill basic needs includes: availability of animal protein (fish), cereal (rice) and housing space. In case of availability of cereal or animal protein, the landless farmer and fisherman were selected to represent the lower income tier of population in the society along with the average household. If their socio-economic condition can be improved, then overall socio-economic condition is expected to improve. In option C, availability of both cereal and protein to the farmer and fisherman will be better than other options.

There are two selected indicators of fairness in resource distribution: accessibility to flooded area for subsistence fishing and temporal distribution of occupation. It is assumed that more settlement area will be within the floodplain and so, more people will get access to subsistence fishing. In this dissertation, it has been observed that settlement area within the floodplain had been declining under different options compared to the present situation. However, the temporal distribution of employment in agriculture (more than 9 months) showed substantial improvement in option C. Currently, agriculture in the study area is mainly dominated by Boro cultivation, which results in concentrated employment in the first five months of the year and the employment opportunity drops sharply during the rest of the months. In option C, sustainable cropping pattern is suggested which emphasizes cultivation of more floodplain crops (jute, aus and aman). After implementation of this newly suggested cropping pattern, uniform distribution of employment throughout the year can be achieved. It is observed in the study area in option C, more than 9 months employment opportunity is available for 31,395 people, whereas this number is only 7,344 and 9,559 in option A and B respectively.

Socio-economic improvement lies at the heart of sustainable resources management. Fulfilling basic needs, fairness in resource distribution, economic sustenance, access to public services and food availability covers this objective. It has been observed, in the future average household income will increase. resulting in better ability of the household to meet their basic needs. Suppose presently, 76% of the households can afford the required amount of cereal (rice). In option C, this number will improve to 80% even though the population will nearly double. In option C, percentage of employment will be two times higher than A and 1.5 times higher than in B This is mainly due to better distribution of employment in agriculture, set up of new industries such as jute, garments. poultry, etc and development of communication facilities.

This research developed a GIS based risk assessment procedure which demonstrates when and where and what type of crops should be planted. It suggests the procedure that T. Aus and T. Aman should be planted in medium high and high land to reduce risk from flooding.

Saving approximately reflects the resilience of the community. It is found that per day per capita cost of food is 30 Tk (calculating from BBS selected food basket and cost of food estimated by BBS). It has been observed that currently average farmers cannot meet the cost of basic needs. Not only that, they have to borrow money. In the future, they will be able to save money due to increased income from higher production. Fisherman's income is reduced in option A and B as their access to waterbodies will be restricted due to increased leasing of water bodies. However, in option C their income as well as savings will increase as it does not encourage leasing of water body. Thus, increased households savings will increase their resilience in the future.

In summary, this decision support framework on sustainable land and water management has performed successfully to capture the changes in land and water use activities and corresponding impacts on floodplain fuctions, environment and on socio-economic condition. This framework will be helpful in understanding the interdependence of social, economic and environmental resources and it will facilitate in developing an integrated management plan for land and water resources in a floodplain environment.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Development plans are usually evaluated on the performance of output only. This study has developed a decision support framework for sustainable land and water management for a floodplain. In this framework, in addition to output, functionality and productivity of floodplain resources were used for evaluating sustainable land and water resource management objective. The developed framework, has the ability to visualize the changes in state (i.e. floodplain function) and the impact on floodplain environment and socio-economic condition. Further, it is simple enough to be implement in a floodplain, to select a sustainable land and water management in a floodplain. In an effort to change the mindset of the people from thinking as the user of floodplain resources to a custodian of these resources in order to meet both present and future generation needs, the concept of "Inverted Pyramid" has been developed.

In this study, there are two competing objectives: socio economic improvement and maintaining floodplain environment. To evaluate the objectives of sustainable land and water management framework, this research has developed 8 sub-objectives, 22 criteria and 36 indicators. Land and water resource functions have been defined for floodplain. To characterize the floodplain functions, four sub functions: hydrological, environmental, ecological and socio-economic condition has been considered. The indicators have been developed to characterize and assess the change in state of floodplain function. The hydrological function includes a number of indicators under certain criteria: regulatory, connectivity, storage and regeneration function. Fertilizer and pesticide use rate, aquatic species diversity, etc. are taken as indicators to characterize and represent the environmental function. To evaluate the socio-economic condition, cereal (rice) and fish (protein) productivity as well as ensuring human habitat were used. The indicators of socio-economic condition include: income, savings, employment, reduce risk from flooding, improve health and nutrition, and access to public services.

Ensuring equitable distribution of land and water resources and safeguarding the ecosystem have been used as constraint in the sustainable resource management framework. Constraints of land and water use have been assessed on the basis of two sub-criteria: fulfill basic needs and fairness in resource distribution. Indicators to fulfill basic needs, determine how many people are able to meet the minimum requirement of basic needs (societal demand: cereal and fish and living space). Fairness in resource distribution is assessed in terms of accessibility to flooded area for subsistence fishing and temporal distribution of occupation in agriculture. The constraints to safeguard the ecosystem are: environmental flow i.e. minimum dry season, wetland area to sustain aquatic habitat and floodplain vegetation area. Besides constraints, the opportunities have been calculated for four different types of land and water use in the rural areas of floodplain. Based on physical suitability and social preferences, the opportunities have been developed and assessed using criteria based GIS model.

The sustainable land and water management framework have been empirically tested in Jamalpur district, part of old Brahmaputra and Jamuna floodplain. To assess and understand the interdependency and interrelationship between land and water use, data was collected through FGDs, KII and household survey. Besides field investigation, RS, GIS, hydrodynamic and hydrological models have also been used. To test the decision support framework, three options (Option A: Autonomous development based on existing management trends, Option B: Implementation of regional water management plan in FAP 3.1, and Option C: Balanced land and water use activities based on driving factors, such as, policies, strategies and needs and requirements for society and ecosystem) have been developed to project land and water use activities for the year 2050. In option C, emphasis was given to make floodplain function to meet the socio-economic needs of future generation.

These options have been evaluated through multi criteria analysis (MCA) using Analytical Hierarchical Process (AHP). RS, GIS, hydrodynamic and hydrological models have been used to generate indicator values to evaluate objectives. The framework not only evaluated the options, but also assessed the historical data (2001, 2008). On evaluation, it is observed that option B scored highest in terms of socio-economic improvement, because it is the prime objective of regional plan. However, it does not adequately address floodplain environment i.e. maintaining hydrological condition, protecting the environment and safeguarding the eco-system. For example, maintaining floodplain functions, option B scored the lowest, whereas, it scored the highest in option C. Option C does not score well in terms of socio-economic improvement but overall score of option C is highest with respect to sustainable land and water use. This is mainly due to improvement in floodplain environment, improving equitable distribution of land and water use and safeguarding the ecosystem. In case of ensuring equitable resource distribution, option C scored the highest, followed by option B and A. Option C also scored better in safeguarding the ecosystem whereas, option A has the lowest score followed by option B. Option C emphasized three areas: maintaining floodplain functions, safeguarding the ecosystem and ensuring equitable distribution of land and water resources and it adopted necessary measures to attain sustainable land and water management in a floodplain.

In the future, this decision support framework on sustainable land and water management will be helpful in providing relevant information to resource planners to enable them to support formulation, analysis and evaluation of alternative water management strategies. This framework will be able to account for changes in different land and water use options and scenario like upstream withdrawal and climate change as well as structural and non-structural interventions. Finally, this framework will help national planners in understanding the interdependence of social, economic and environmental resources and it will help in developing an integrated management plan for land and water use in national planning.

6.2 Recommendations for Future Research

The criteria and indicators developed for the study area has used current weights defined by the experts. The weights used, need to be improved considering the stakeholders view in field levels.

Criteria and indicators identified for decision support framework of sustainable land and water management has been framed considering only the non-tidal deltaic floodplains, but future research should include tidal floodplains in coastal area.

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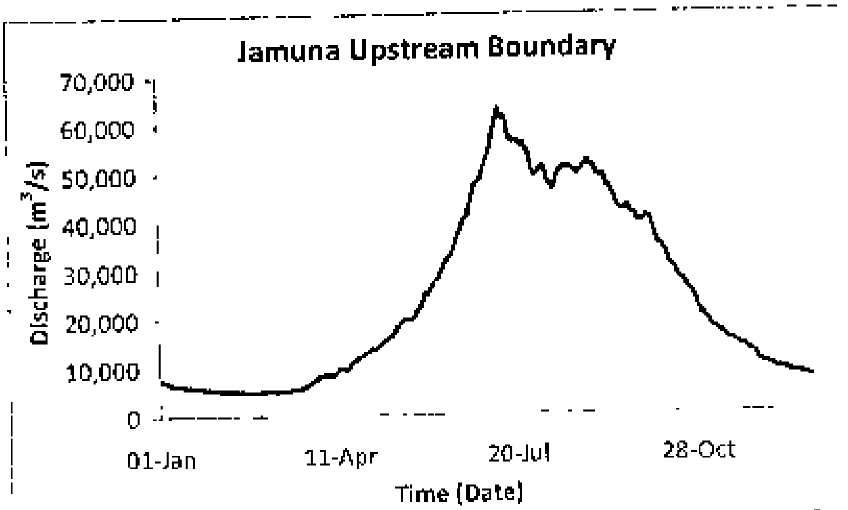
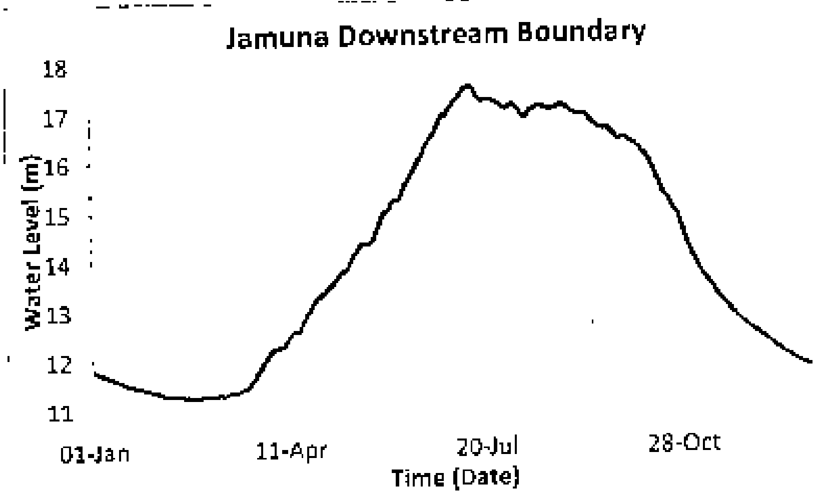
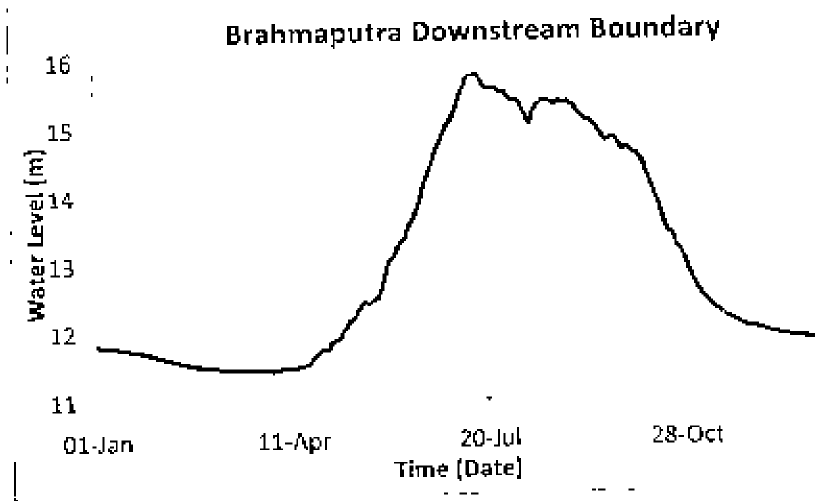
Annex A

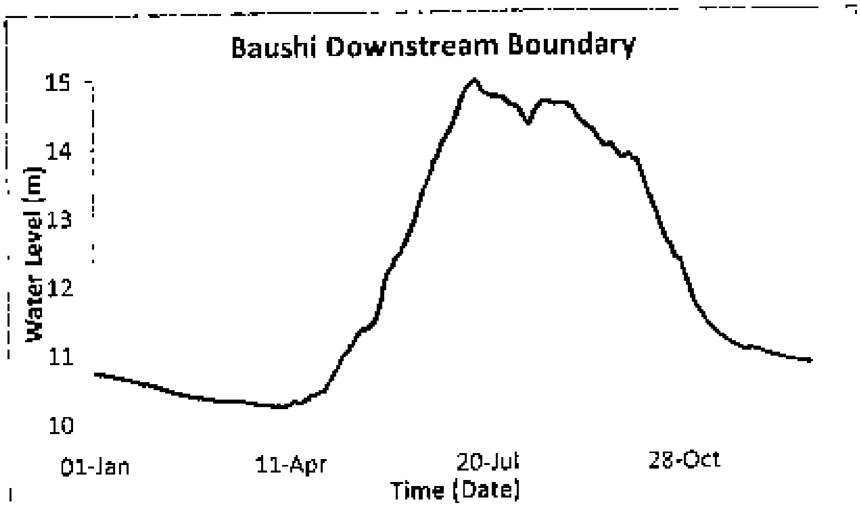
Hydrological and Model Data of the Study Area

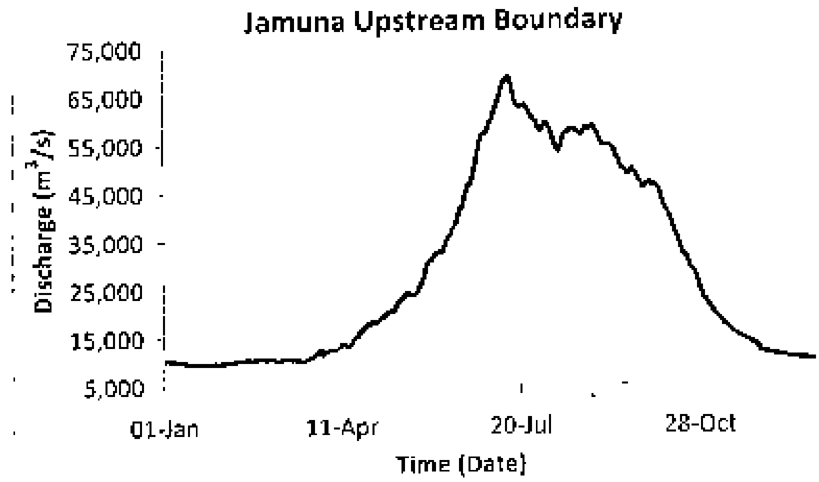
Hydrographs at different boundary locations for different options

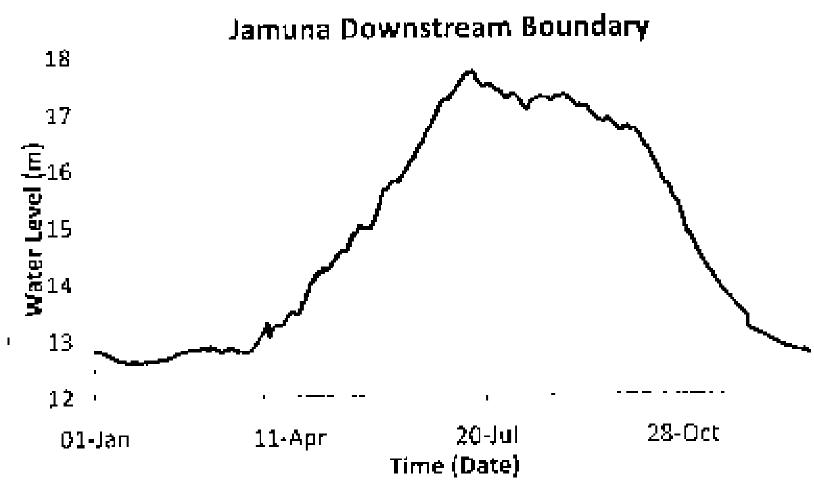


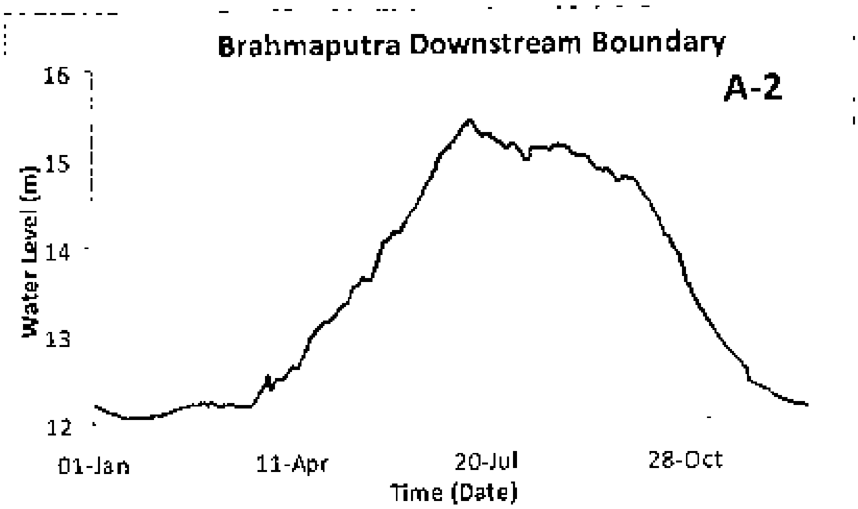




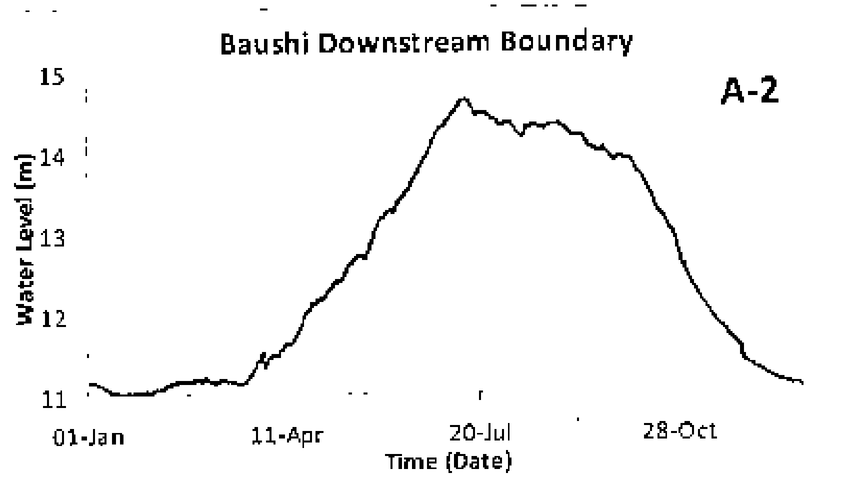

Baushi Downstream Boundary
Water Level (m)
15
14
13
12
11
10
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)


Jamuna Upstream Boundary
Discharge (m^3/s)
75,000
65,000
55,000
45,000
35,000
25,000
15,000
5,000
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

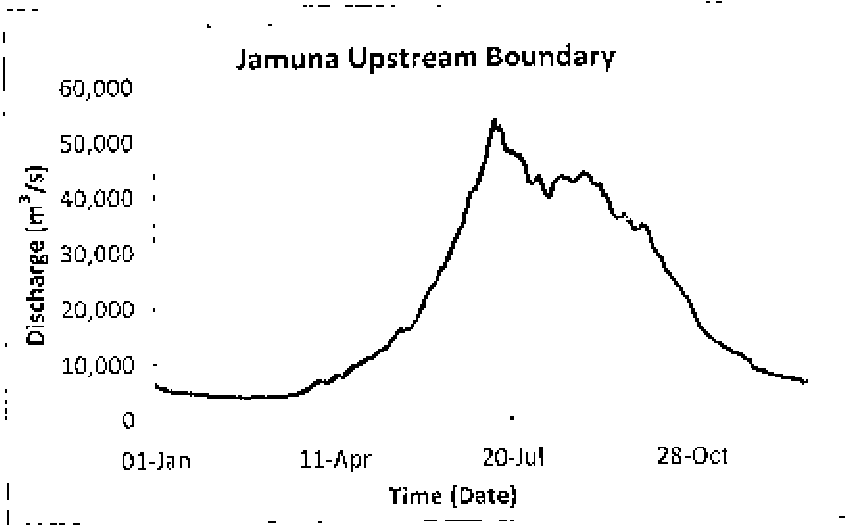

Jamuna Downstream Boundary
Water Level (m)
18
17
16
15
14
13
12
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)



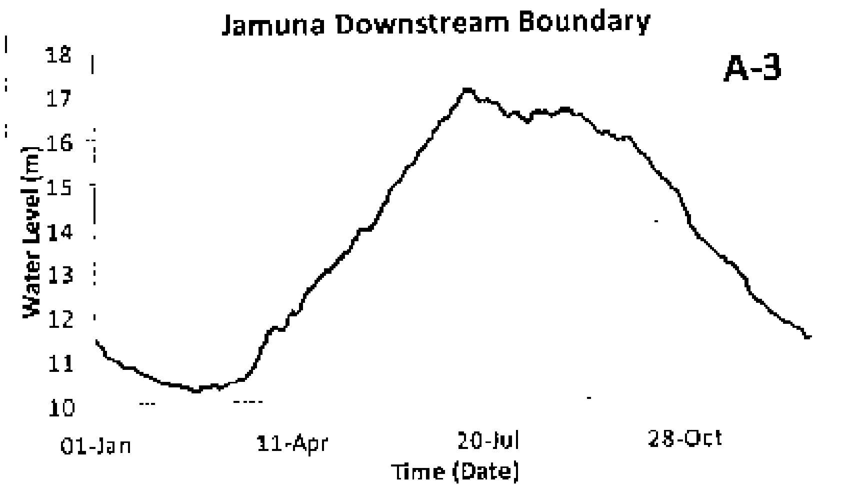
Brahmaputra Downstream Boundary
A-2
16
15
14
13
12
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

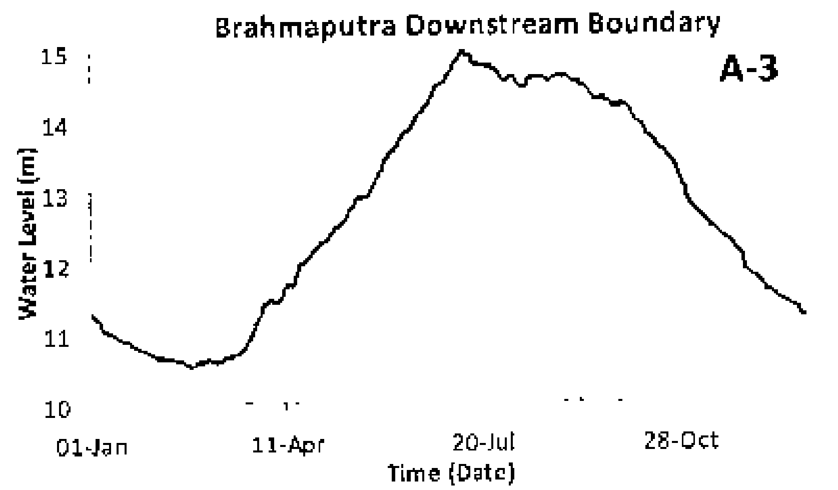


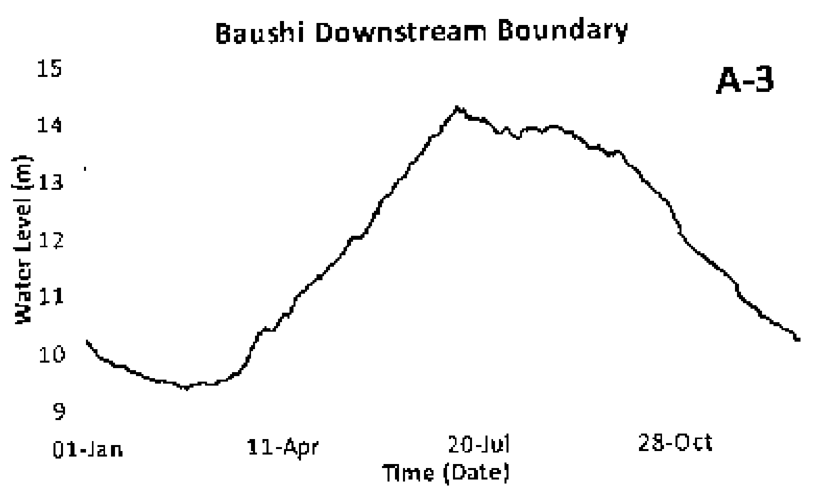
Baushi Downstream Boundary
A-2
15
14
13
12
11
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

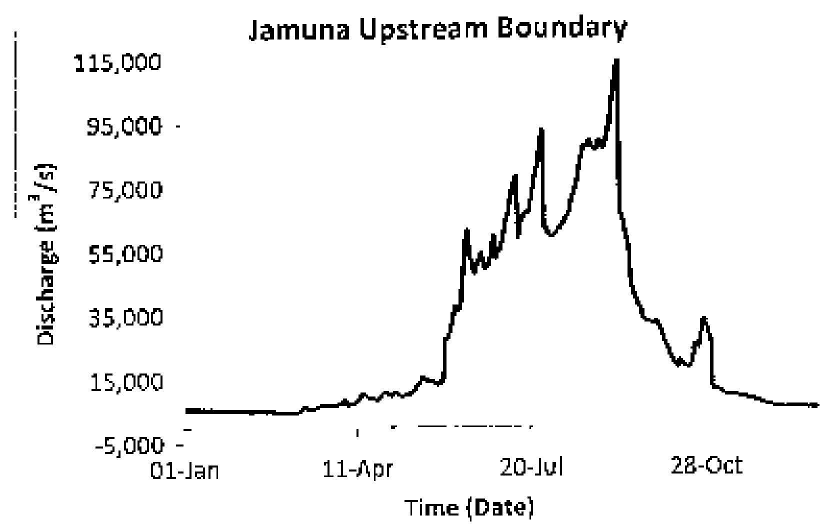


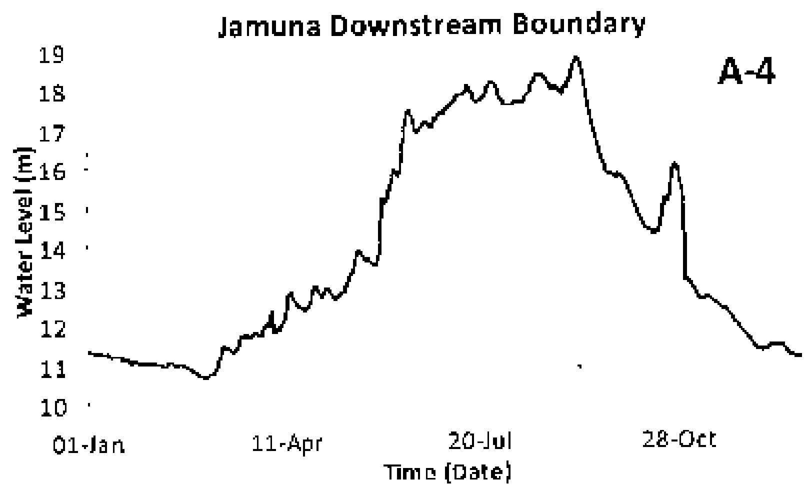
Jamuna Upstream Boundary
60,000
50,000
40,000
30,000
20,000
10,000
0
Discharge (m3/s)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

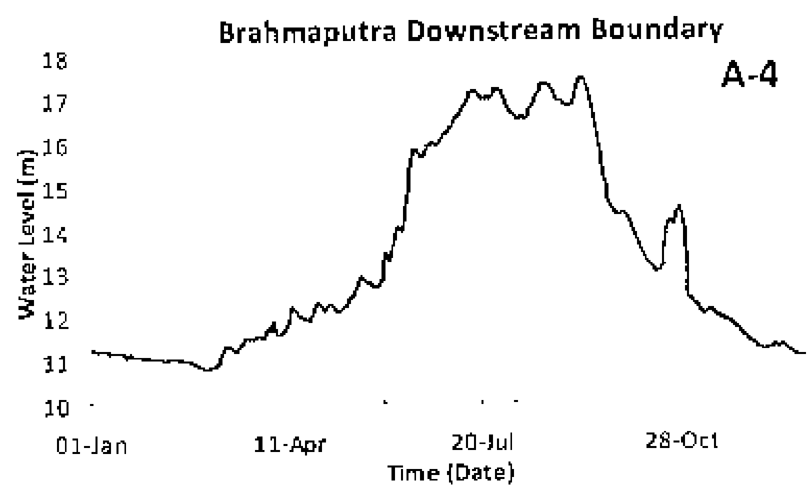

Jamuna Downstream Boundary
A-3
Water Level (m)
18
17
16
15
14
13
12
11
10
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

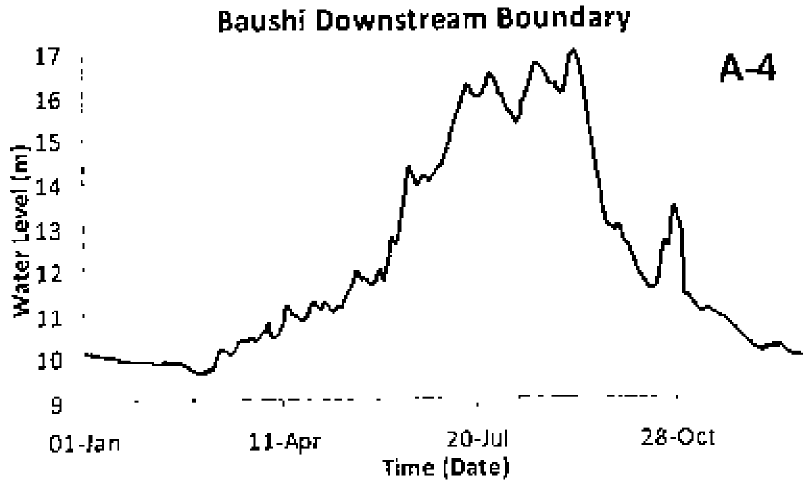

Brahmaputra Downstream Boundary
A-3
Water Level (m)
15
14
13
12
11
10
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

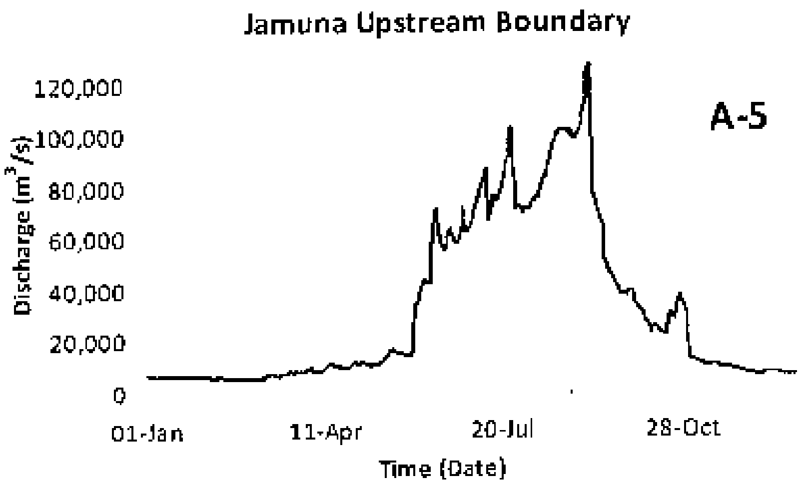

Baushi Downstream Boundary
A-3
Water Level (m)
15
14
13
12
11
10
9
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

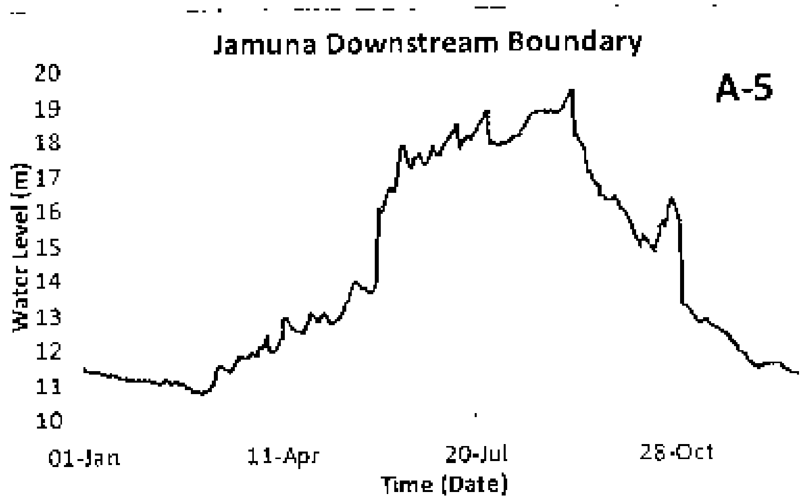

Jamuna Upstream Boundary
115,000
95,000
75,000
55,000
35,000
15,000
-5,000
Discharge (m3/s)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

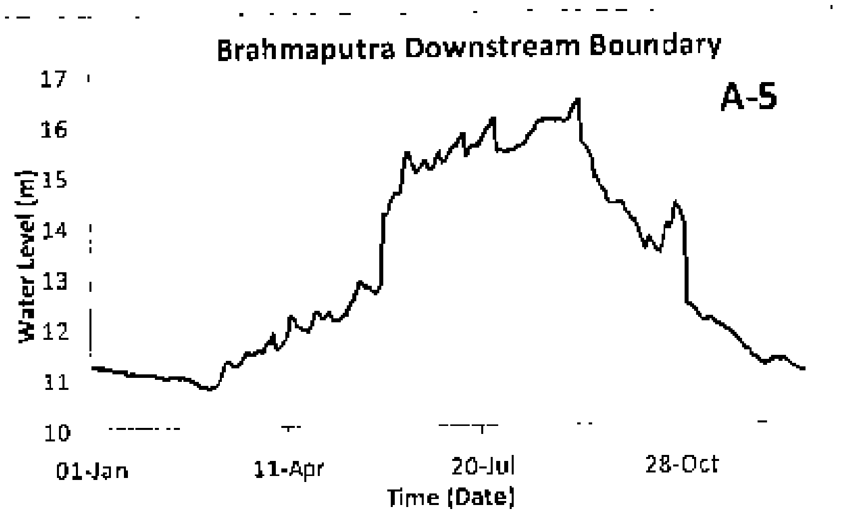

Jamuna Downstream Boundary
A-4
19
18
17
16
15
14
13
12
11
10
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)


Brahmaputra Downstream Boundary
A-4
18
17
16
15
14
13
12
11
10
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

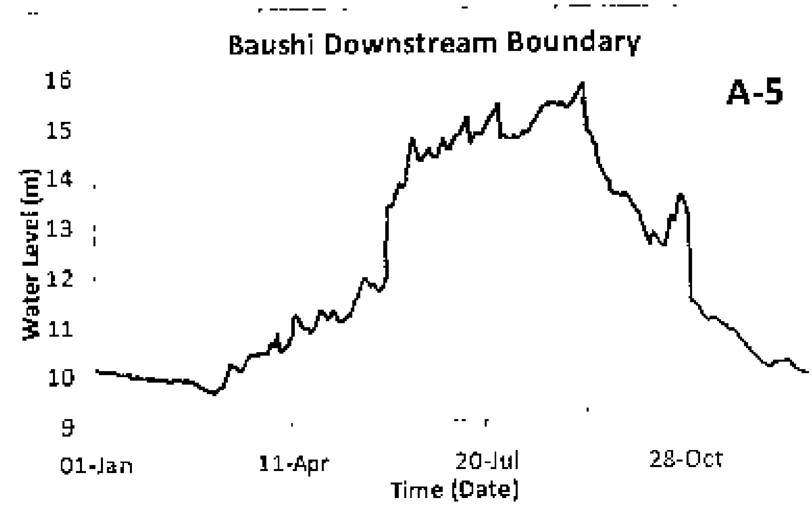

Baushi Downstream Boundary
A-4
Water Level (m)
17
16
15
14
13
12
11
10
9
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)


Jamuna Upstream Boundary
A-5
Discharge (m3/s)
120,000
100,000
80,000
60,000
40,000
20,000
0
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

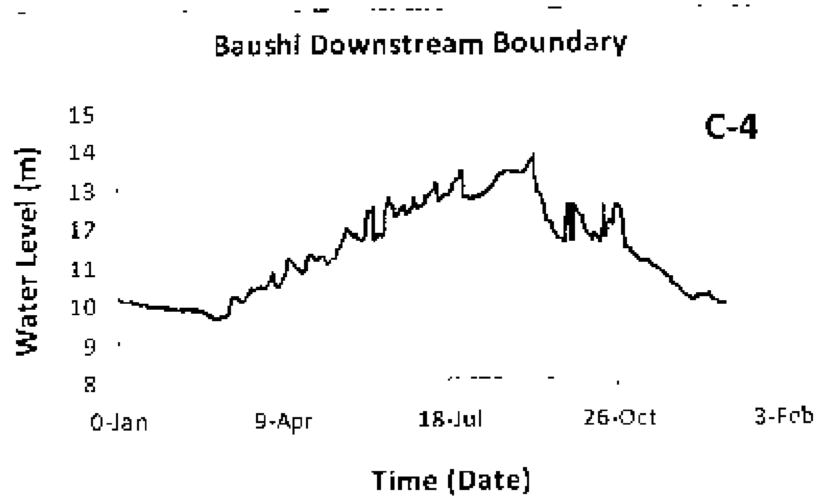

Jamuna Downstream Boundary
A-5
Water Level (m)
20
19
18
17
16
15
14
13
12
11
10
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)



Brahmaputra Downstream Boundary
A-5
17
16
15
14
13
12
11
10
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

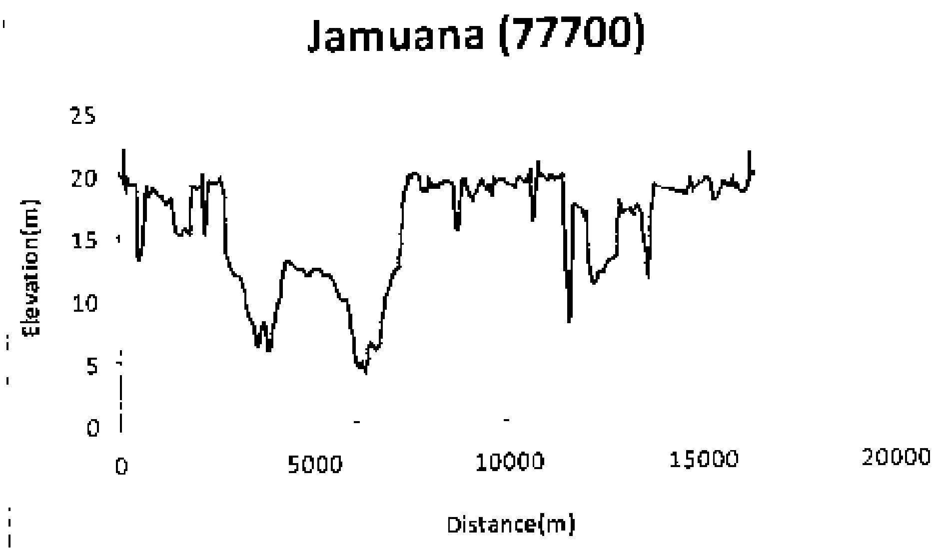


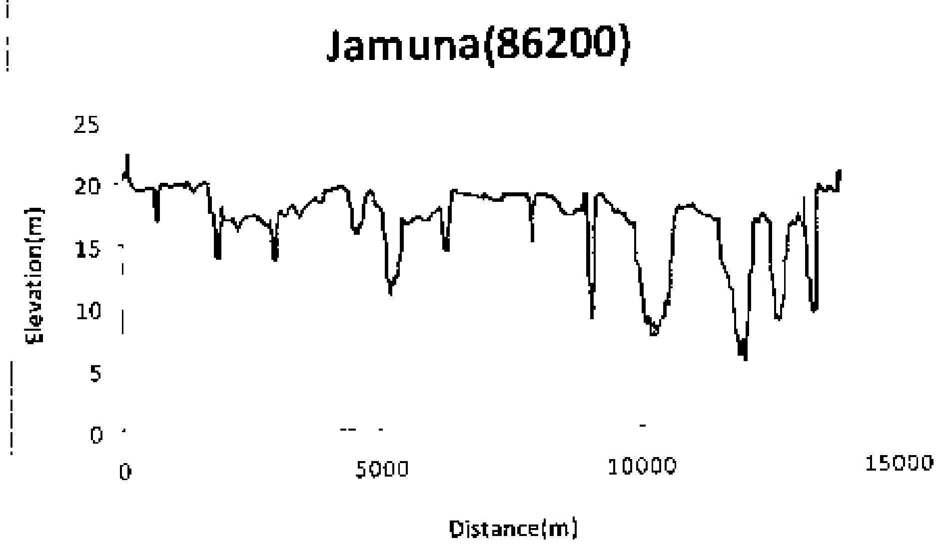
Baushi Downstream Boundary
A-5
16
15
14
13
12
11
10
9
Water Level (m)
01-Jan
11-Apr
20-Jul
28-Oct
Time (Date)

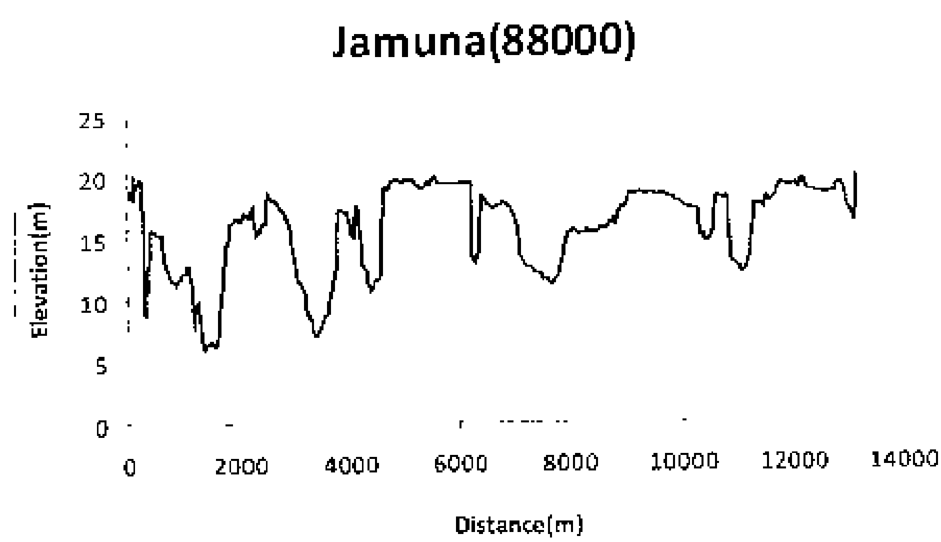


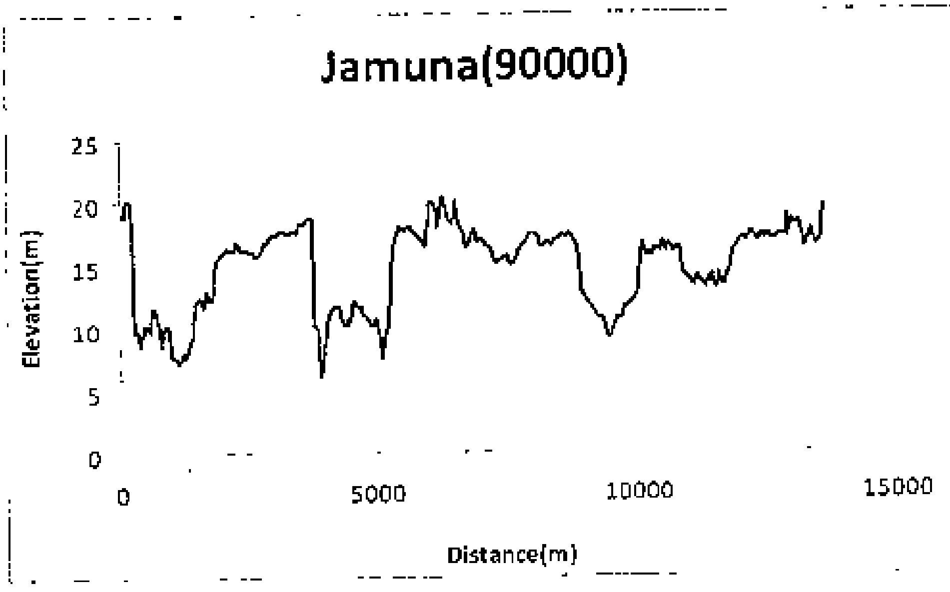
Baushi Downstream Boundary
C-4
15
14
13
12
11
10
9
8
Water Level (m)
0-Jan
9-Apr
18-Jul
26-Oct
3-Feb
Time (Date)

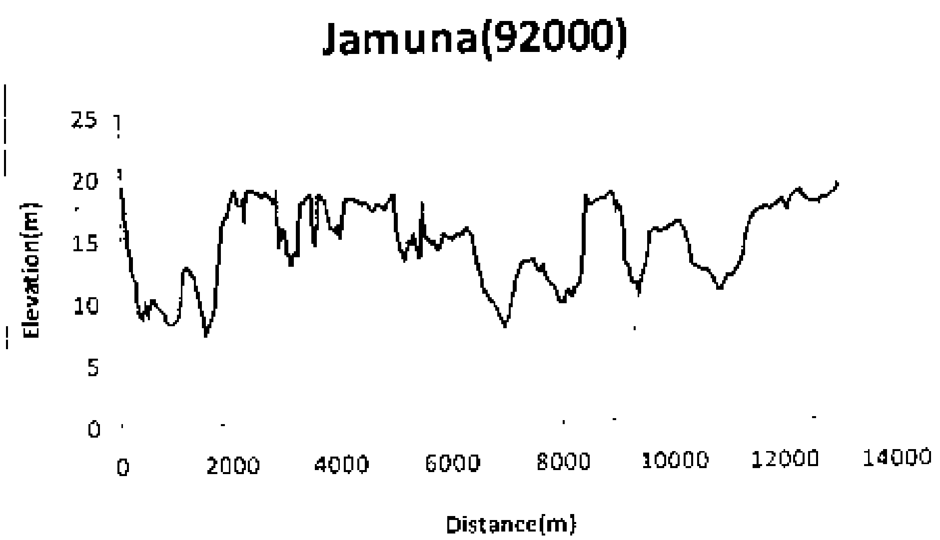
River cross sections at different locations

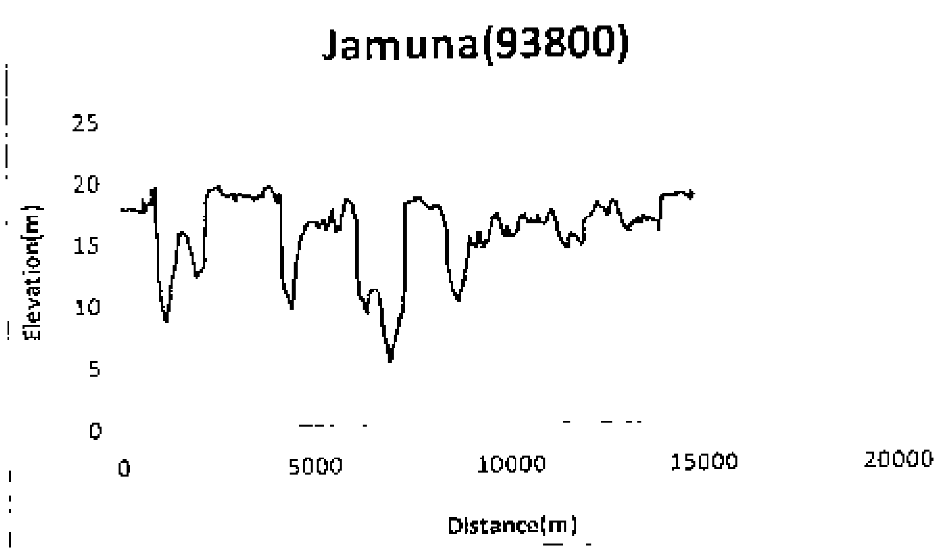


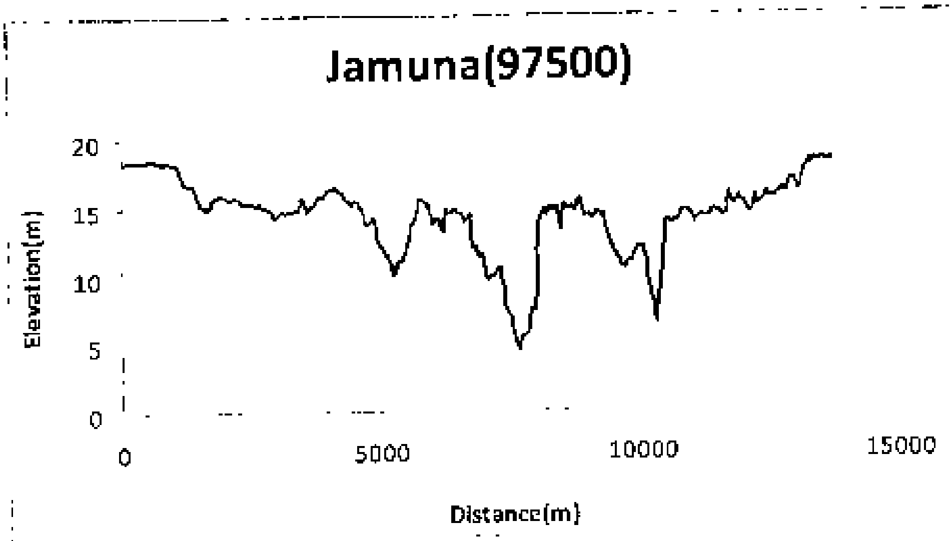


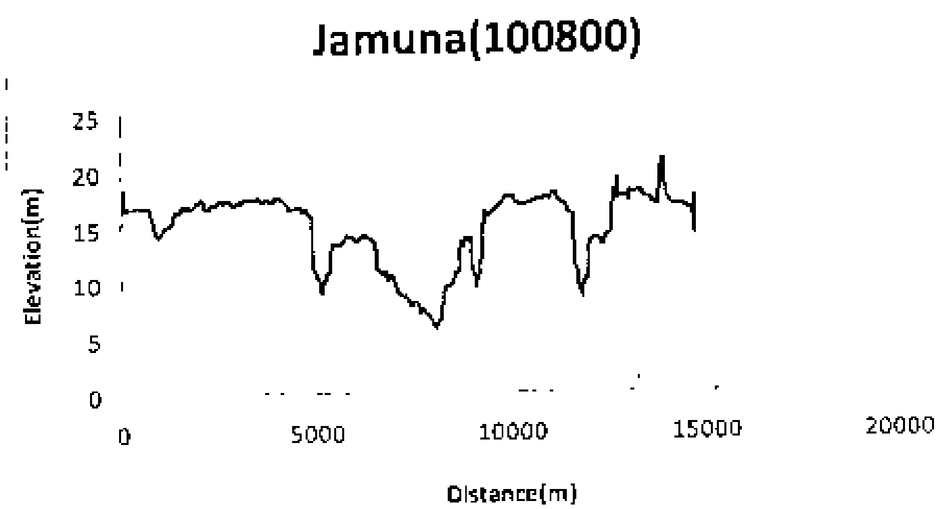


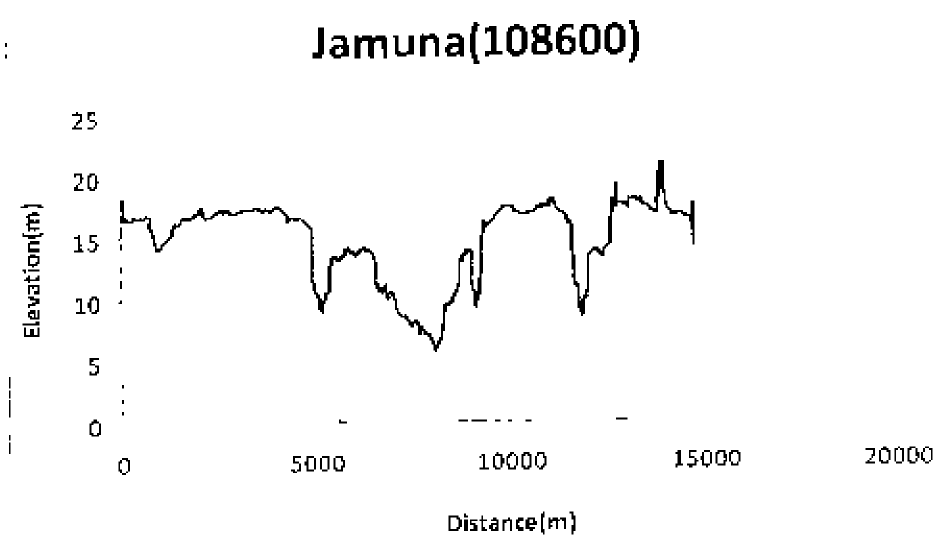

Jamuna(90000)
Elevation(m)
25
20
15
10
5
0
0
5000
10000
15000
Distance(m)

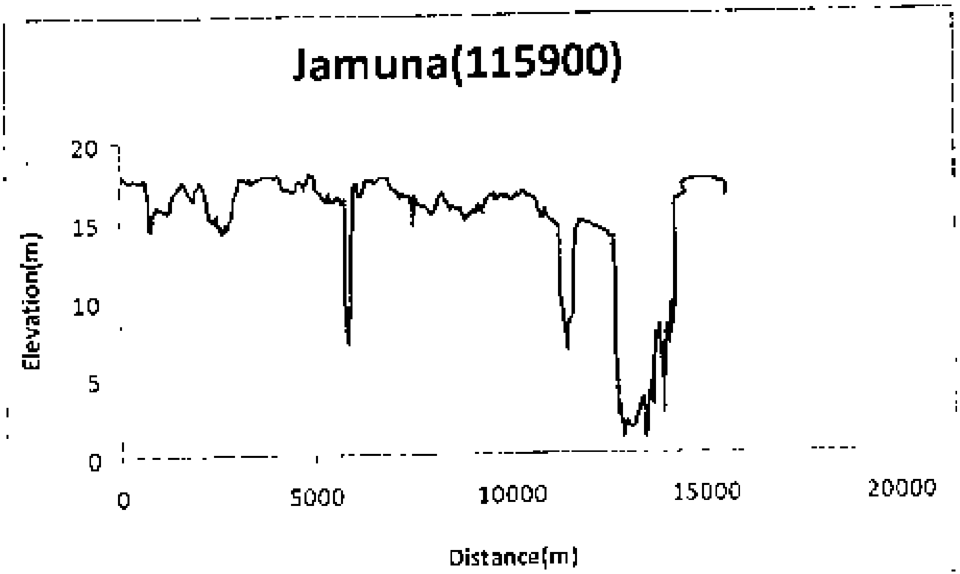

Jamuna(92000)
Elevation(m)
25
20
15
10
5
0
0
2000
4000
6000
8000
10000
12000
14000
Distance(m)

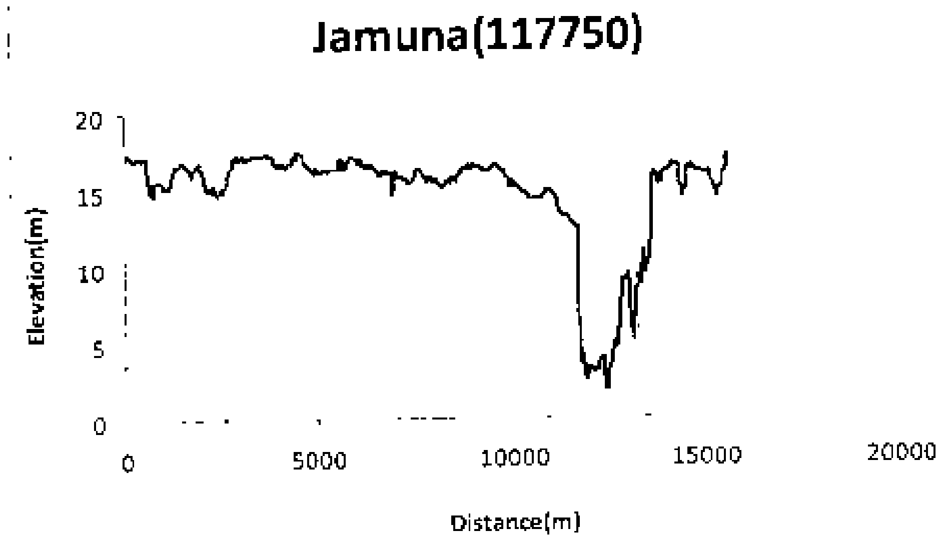

Jamuna(93800)
Elevation(m)
25
20
15
10
5
0
0
5000
10000
15000
20000
Distance(m)

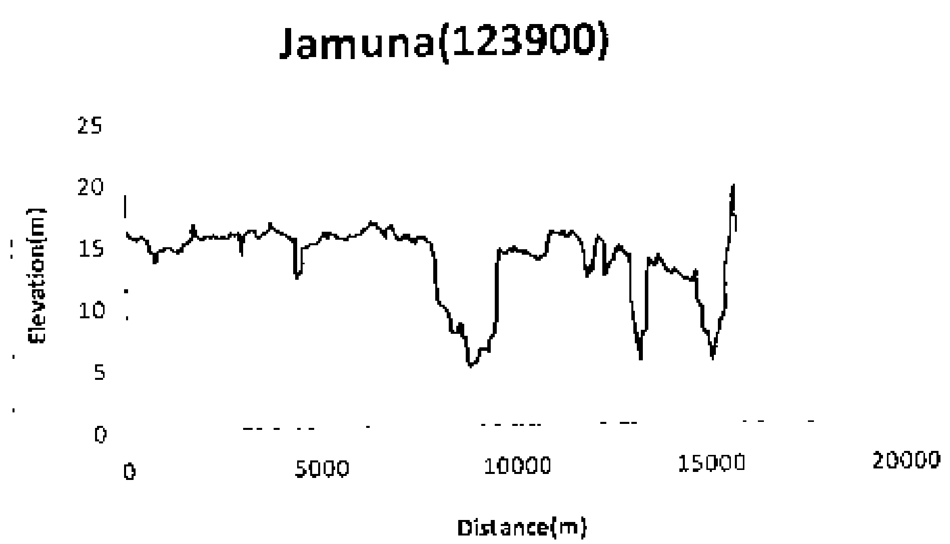

Jamuna(97500)
Elevation(m)
20
15
10
5
0
0
5000
10000
15000
Distance(m)

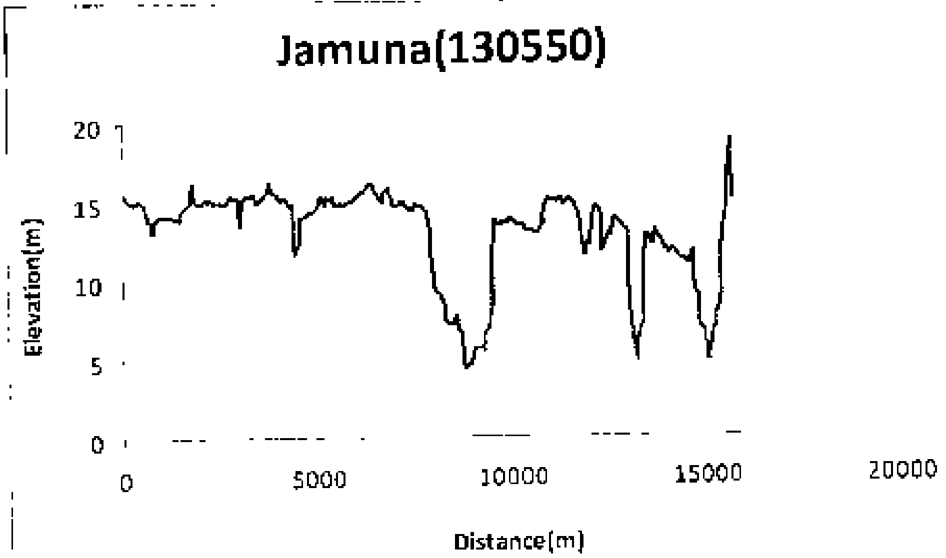

Jamuna(100800)
Elevation(m)
25
20
15
10
5
0
0
5000
10000
15000
20000
Distance(m)


Jamuna(108600)
Elevation(m)
25
20
15
10
5
0
0
5000
10000
15000
20000
Distance(m)

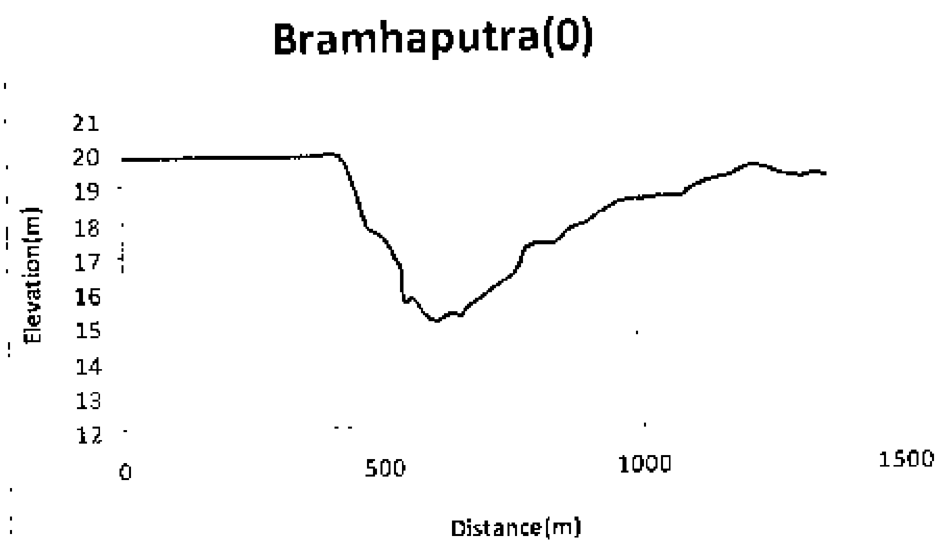

Jamuna(115900)
20
15
10
5
0
Elevation(m)
0
5000
10000
15000
20000
Distance(m)


Jamuna(117750)
20
15
10
5
0
Elevation(m)
0
5000
10000
15000
20000
Distance(m)

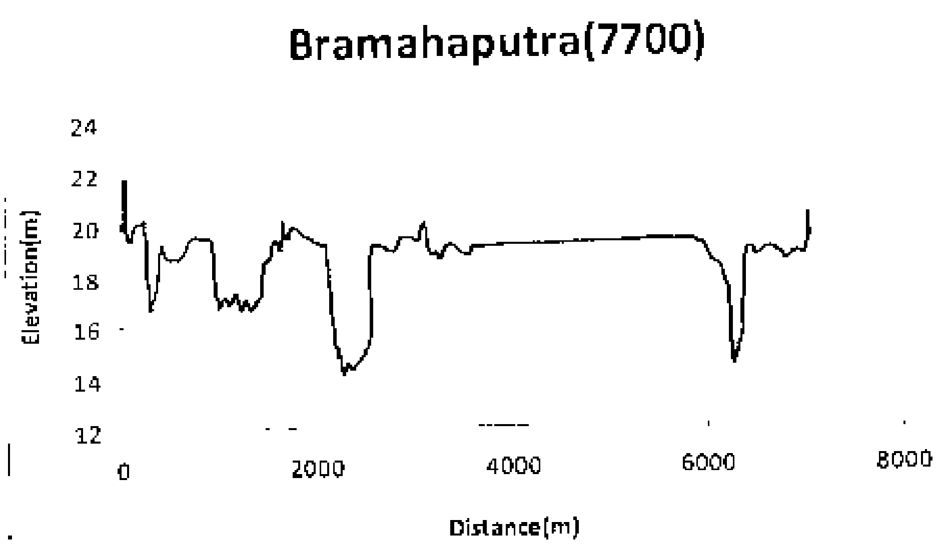

Jamuna(123900)
25
20
15
10
5
0
Elevation(m)
0
5000
10000
15000
20000
Distance(m)



Jamuna(130550)
20
15
10
5
0
Elevation(m)
0
5000
10000
15000
20000
Distance(m)

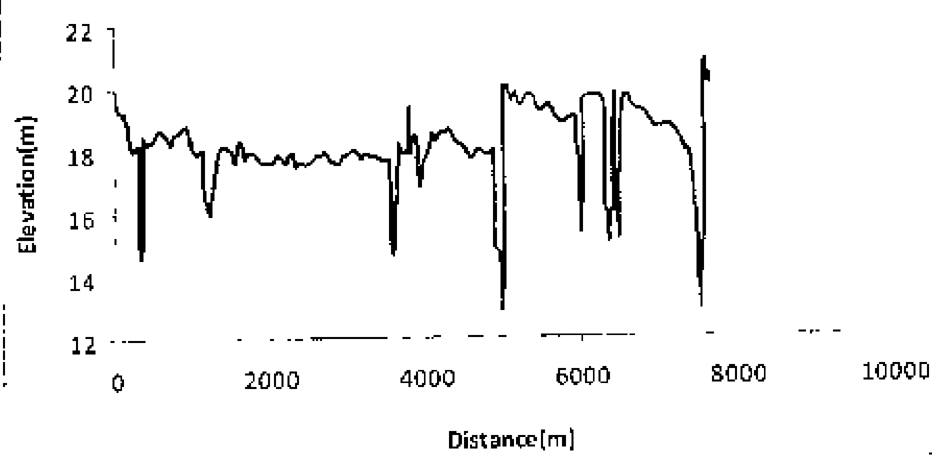


Bramhaputra(0)
21
20
19
18
17
16
15
14
13
12
Elevation(m)
0
500
1000
1500
Distance(m)

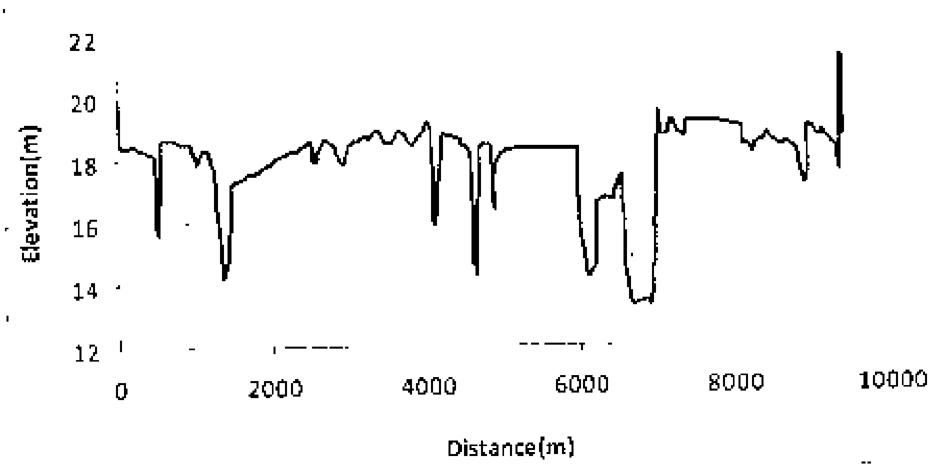


Bramahaputra(7700)
24
22
20
18
16
14
12
Elevation(m)
0
2000
4000
6000
8000
Distance(m)

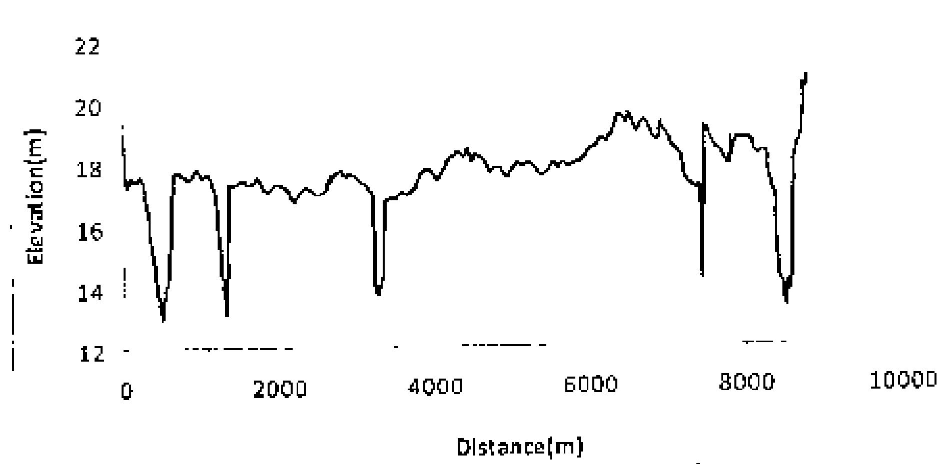
Bramhaputra(15000)

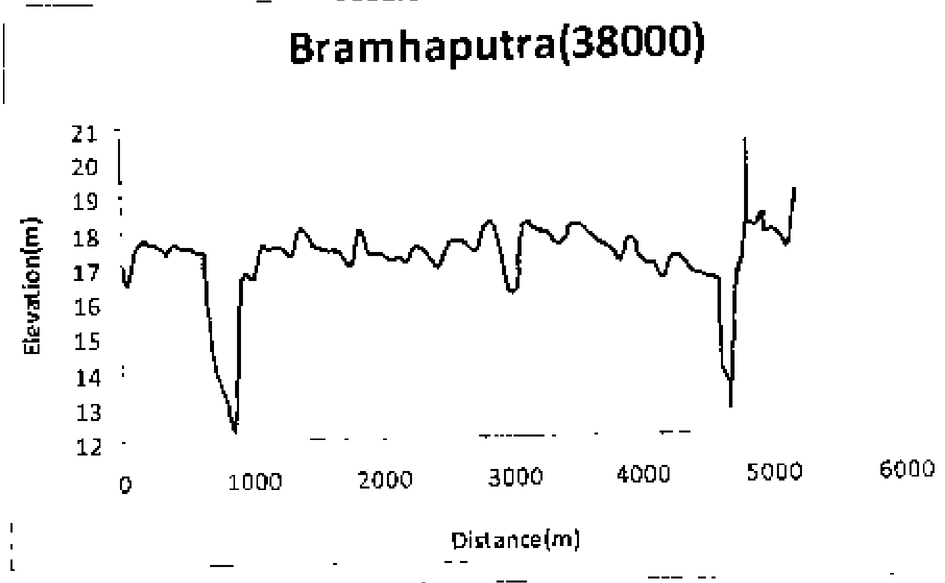


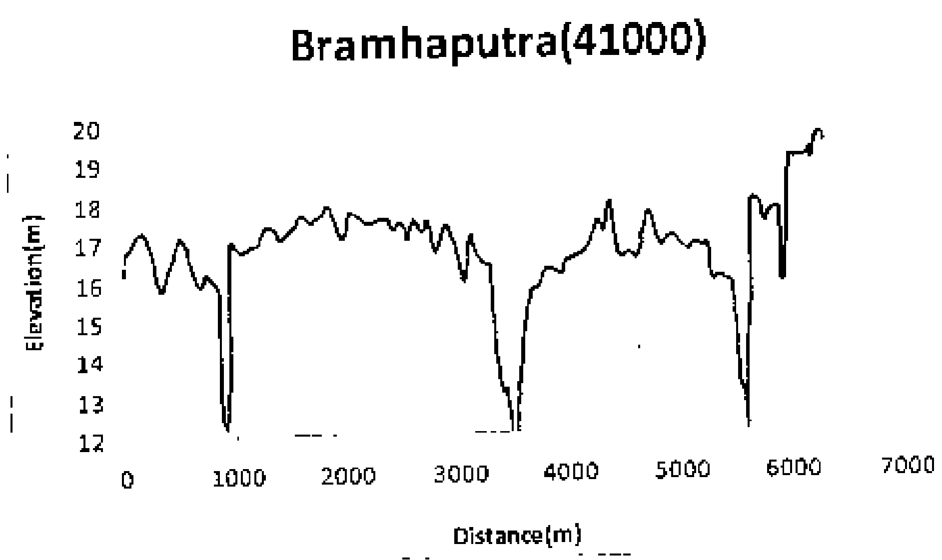
Bramhaputra(21000)

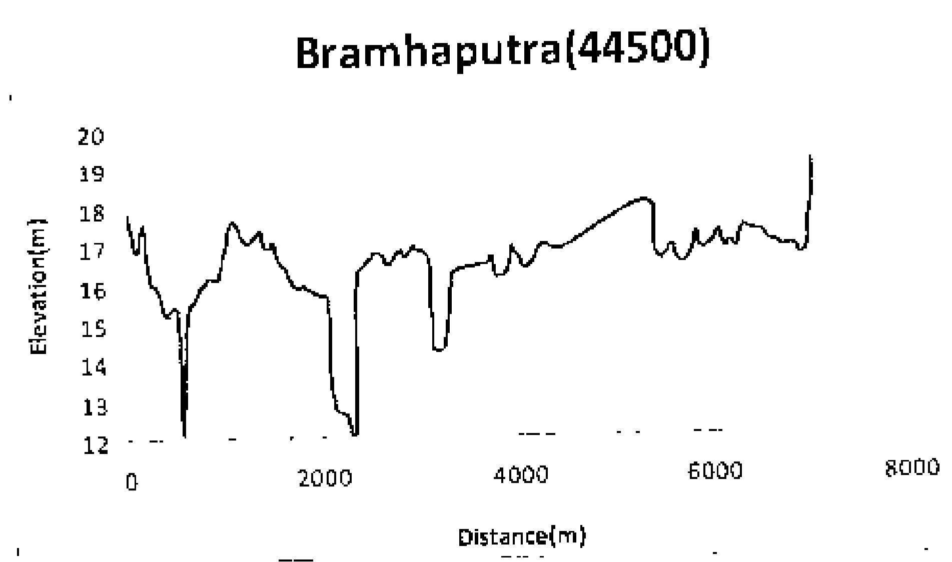


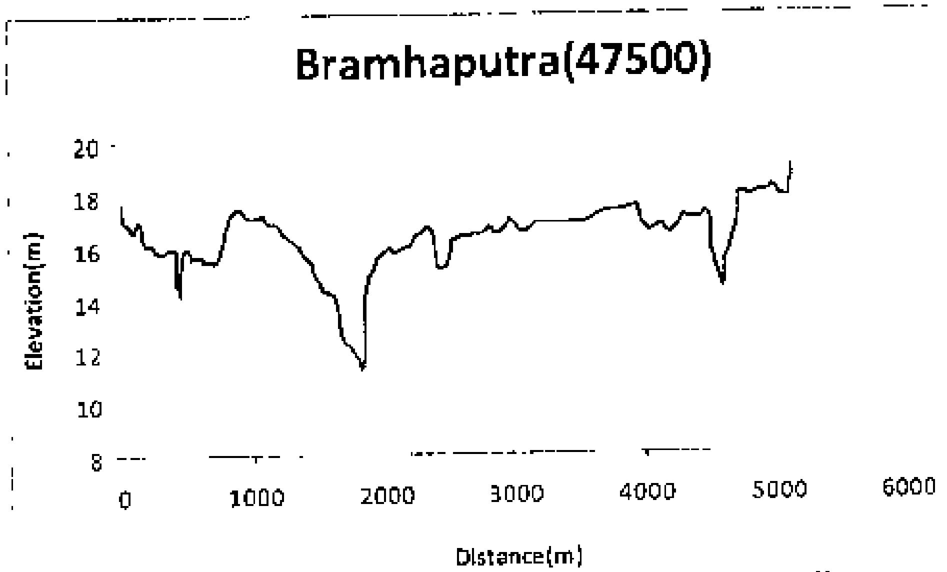
Bramhaputra(31000)



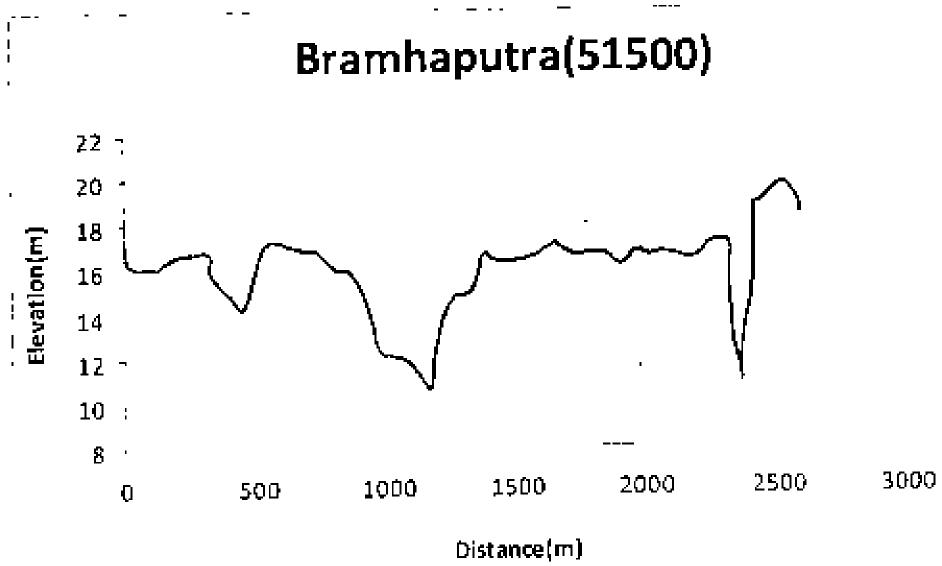

Bramhaputra(38000)
21
20
19
18
17
16
15
14
13
12
0
1000
2000
3000
4000
5000
6000
Elevation(m)
Distance(m)


Bramhaputra(41000)
20
19
18
17
16
15
14
13
12
0
1000
2000
3000
4000
5000
6000
7000
Elevation(m)
Distance(m)

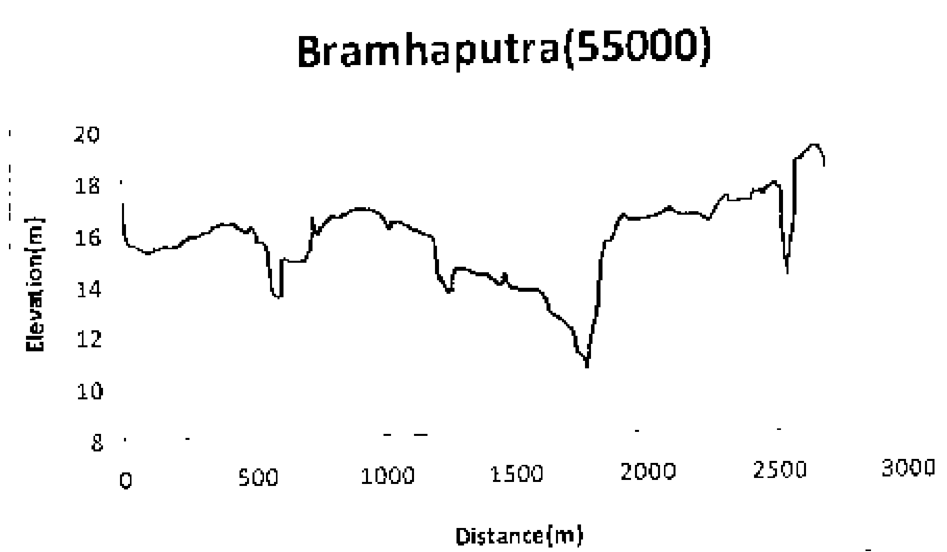

Bramhaputra(44500)
20
19
18
17
16
15
14
13
12
0
2000
4000
6000
8000
Elevation(m)
Distance(m)



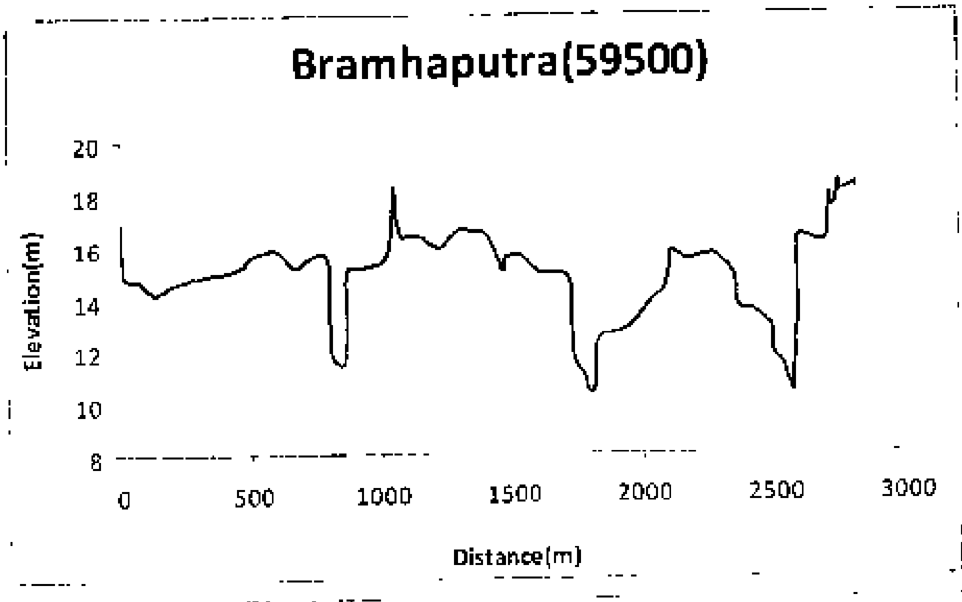
Bramhaputra(47500)
Elevation(m)
20
18
16
14
12
10
8
0
1000
2000
3000
4000
5000
6000
Distance(m)

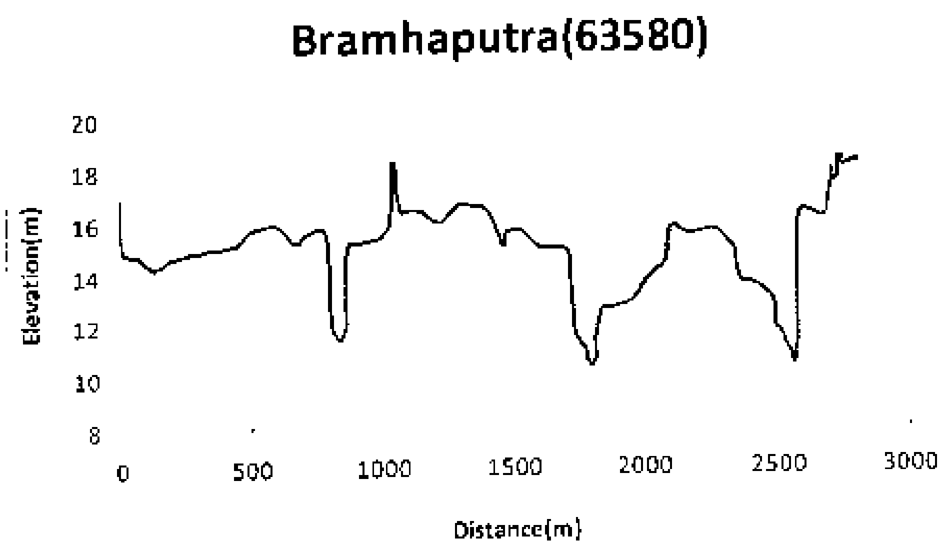


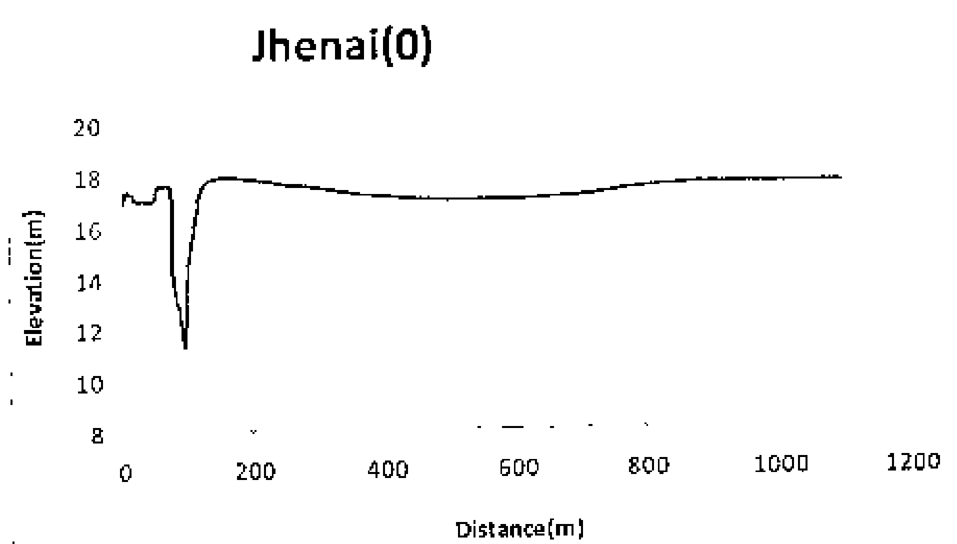
Bramhaputra(51500)
Elevation(m)
22
20
18
16
14
12
10
8
0
500
1000
1500
2000
2500
3000
Distance(m)

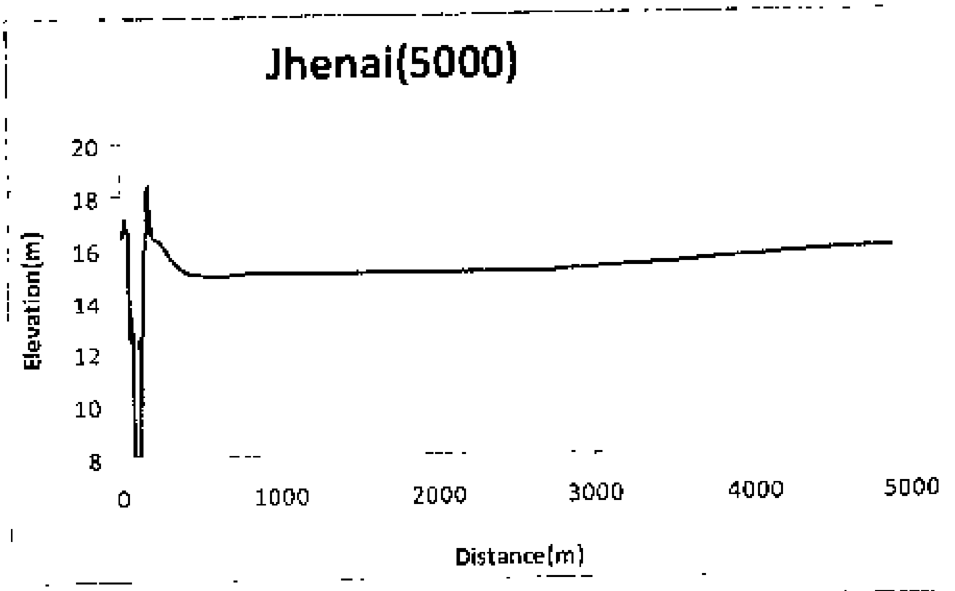


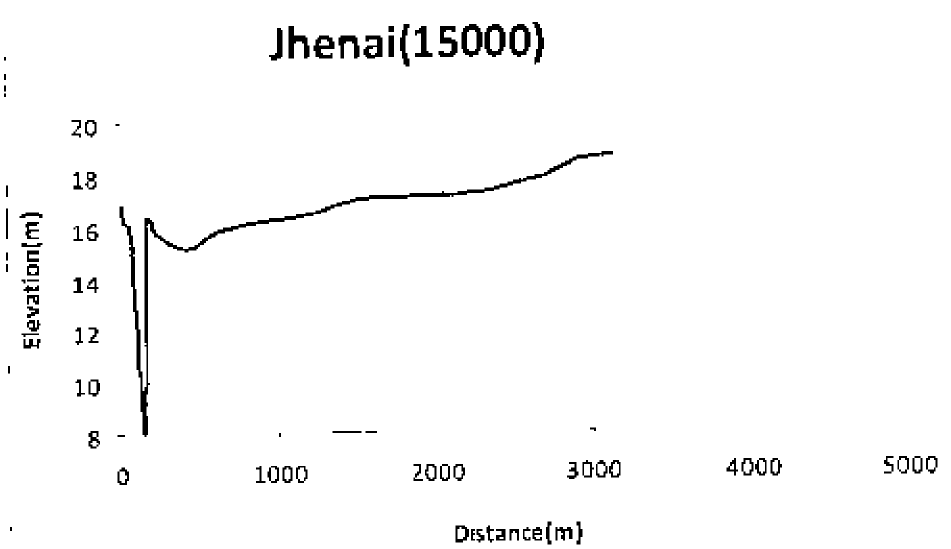
Bramhaputra(55000)
Elevation(m)
20
18
16
14
12
10
8
0
500
1000
1500
2000
2500
3000
Distance(m)

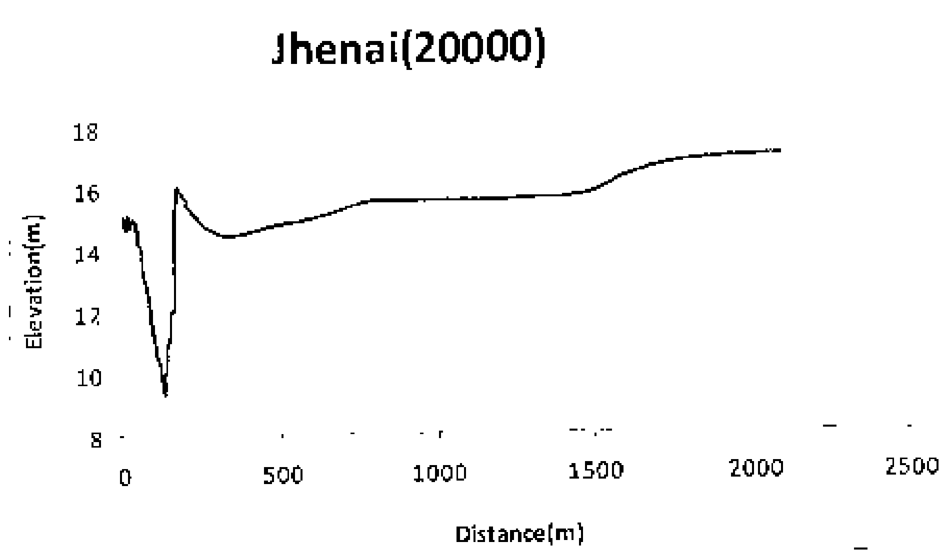

Bramhaputra(59500)
20
18
16
14
12
10
8
Elevation(m)
0
500
1000
1500
2000
2500
3000
Distance(m)

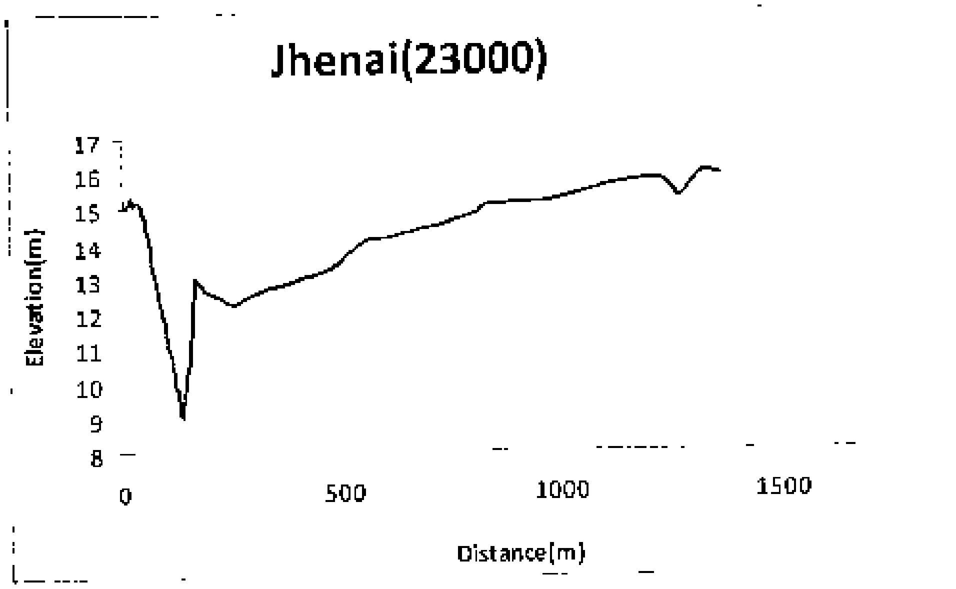

Bramhaputra(63580)
20
18
16
14
12
10
8
Elevation(m)
0
500
1000
1500
2000
2500
3000
Distance(m)


Jhenai(0)
20
18
16
14
12
10
8
Elevation(m)
0
200
400
600
800
1000
1200
Distance(m)

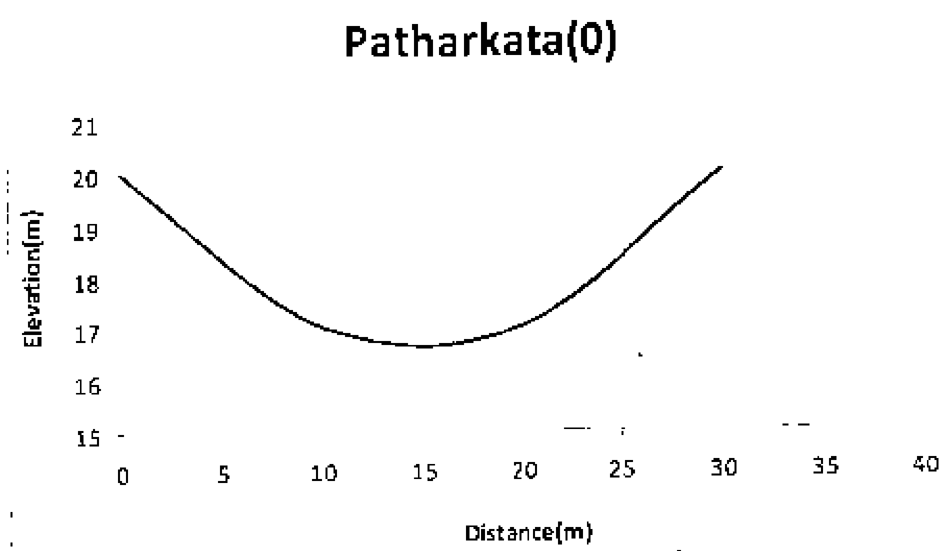

Jhenai(5000)
20
18
16
14
12
10
8
Elevation(m)
0
1000
2000
3000
4000
5000
Distance(m)


Jhenai(15000)
20
18
16
14
12
10
8
Elevation(m)
0
1000
2000
3000
4000
5000
Distance(m)

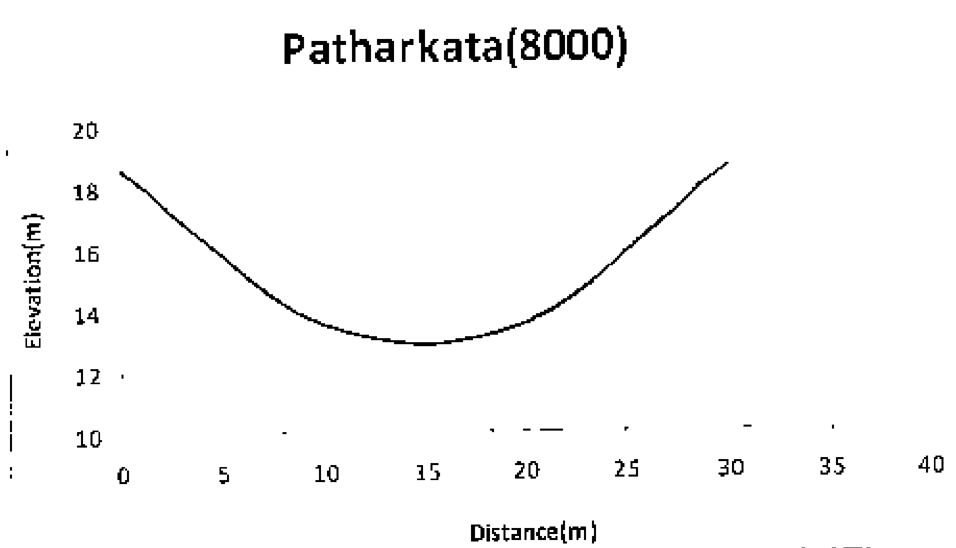

Jhenai(20000)
18
16
14
12
10
8
Elevation(m)
0
500
1000
1500
2000
2500
Distance(m)



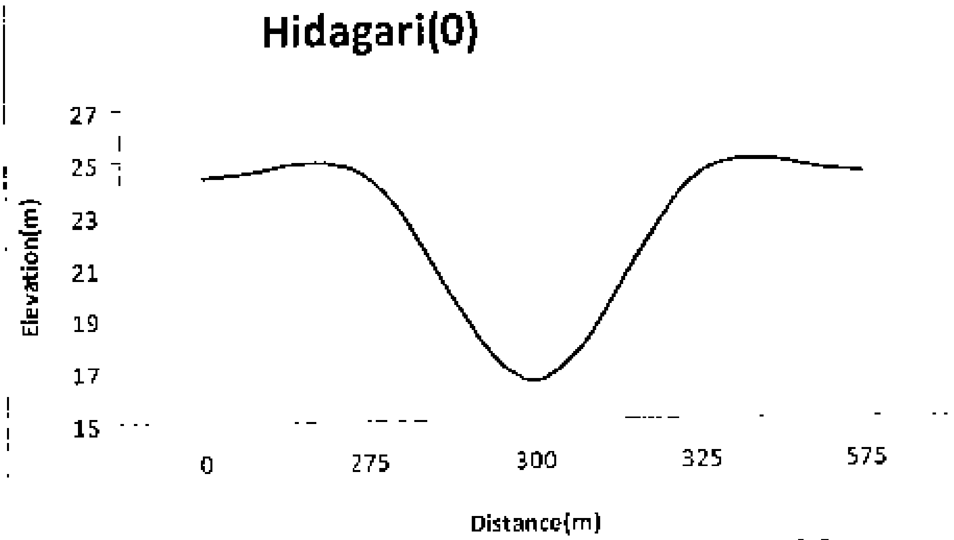
Jhenai(23000)
17
16
15
14
13
12
11
10
9
8
Elevation(m)
0
500
1000
1500
Distance(m)

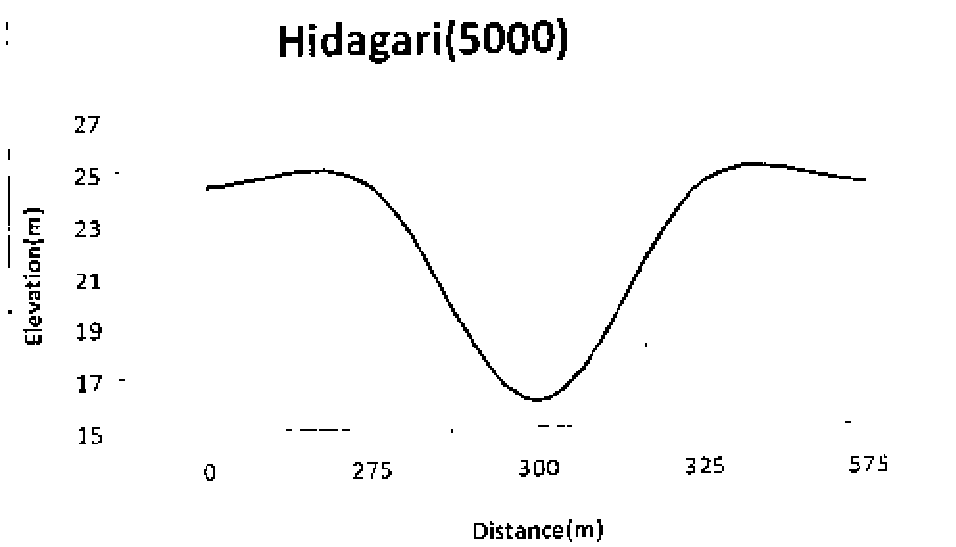


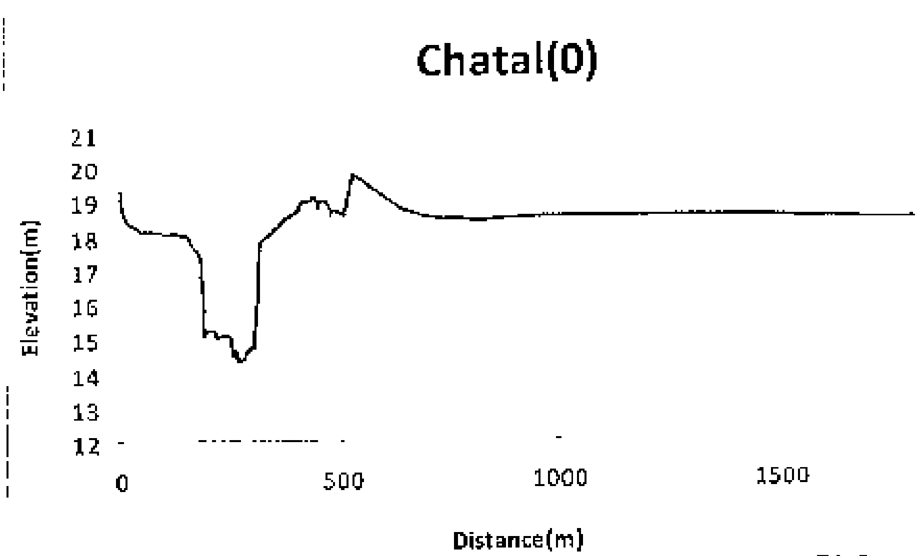
Patharkata(0)
21
20
19
18
17
16
15
Elevation(m)
0
5
10
15
20
25
30
35
40
Distance(m)

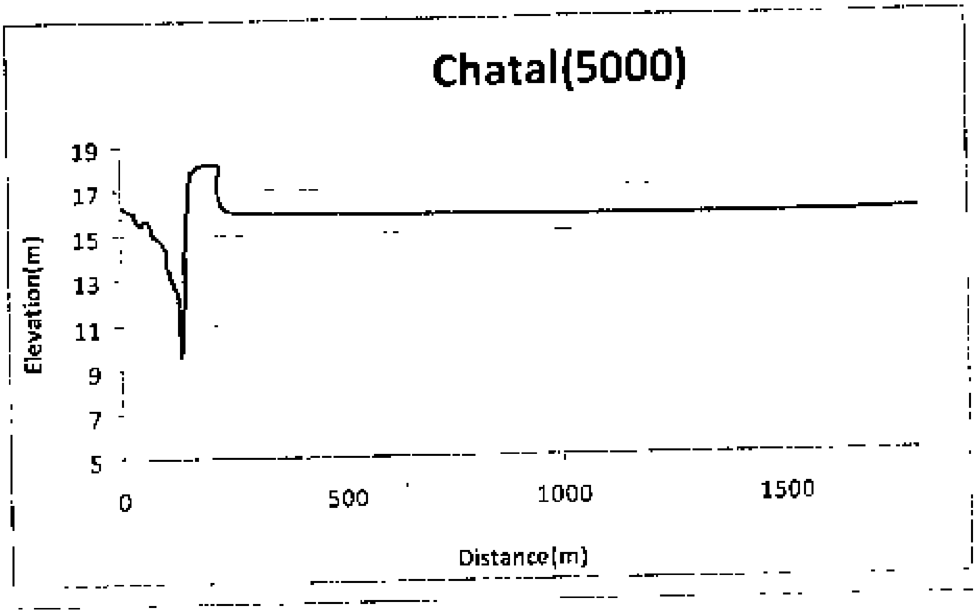


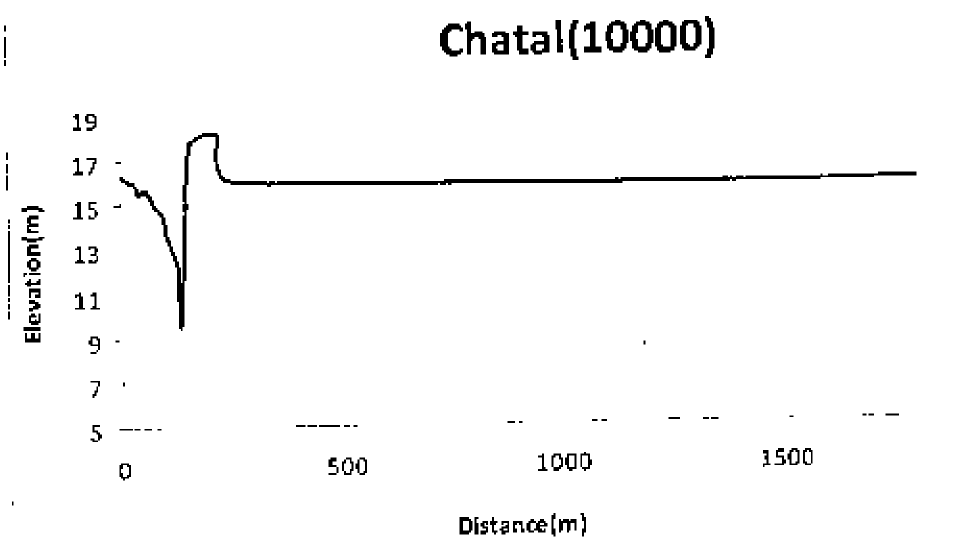
Patharkata(8000)
20
18
16
14
12
10
Elevation(m)
0
5
10
15
20
25
30
35
40
Distance(m)

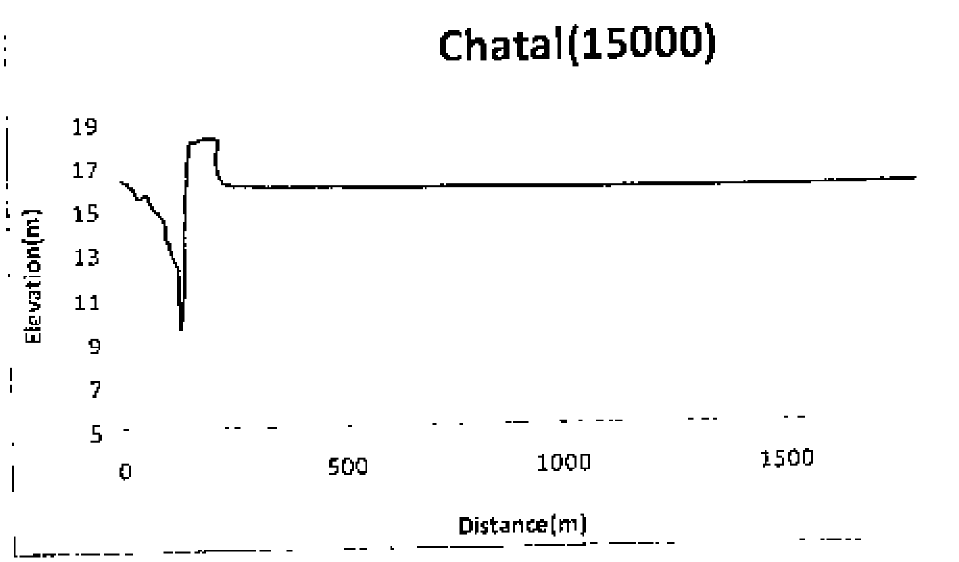

Hidagari(0)
Elevation(m)
27
25
23
21
19
17
15
0
275
300
325
575
Distance(m)

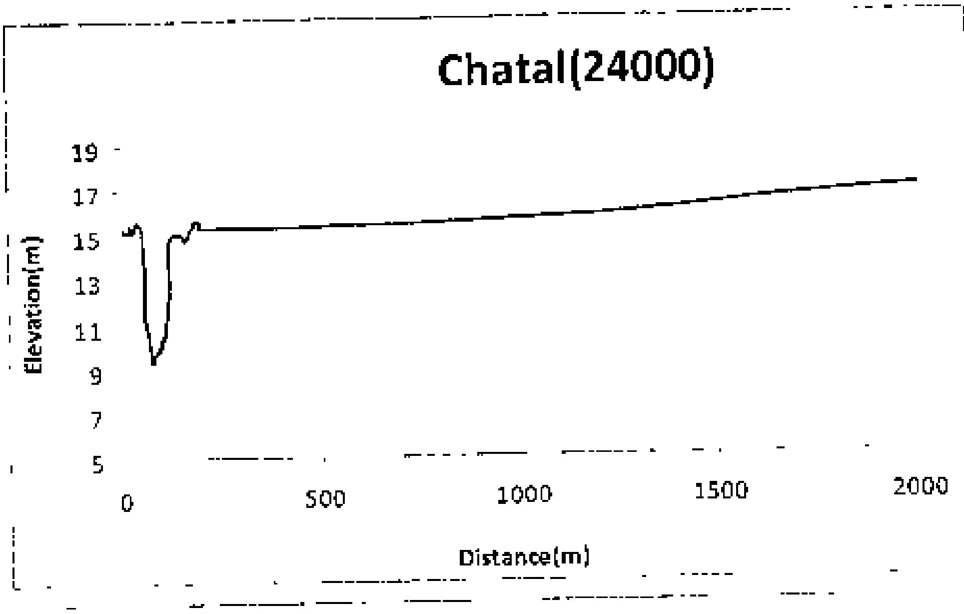

Hidagari(5000)
Elevation(m)
27
25
23
21
19
17
15
0
275
300
325
575
Distance(m)

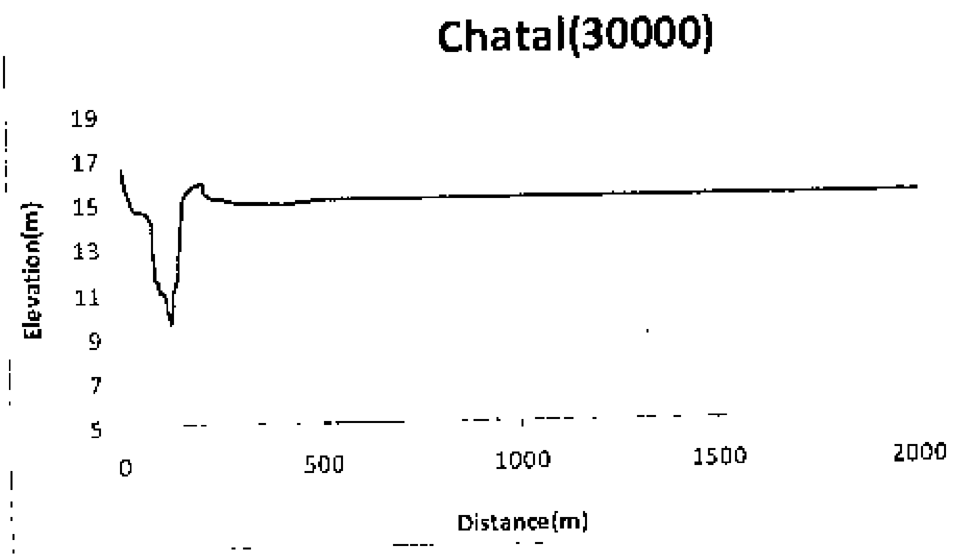

Chatal(0)
Elevation(m)
21
20
19
18
17
16
15
14
13
12
0
500
1000
1500
Distance(m)

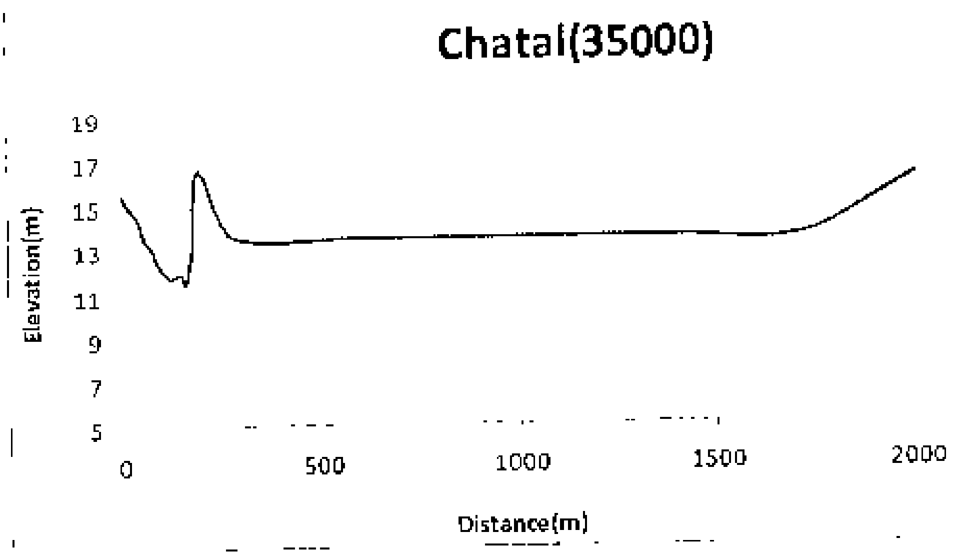

Chatal(5000)
Elevation(m)
19
17
15
13
11
9
7
5
0
500
1000
1500
Distance(m)

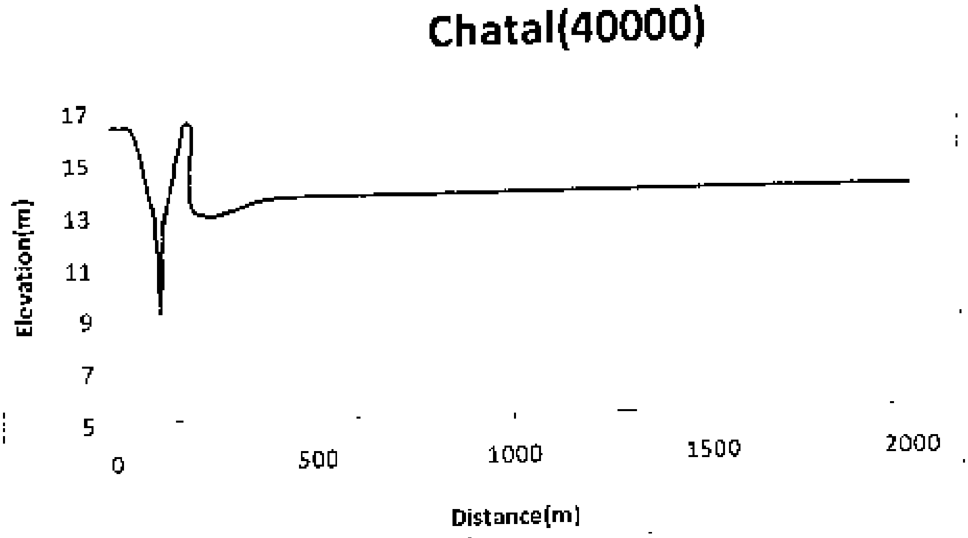

Chatal(10000)
Elevation(m)
19
17
15
13
11
9
7
5
0
500
1000
1500
Distance(m)


Chatal(15000)
Elevation(m)
19
17
15
13
11
9
7
5
0
500
1000
1500
Distance(m)


Chatal(24000)
19
17
15
13
11
9
7
5
Elevation(m)
0
500
1000
1500
2000
Distance(m)


Chatal(30000)
19
17
15
13
11
9
7
5
Elevation(m)
0
500
1000
1500
2000
Distance(m)


Chatal(35000)
19
17
15
13
11
9
7
5
Elevation(m)
0
500
1000
1500
2000
Distance(m)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13
11
9
7
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Elevation(m)
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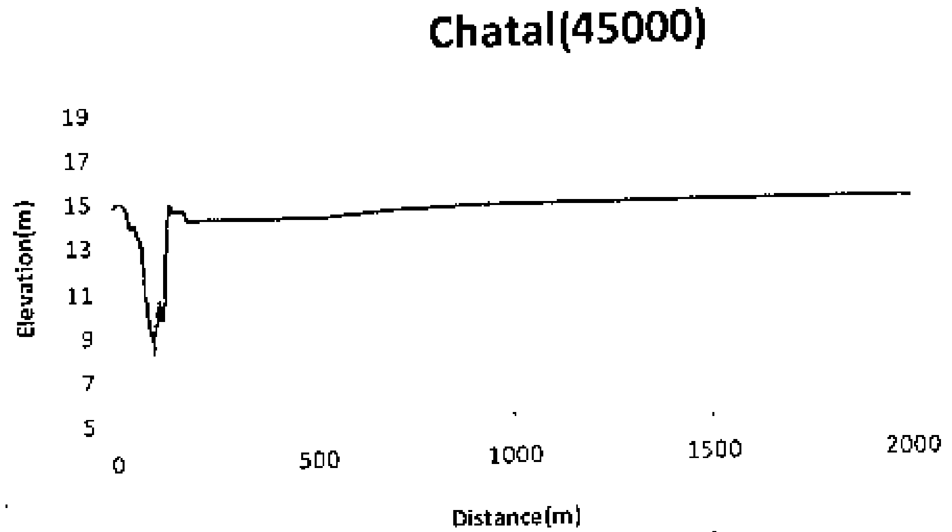
500
1000
1500
2000
Distance(m)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13
11
9
7
5
Elevation(m)
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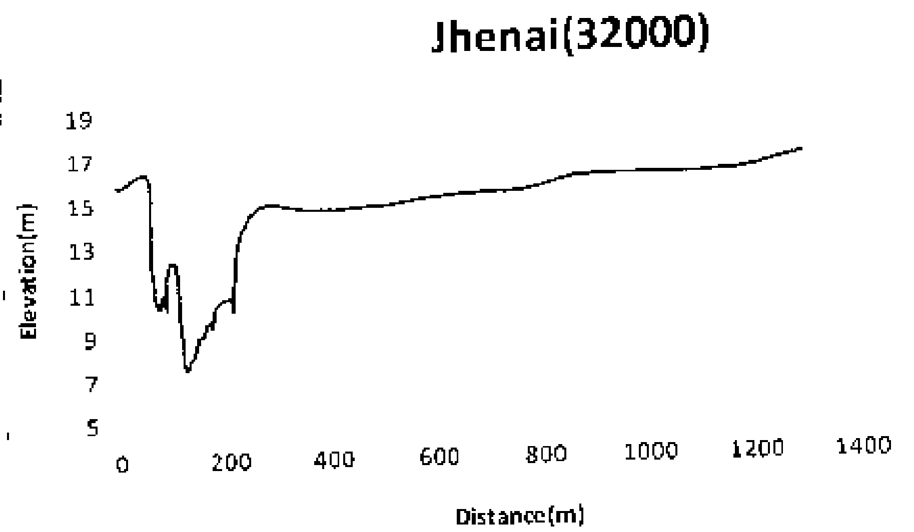
500
1000
1500
2000
Distance(m)


Jhenai(32000)
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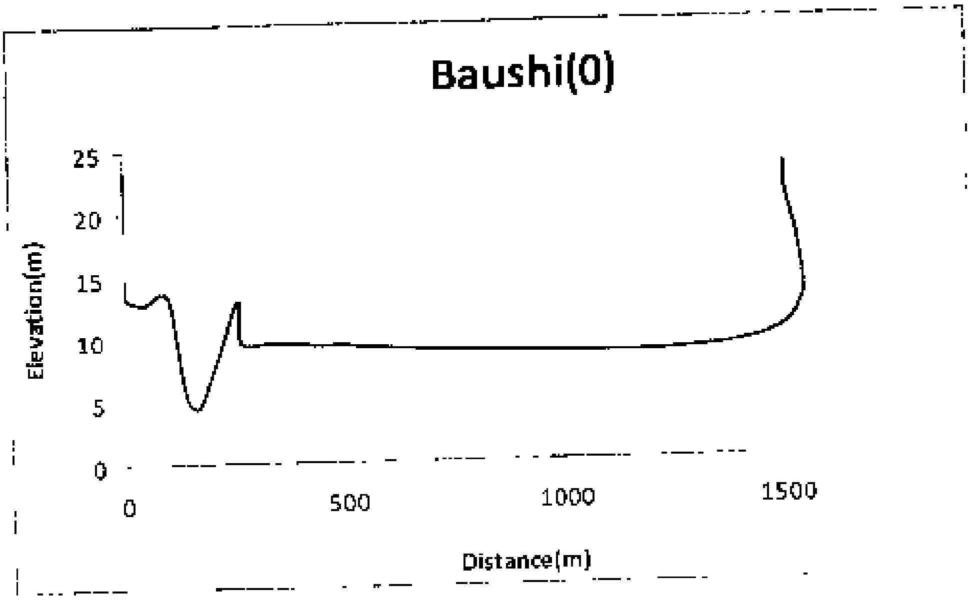
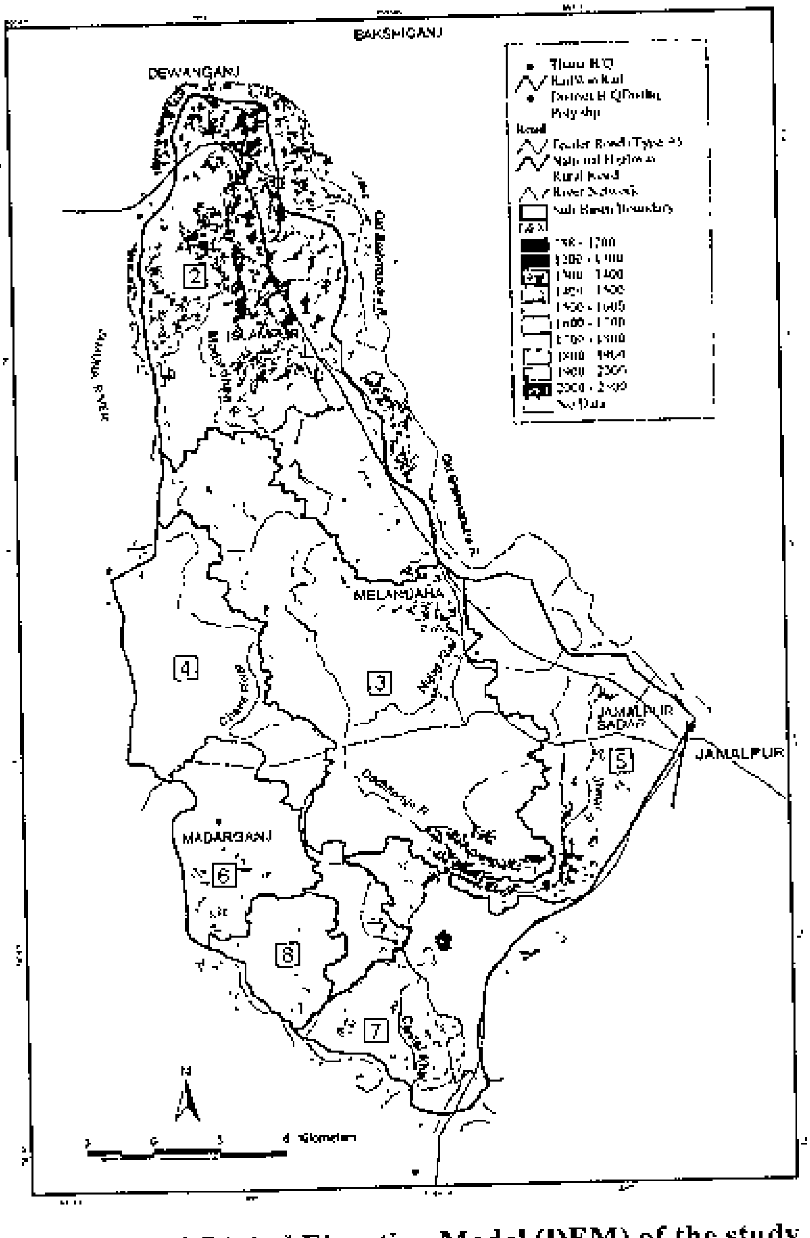
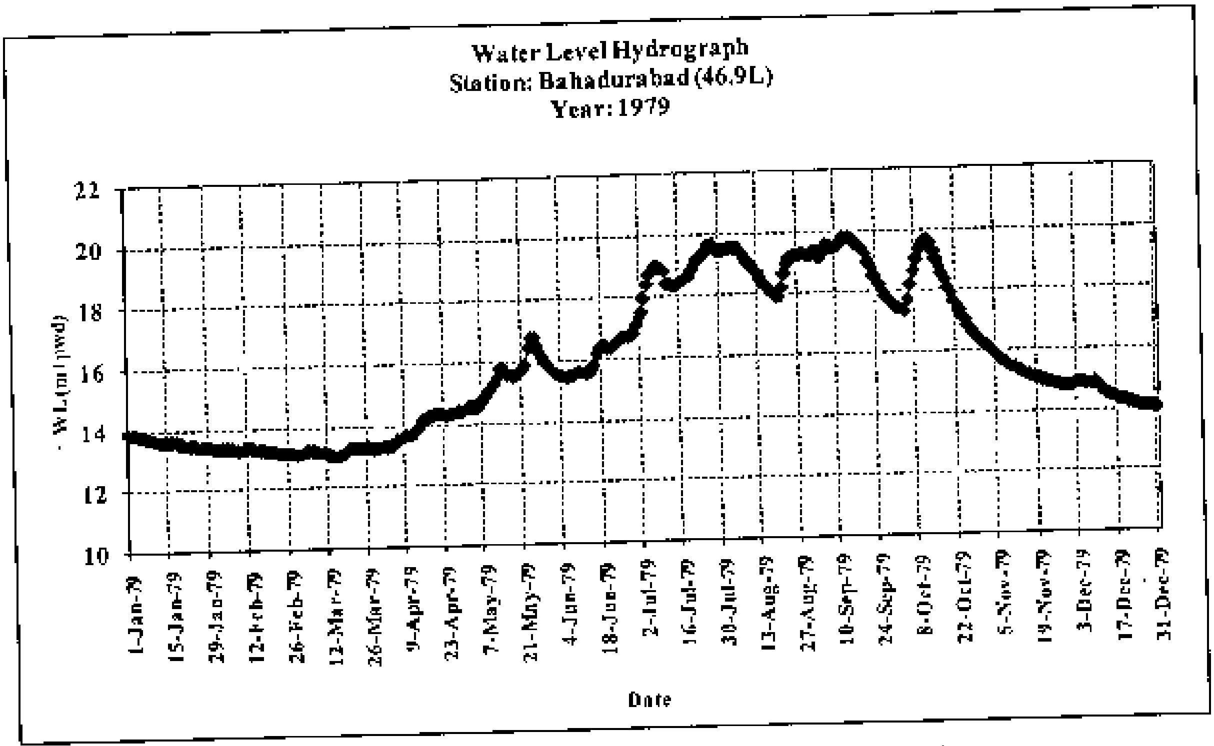
17
15
13
11
9
7
5
Elevation(m)
0
200
400
600
800
1000
1200
1400
Distance(m)

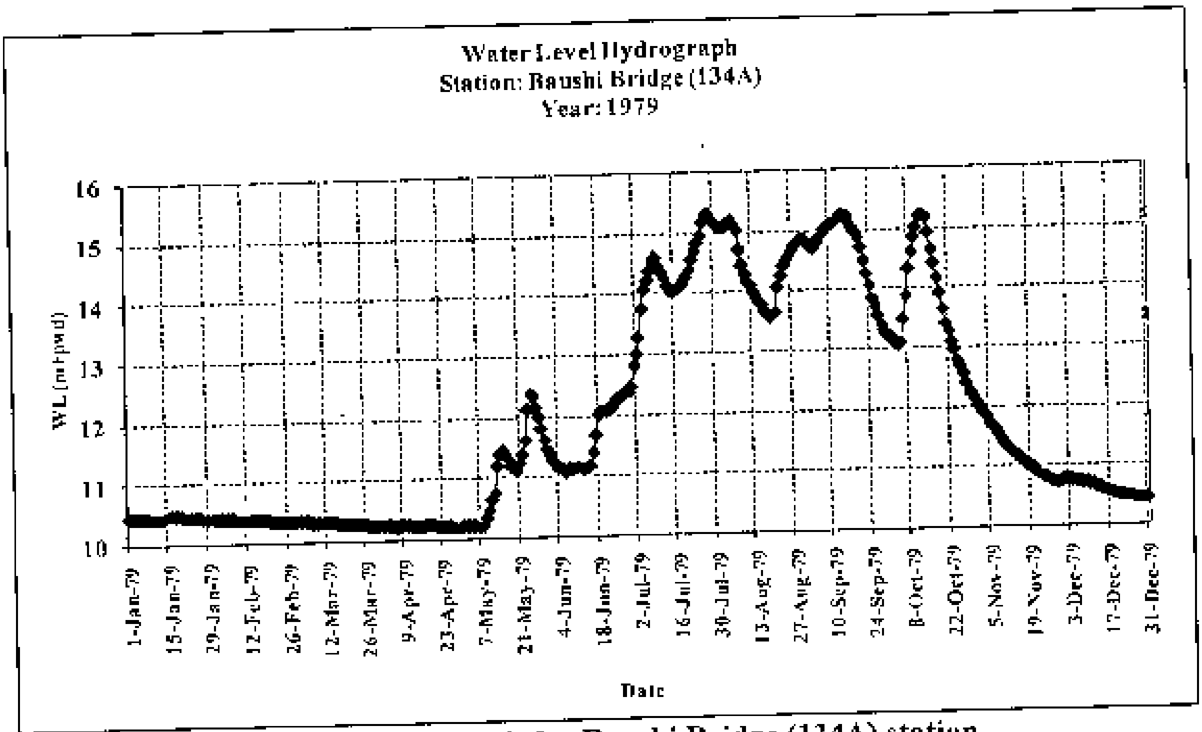




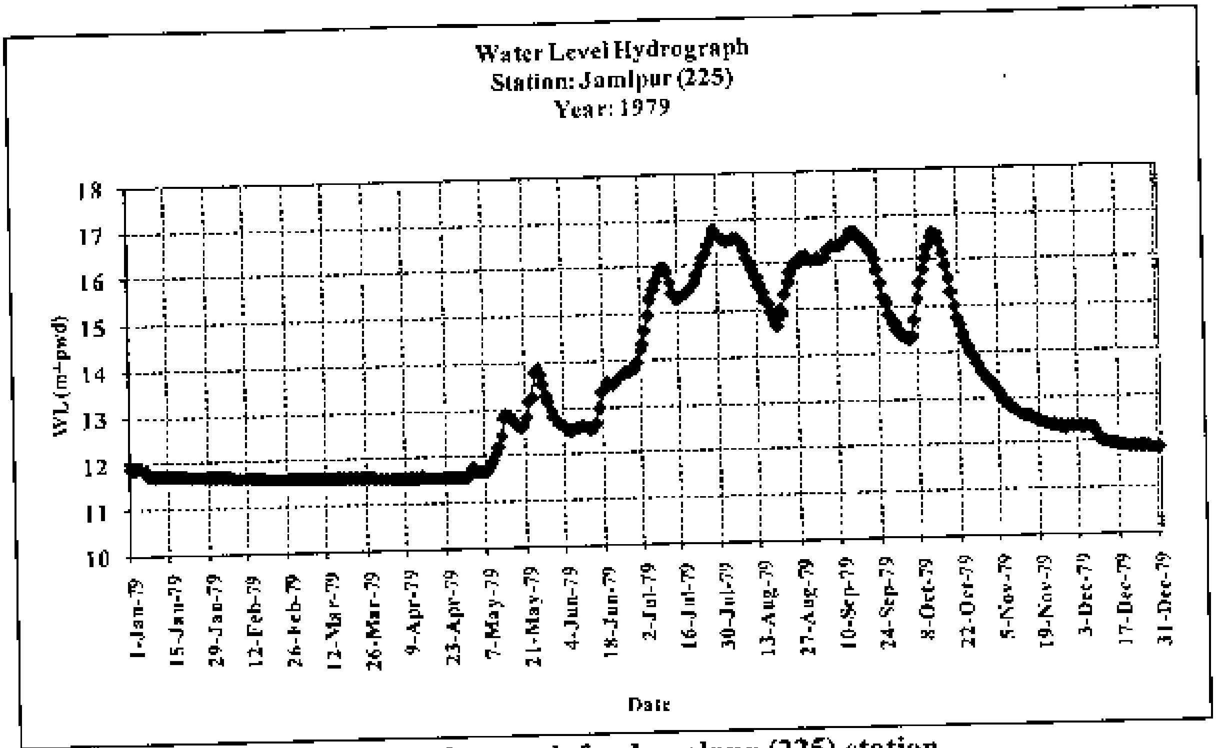
Topography and Digital Elevation Model (DEM) of the study area



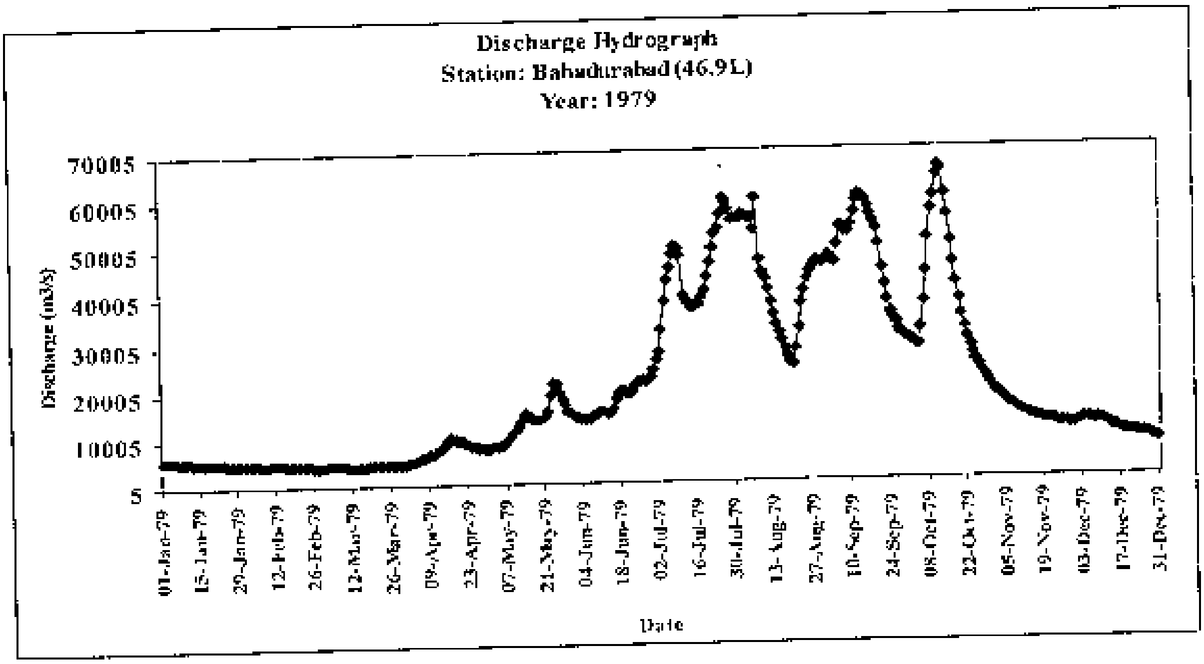
Water level hydrograph for Bahadurabad (49.6L) station



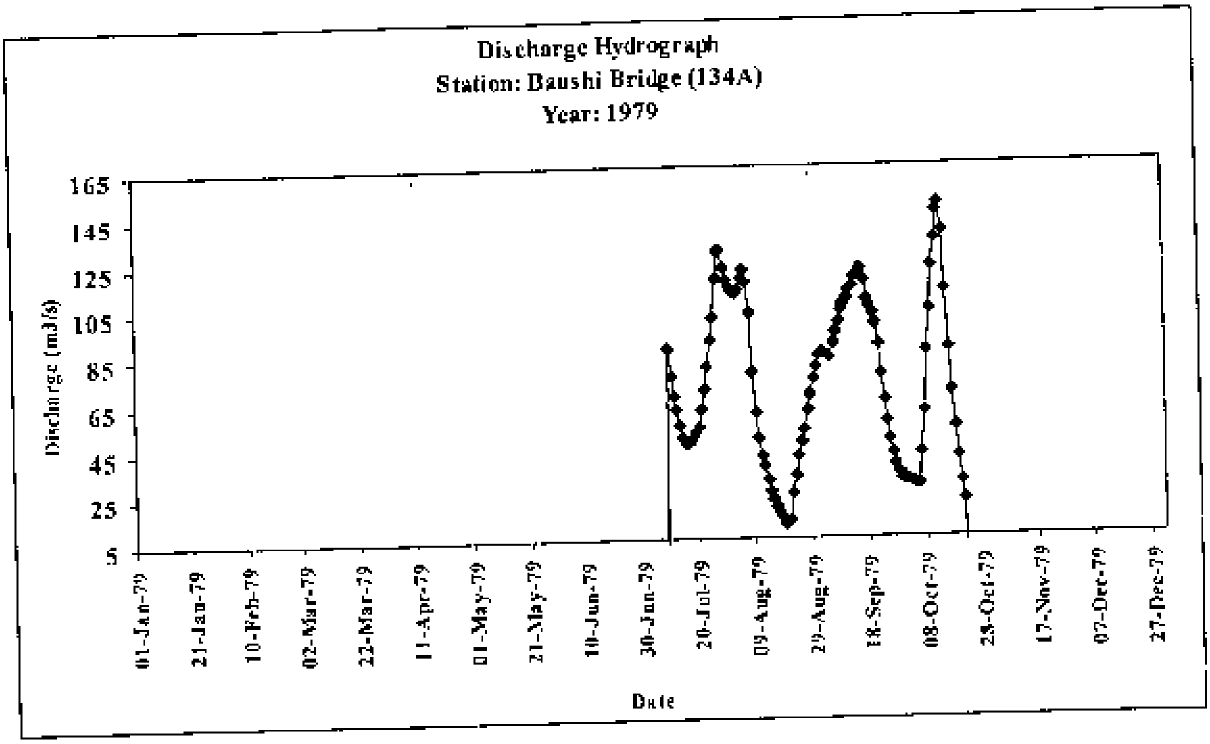
Water level hydrograph for Baushi Bridge (134A) station



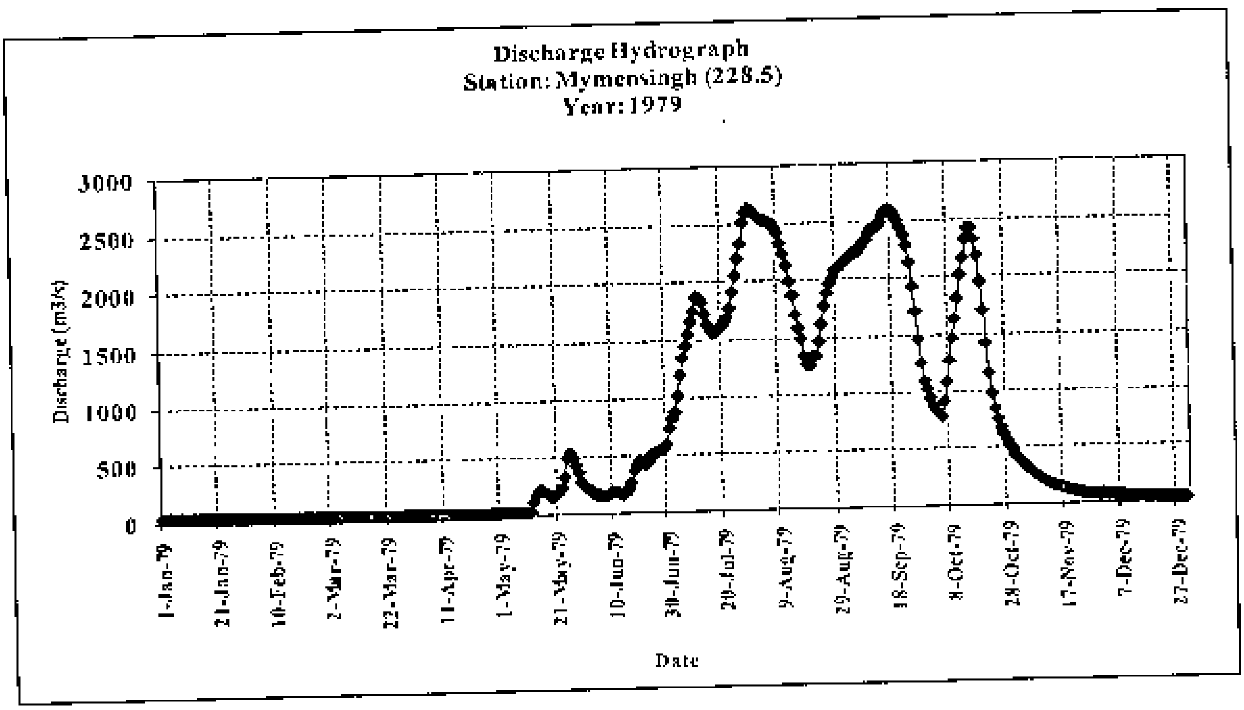
Water level hydrograph for Jamalpur (225) station



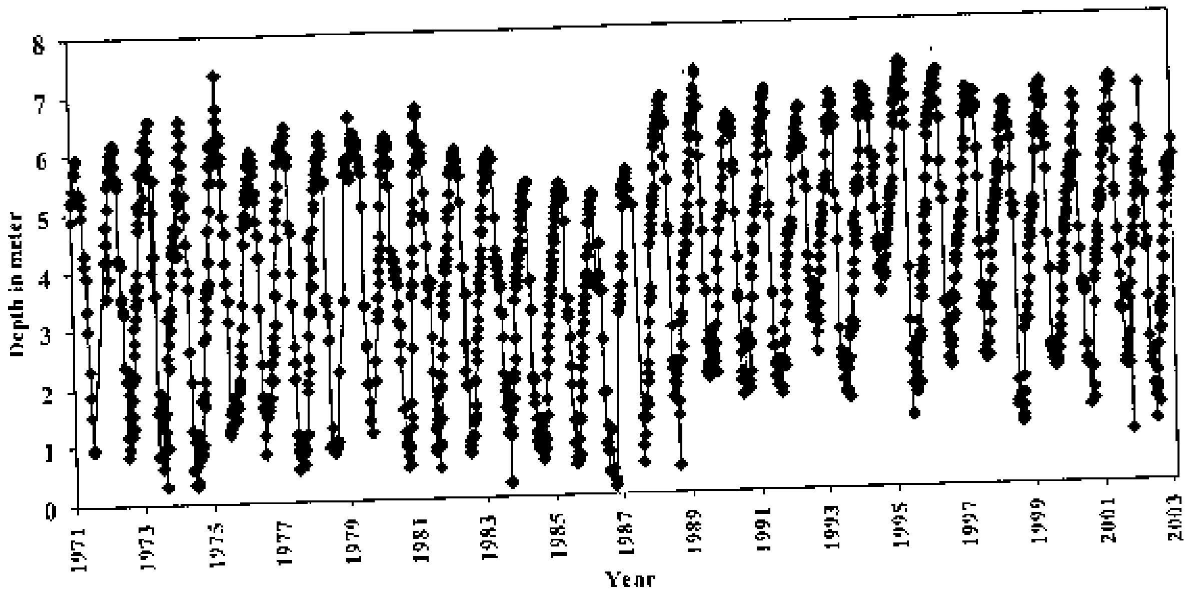
Discharge hydrograph of Bahadurabad (46.9L) station for year 1979



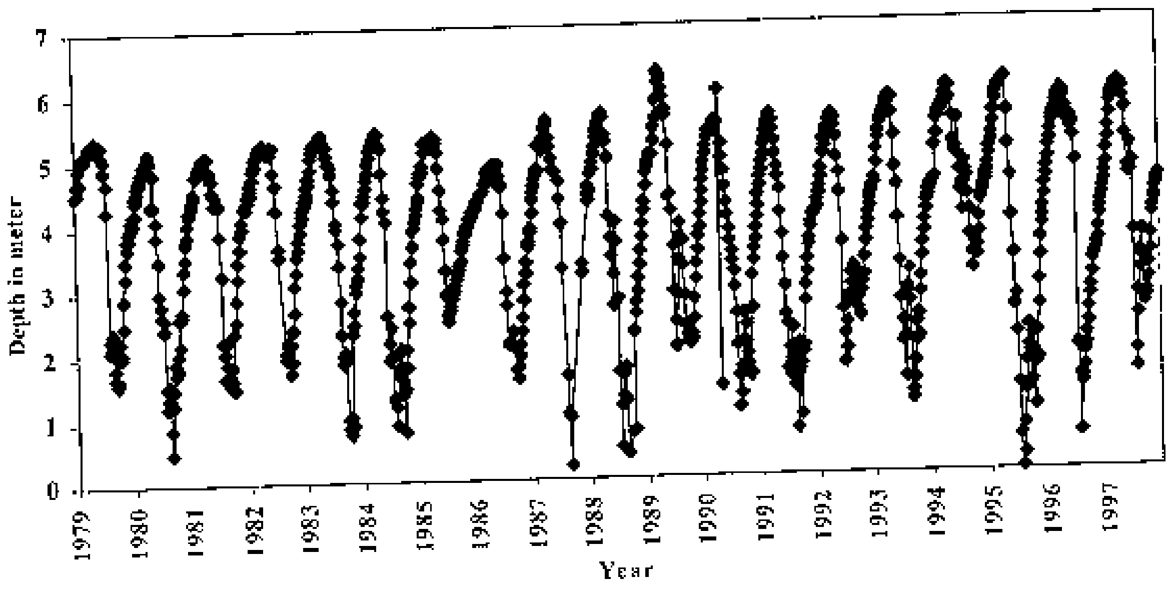
Discharge hydrograph of Baushi bridge (134A) station for year 1979



Discharge hydrograph of Mymensingh (228.5) station for year 1979



Groundwater depth for Melandaha (Well ID: 3961016)



Groundwater depth for Madarganj (Well ID: 3958015)

Major tree species with canopy coverage

Tree species	% of canopy coverage
Kanthal *(Artocarpus heterophyllus)*	9.6
Bansh (*Bamboosa* sp.)	9
Aam *(Mangifera indica)*	8
Kola (*Musa paradisiacal*)	6.4
Suparee *(Areca catechu)*	5.6
Peetraj *(Aponomyxis polystychya)*	4.2
Taal (*Borassus flabelifer*).	3 4
Shimul (*Bombax ceiba*),	3
Jeegar *(Lannea coromandelica)*	2.6
Koroi *(Albizia procera)*	2.6
Narikel *(Cocos nucifera)*	2.6
Kadam *(Anthocephalus chinensis)*	2.4
Raintree (*Albizzia saman*)	2
Bokain *(Melia azadirachta)*	1.6
Jaam (*Syzygium cumini*)	1.6

Indicative fish species diversity of different fish habitats

Scientific name	Local name	Habitat Type				
		River	Khal	Beel	Floodplain	Culture pond
Puntius spp	Punti	P	P	P	P	A
Salmostoma spp.	Chela	P	A	A	A	A
Anabas testudineus	Koi	A	A	P	A	A
Colisa fasciatus	Kholisha	A	P	P	P	A
Colisa spp.	Boicha/Chata	A	P	P	P	A
Channa punctatus	Taki	A	P	P	P	A
C striatus	Shole	A	P	P	A	A
Heteropneustes fossilis	Shing	A	A	P	A	A
Xenontedon cancila	Kaikkya	A	A	P	P	A
Mystus spp.	Tengra	P	P	P	P	A
Clupisoma garua	Ghero	P	A	A	A	A
Eutropichthyes vacha	Bacha	P	A	A	A	A
Mystus spp.	Golsha	A	A	P	A	A
Wallago attu	Boal	P	A	P	A	A

Scientific name	Local name	Habitat Type				
		River	Khal	Beel	Floodplain	Culture pond
Mastacembelus pancalus	Chirka/ chhoto baim	P	P	P	A	A
Mastacembelus spp	Baim	P	P	P	P	A
Lepidocephalus guntea	Gutum	P	P	P	A	A
Leander styliferus	Icha	P	P	P	P	A
Pangasius sutchi	Pangus	A	A	A	A	P
Labeo rohita	Rui	P	A	P	A	P
Catla catla	Catla	A	A	P	A	P
Cirrhinus mrigala	Mrigal	A	A	A	A	P
Hypophthalmichthys molitrix	Silver Carp	A	A	A	A	P
Cyprinus carpio	Carpio	A	A	P	A	P
Oreochromis niloticus	Telapia	A	P	A	A	P

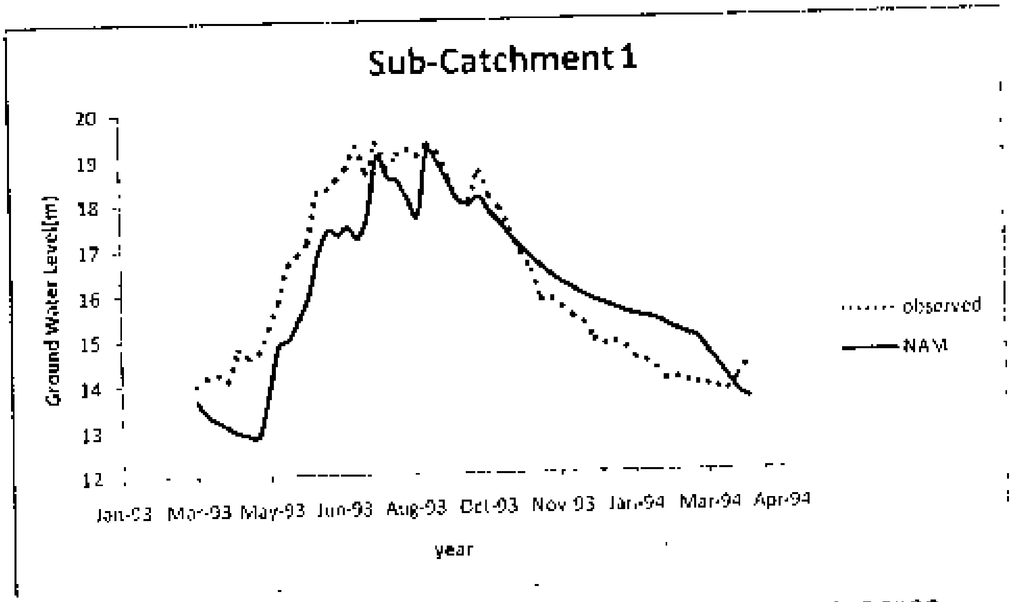
Here, A=Absent and P=Present

Parameters for hydrological model (NAM) of the sub-catchments

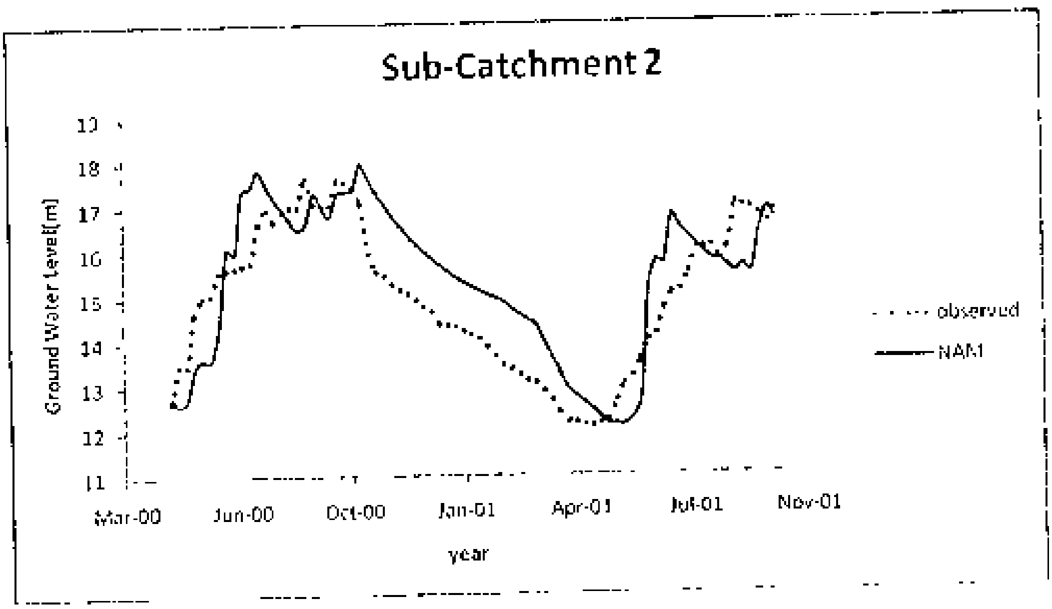
Sub catchment	1	2	3	4	5	6	NCRM
Area	148	169	82	63	64	76	713
Maximum water content in surface storage (Umax):	100	100	100	100	100	100	
Maximum water content in root zone storage (Lmax):	250	250	250	250	250	250	
Overland flow runoff coefficient (CQOF)	0.5	0.5	0.5	0.5	0.5	0.7	
Time constant for interflow (CKIF)	600	500	500	500	750	500	500
Time constants for routing overland flow (CK1, 2):	24	24	24	24	24	24	24
Root zone threshold value for overland flow (TOF):	0.7	0.7	0.3	0.7	0.7	0.3	
Root zone threshold value for inter flow (TIF)	0.5	0.5	0.5	0.5	0.5	0.5	
Root zone threshold value for groundwater recharge (Tg)	0.3	0.3	0.5	0.3	0.5	0.5	0.5
Time constant for routing baseflow (CKBF)	1000	2000	2200	800	1500	1200	300
Ratio of groundwater catchment to topographical catchment area (Carea)	0.83	0.8	0.8	0.8	0.8	0.7	
Specific yield for the groundwater storage (Sy)	0.055	0.055	0.08	0.06	0.09	0.052	0.06
Maximum groundwater	5	4	4.5	5	4.5	3.5	4

Sub catchment	1	2	3	4	5	6	NCRM
depth causing baseflow (GWLBF0)							
Depth for unit capillary flux (GWLBF1)	1.26	1.26	1.26	1.26	1.26	1.26	1.26
L/Lmax	0.5	0.5	0.5	0.5	0.5	0.5	

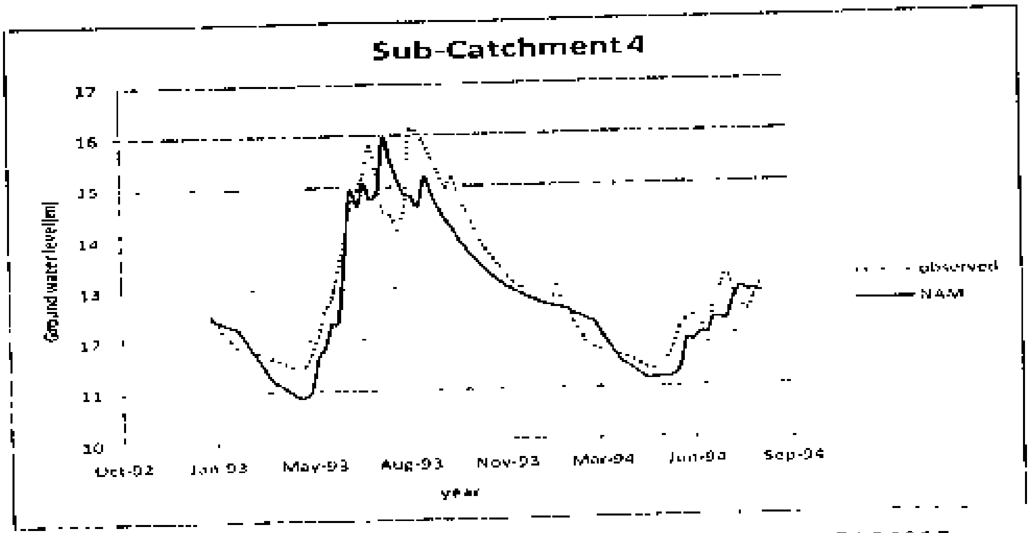
Note: North Centra Regional Model (NCRM) Parameters have been taken from FAP study report



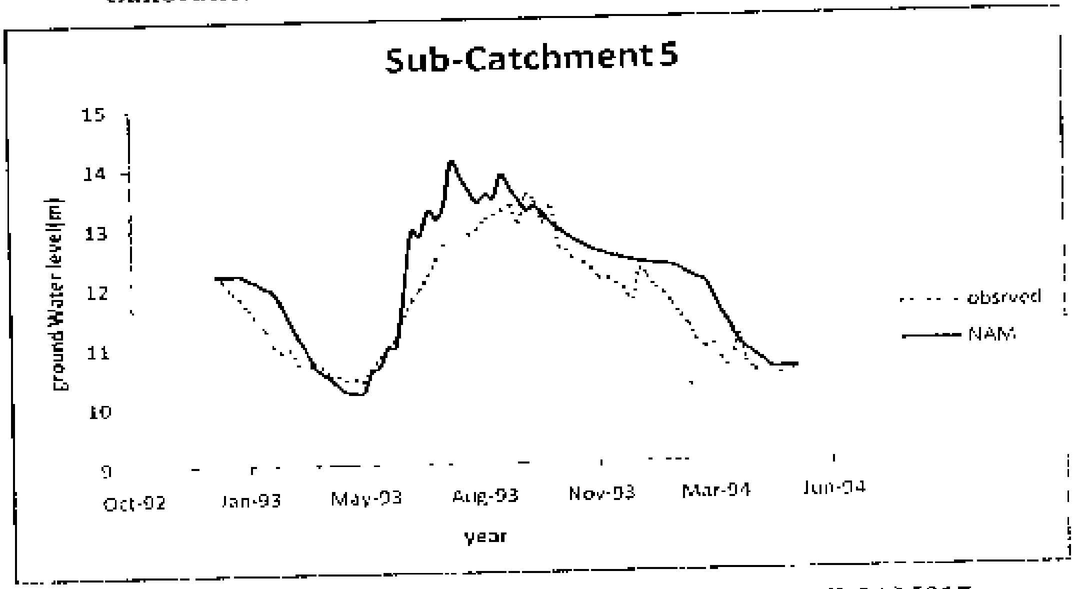
Calibration of sub-catchment 1 with observation well JAM003



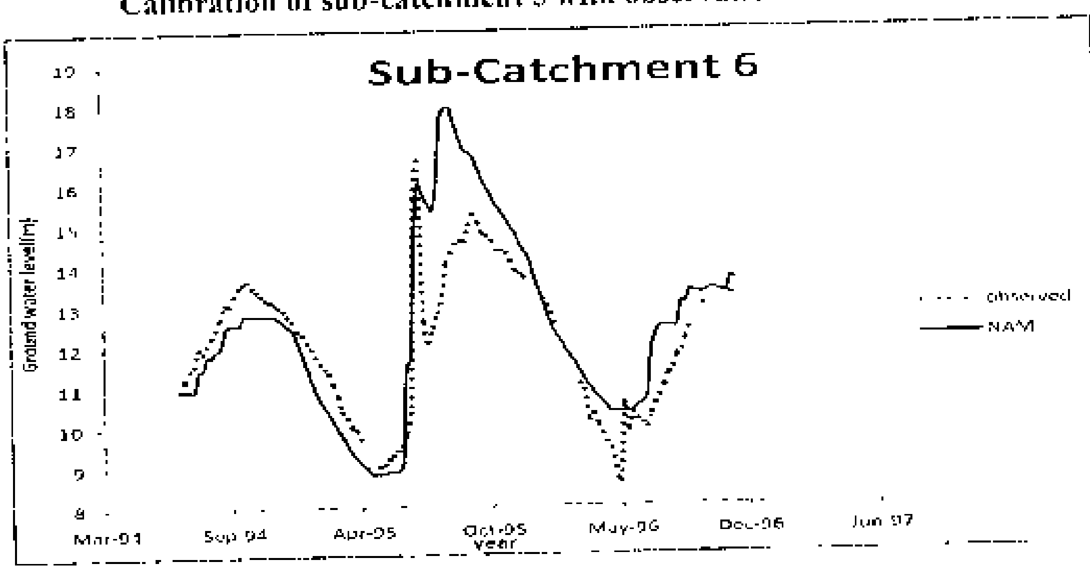
Calibration of sub-catchment 2 with observation well JAM016



Calibration of sub-catchment 4 with observation well JAM015

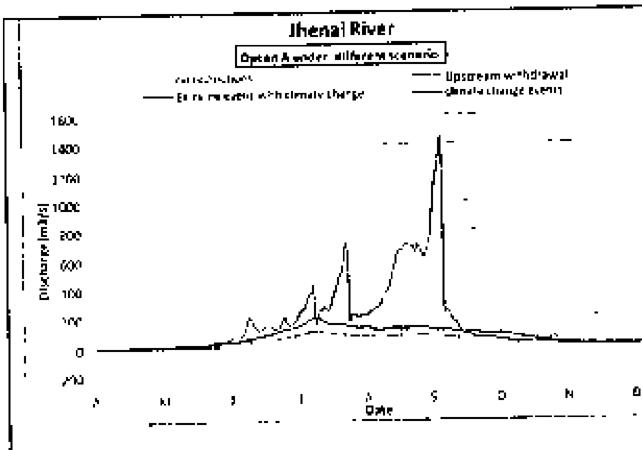


Calibration of sub-catchment 5 with observation well JAM017

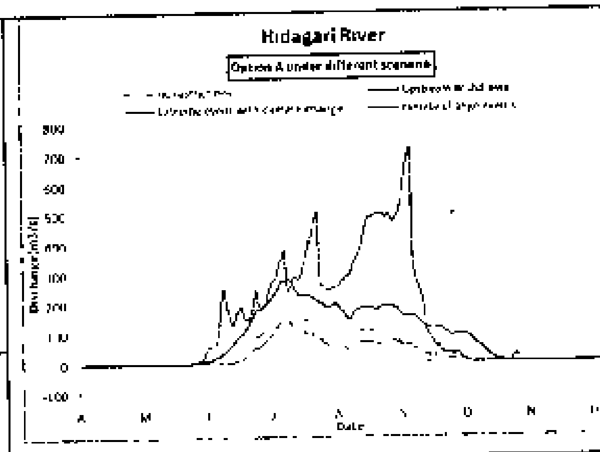


Calibration of sub-catchment 6 with observation well JAM013

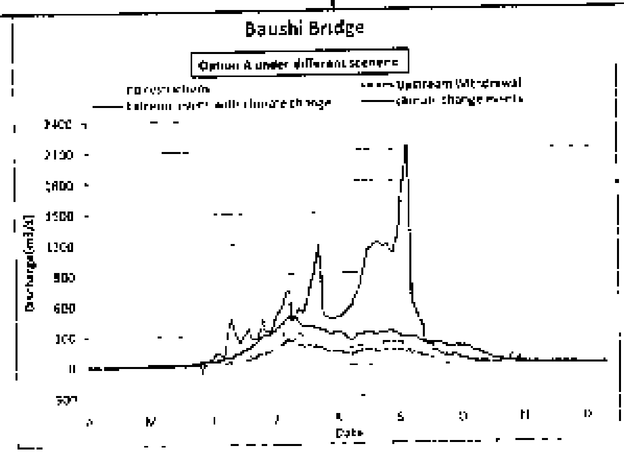
Hydrograph influenced by externalities for option A



(a) Jhinai

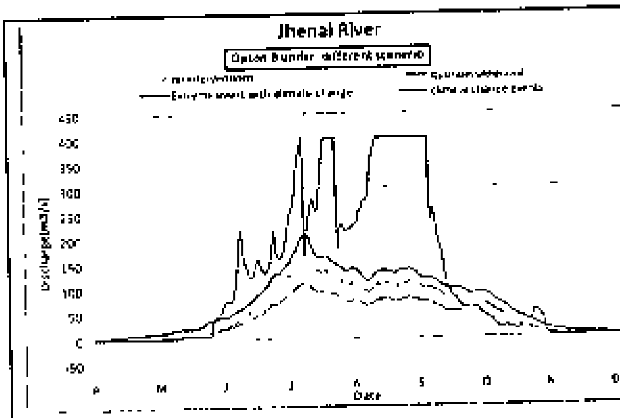


(b) Hidagari

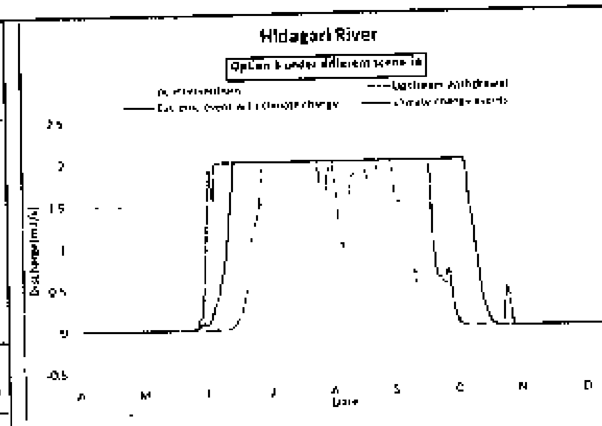


(c) Baushi bridge

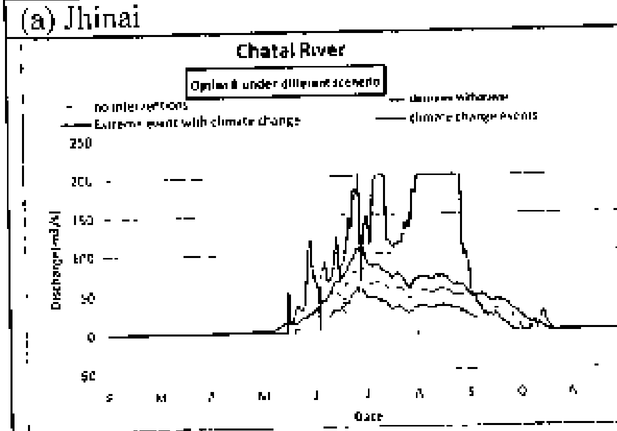
Hydrograph influenced by externalities for option B



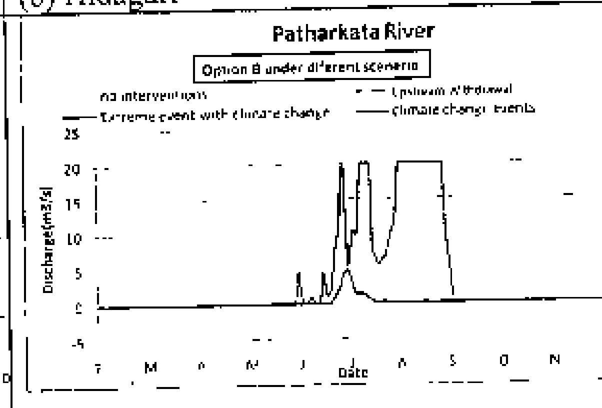
(a) Jhinai



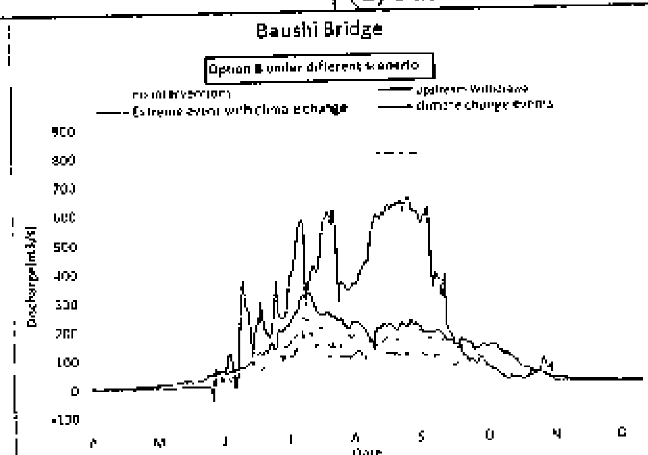
(b) Hidagari



(c) Chatal

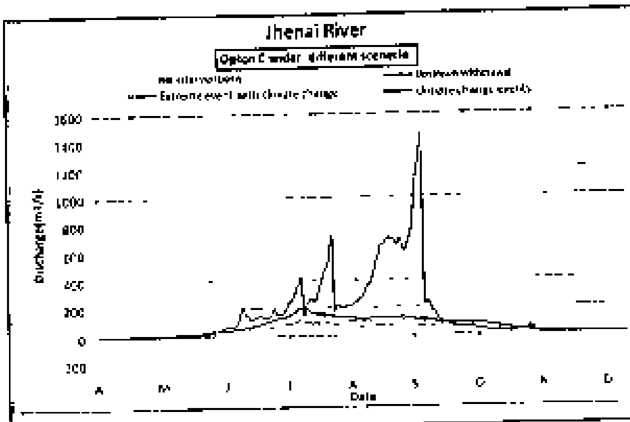


(d) Patharkata

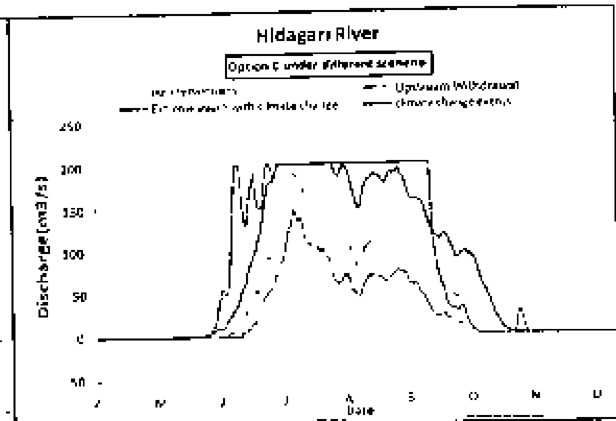


(e) Baushi bridge

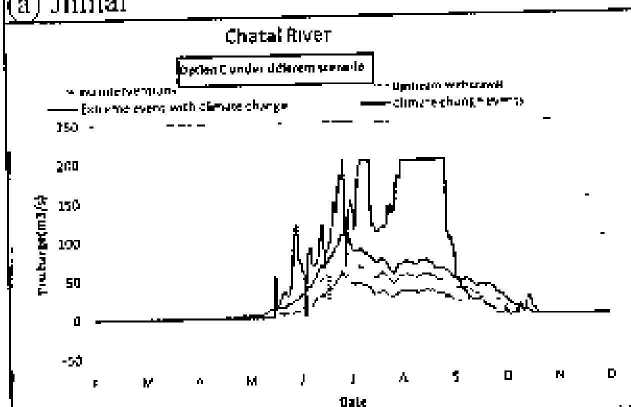
Hydrograph influenced by externalities for option C



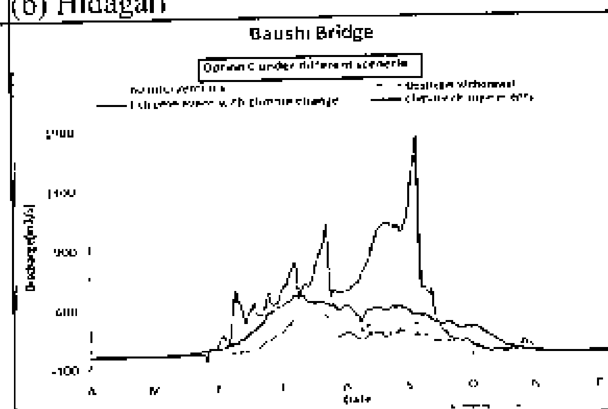
(a) Jhinai



(b) Hidagari



(c) Chatal



(d) Baushi bridge

Annex B

Questionnaire for Household Survey

Questionnaire for Houschold Survey

Date: ....

Name of the respondents:
Age:
Village: **Union:** **Upazila:**

Occupation:
Primary:
Secondary:

1. Family Information

Name of Family Members	Age	Education*	Employment status	Present Occupation**

*** Illiterate=1, Literate=2, Primary=3, Secondary=4, Higher Secondary=5, University=6, Infant=7**

**** Farmer=1, Fisherman=2, Agre-Wage Labour=3, Non Agri- Labour=4, Industry Labour=5, Transport Labour=6, Business=7, House wife=8, Student=9, Service=10, Others=11, Infant=12**

2. Occupation Group

2.1. Farmer

Landless ☐		Land owner ☐	
Amount of Land:			
Income Profile:			
Dry Season (November-May)		**Wet Season (June-October)**	
Types of Crop (Aman/Boro)		Types of Crop(Aman/Boro)	
Crop variety (HYV/Local)		Crop variety (HYV/Local)	
Fertilizer Application (Kg/Ha):		Fertilizer Application (Kg/Ha):	
Months worked		Months worked	

Days worked per month		Days worked per month	
Hours worked per day		Hours worked per day	
Average daily income (Tk)		Average daily income (Tk)	
Average daily income about 10 years ago		Average daily income about 10 years ago	
Other sources of income		**Other sources of income**	
- Crop		- Crop	
- Non-crop		- Non-crop	
Income from other sources (Tk/Month)		Income from other sources (Tk/Month)	

2.2. Fisherman

Name of fishing area:			
Area of that water body:			
Gear Used (Net and Boat):			
Catch per effort:			
Income Profile:			
Dry Season (November-May)		**Wet Season (June-October)**	
Months worked		Months worked	
Days worked per month		Days worked per month	
Hours worked per day		Hours worked per day	
Average daily income (Tk)		Average daily income (Tk)	
Average daily income about 10 years ago		Average daily income about 10 years ago	
Per day catch		Per day catch	
Other sources of income		Other sources of income	
Income from other sources (Tk/Month)		Income from other sources (Tk/Month)	

2.3. Wage Labour

Types of work:			
Income Profile:			
Dry Season (November-May)		**Wet Season (June-October)**	
Months worked		Months worked	
Days worked per month		Days worked per month	
Hours worked per day		Hours worked per day	
Average daily income (Tk)		Average daily income (Tk)	
Average daily income about 10 years ago		Average daily income about 10 years ago	
Other sources of income		Other sources of income	
Income from other sources (Tk/Month)		Income from other sources (Tk/Month)	

2.4. Industry

Type of Industry:			
Area of the industry:			
Total no of labour worked in the industry:			
Income Profile:			
Dry Season (November-May)		**Wet Season (June-October)**	
Months worked		Months worked	
Days worked per month		Days worked per month	
Hours worked per day		Hours worked per day	
Average daily income (Tk)		Average daily income (Tk)	
Average daily income about 10 years ago		Average daily income about 10 years ago	
Other sources of income		Other sources of income	
Income from other sources (Tk/Month)		Income from other sources (Tk/Month)	

2.5. Transportation Worker

Types of work:			
Fare in per Km kucha road (Tk)			
Fare in per Km pucca road (Tk)			
Income Profile:			
Dry Season (November-May)		**Wet Season (June-October)**	
Months worked		Months worked	

Days worked per month		Days worked per month	
Hours worked per day		Hours worked per day	
Average daily income (Tk)		Average daily income (Tk)	
Average daily income about 10 years ago		Average daily income about 10 years ago	
Other sources of income		Other sources of income	
Income from other sources (Tk/Month)		Income from other sources (Tk/Month)	

3. Family Expenditure Profile

Item		Expenditure (TK)/season
Food	Cost/day	
Shelter/housing	Cost/year	
Clothing	Cost/year	
Health (disease)	Cost/month	
Education	Cost/month	
Transportation	Mode	
	Cost/day	
Others		
Total		

4. Major Food items consumed in the last week

Item	Quantity	Price (Tk/kg)
Rice		
Flour		
Fish		
Meat		
Vegetables		
Pulse		
Milk		
Fruits		
Eggs		
Oil		
Sugar		
Others		

5. Asset profile

Asset	Type	Quantity and Value in current price (Tk)
Land	Agricultural	
	Non-agricultural	
Household	Moveable	
	Fixed	
Livestock		

6. Preference among different occupation for changing his current occupation

Profession	Reason to choose

7. Flood Information

7.1 Year of occurrence of large flood:

7.2 Whether the flood water come to his homestead: ☐ Yes ☐ No

7.3 If yes, then what is the depth of water to his/her yard:

7.4 Flood damage profile

Depth of water (metre)	% of Damage
One	
Two	
Three	

Annex C

Socio-economic Statistics

Table C-1: Agricultural input (labour, seed, fertilizer and pesticides) matrix

Inputs	Options	Aman, Local	Aman, HYV	Boro, HYV	T.Aus	Jute	Sugarcane	Rabi (Wheat)	Mustard
Labour (Man-days)		100	130	160	140	170	170	105	60
Seed (Kg/ha)		30	35	40	30	10	2,000	140	10
Fertilizer (Kg/ha)	2001	65	95	330	130	120	300	270	100
	2008	90	130	450		120	300	270	100
	Option A	90	130	450		120	300	270	100
	Option B	90	130	450		120	300	270	100
	Option C	85	124	428	130	120	300	270	100
Pesticide (Kg/ha)	2001	3.80	4.75	8		1	1.10	0.25	0.50
	2008	4.5	5.5	10		1	1.10	0.25	0.50
	Option A	4.5	5.5	10		1	1.10	0.25	0.50
	Option B	4.5	5.5	10		1	1.10	0.25	0.50
	Option C	4.15	5.25	8	4.15	1	1.10	0.25	0.50

Table C-2: Unit cost of inputs

Inputs Type	Type of Crops	Price (TK/Kg)
Seed	Boro, HYV	150
	Boro, Local	25
	Aman, HYV	150
	Aman, Local	25
	Aus,HYV	150
	Jute	100
	Sugarcane	2.5
	Wheat	26
Fertilizer	Urea	12
	TSP	22
	MP	25
	Zinc Sulphate	120
	Zipsum	8
Pesticides		150
Irrigation (For per ha of land)	Boro	12,500
	Aman	3,000
Equipment		4,700
Labour (Per day)		160 (Tk/day)

Table C-3: Cost per unit ha of different crops

Cost of Inputs (Tk)	Options	Aman, Local	Aman, HYV	Boro, HYV	T.Aus	Jute	Sugarcane	Rabi (Wheat)	Mustard
Labour Cost	All options	17.500	22,750	28.000	24,500	29,750	29,750	18,375	10,500
Seed	All options	900	1,750	6,000	900	1,000	5,000	3,640	1,000
Irrigation Cost	All options	2,000	2,500	13,200					
	Option C	7,260	7,920	9,900	7,260				
Equipment Cost	All options	4,500	4,500	5.000	4,500	4,500	4,500	4,500	4,500
Fertilizer Cost	2001	1,326	1,916	6,632	2,600	1,440	6,000	5,400	2,000
	2008	1.800	2,600	9,000	-	1,440	6,000	5,400	2,000
	Option A	1,800	2,60;0	9,000	-	1,440	6,000	5,400	2,000
	Option B	1,800	2,600	9,000	-	1,440	6,000	5,400	2,000
	Option C	1,710	2,480	8,560	2,600	1,440	6.000	5,400	2,000

Table C-3: Cost per unit ha of different crops (*Continued*)

Cost of Inputs (Tk)	Options	Aman, Local	Aman, HYV	Boro, HYV	T.Aus	Jute	Sugarcane	Rabi (Wheat)	Mustard
Pesticide Cost	2001	855	1,069	1,782	-	225	248	56	113
	2008	1.011	1,264	2,106	-	225	248	56	113
	Option A	1,011	1.264	2,106	-	225	248	56	113
	Option B	1,011	1,264	2,106	-	225	248	56	113
	Option C	933	1,166	1,944	933	225	248	56	113
Total Input Cost	2001	27,081	34,485	60,614	32,500	36,915	45,498	31,971	18.113
	2008	27,711	35,364	63,306	29,900	36,915	45,498	31,971	18,113
	Option A	27,711	35.364	63.306	29,900	36,915	45,498	31,971	18,113
	Option B	27,711	35.364	63.306	29,900	36,915	45,498	31,971	18,113
	Option C	32,803	40,566	59,404	40,693	36,915	45,498	31,971	18,113

Table C-4: Output matrix for different crops

	Options	Aman, Local	Aman, HYV	Boro, HYV	T.Aus	Jute	Sugarcane	Rabi (Wheat)	Mustard
Yield Rate (Ton/ha)	2001 and 2008	2.5	3.5	5		1.7	40	3	1
	Option A	3.5	4	6		1.7	40	3	1
	Option B	4	4.5	6.5		1.7	40	3	1
	Option C	4.5	5.5	8	4.5	1.7	40	3	1
Selling Price (Tk/Ton)		18,000	18,000	17,000	15,000	32,000	1,900	15,000	45,000
Total Selling Price (Tk/ha)	2001 and 2008	45,000	63,000	85,000		54,400	76,000	45,000	45,000
	Option A	63,000	72,000	102,000		54,400	76,000	45,000	45,000
	Option B	72,000	81,000	110,500		54,400	76,000	45,000	45,000
	Option C	81,000	99,000	136,000	67,500	54,400	76,000	45,000	45,000
Input Cost (Tk/ha)	2001	27,081	34,485	60,614		36,915	45,498	31,971	18,113
	2008	27,711	35,364	63,306		36,915	45,498	31,971	18,113
	Option A	27,711	35,364	63,306		36,915	45,498	31,971	18,113
	Option B	27,711	35,364	63,306		36,915	45,498	31,971	18,113
	Option C	32,803	40,566	59,404	40,693	36,915	45,498	31,971	18,113
Income (selling Price-Input Cost)	2001	17,919	28,515	24,386		17,485	30,503	13,029	26,888
	2008	17,289	27,636	21,694		17,485	30,503	13,029	26,888
	Option A	35,289	36,636	38,694		17,485	30,503	13,029	26,888
	Option B	44,289	45,636	47,194		17,485	30,503	13,029	26,888
	Option C	48,197	58,434	76,596	26,807	17,485	30,503	13,029	26,888

Table C-5: Income matrix for per ha of settlement

Types of Livestock	No	Average Income from per Animal (Tk/Yr)
Cow	168,963	6,000
Goat	59,243	1.500
Hen	966,278	105
Duck	122,559	120

Table C-6: Income matrix for per ha of wetland

	Types of wetland	2001	2008	Option A	Option B	Option C
Production (Kg/ ha)	Beel	400	350	300	400	600
	River&khal	139	157	160	160	160
	Floodplain	125	100	80	70	75
Average Price (Tk/Kg)		150	150	150	150	150
Total Price (Tk/ha)	Beel	60,000	52,500	45,000	60,000	90,000
	River&khal	20,850	23,550	24,000	24,000	24,000
	Floodplain	18,750	15,000	12,000	10,500	11,250

Table C-7: Income matrix for per ha of different types of road

Types of Road	Type of Vehicle	Employment (person)	Income (Tk.)
National/ regional	Motorized (MV)	50	4,391,963
	Non-motorized (NMV)	30	1,143,454
Total		**80**	**5,535,417**
Feeder Road A	MV	30	2,627,568
	NMV	30	1,142,772
Total		**60**	**3,770,340**
Feeder Road B	MV	20	1,321,333
	NMV	30	1,151,343
Total		**50**	**2,472,677**
Rural	MV	5	324,507
	NMV	25	958,129
Total		**30**	**1,282,637**

Table C-8: Industry and growth centre

Industry and GC	Income (Tk/ha)	Employment (Person/ha)
Total Industry	788,673	17
Upazila growth centre	24,908,175	518
Union growth centre	10,674,935	296
Market	6,671,836	222

Table C-9: Input output matrix of brick field

Name of Industry	Area (ha)	Duration (month)	Labour input					Earth use m3	Water use per season	Fuel (ton)		Total production (No of Bricks/year)
			Permanent		Temporary							
			No of Labour	Average wage/month (Tk)	No of labour	No of days /month	Average wage/day (Tk)			Coal	Wood	
Badsha Brick Field	2.13	5	8	36,000	53	26	138	8,495	1,425	990	20	3,800,000
Sadia Brick Field	0.61	5	5	38,400	50	27	140	4,248	720	400	23	2,000,000
RLB Brick Field	0.81	5	5	17,500	45	28	150	2,830	750	350	22	2,000,000
Rxx Brick Field	1.62	5	4	16,000	40	29	135	4,200	650	750	27	1,500,000
Bashona Brick Field	1.60	5	8	32,000	46	28	150	4,000	1,312	350	23	2,500,000

Table C-10: Input output matrix of rice mill

Name of Industry	Area (ha)	Duration (month)	Labour input							Avg. water use/ season (Liter)	Total Paddy Processed (Mt)	Production of Rice (ton)
			Permanent		Temporary							
			No of Labour	Avg. wage/ month (Tk)	No of male Labour	No of female Labour	No of days/ month	Avg. male wage/ day (Tk)	Avg. female wage/ day (Tk)			
Mrs Broti Rice mill	0.61	9	3	14,400	7	10	25	130	80	35,000	1,591	1,034
Milon Auto Rice milling plant	0.61	9	2	10,000	38	9	28	120	100	4,000,480	4,546	3,011
Nobab Auto Rice milling plant	0.34	9	3	13.500	8	5	28	150	90	800,000	909	591.
Alal Rice mill	0 14	9	1	3,600	1	3	28	120	100	4,500	68	46

Table C-11: Input output matrix of poultry farm

Name of Industry	Area (decimal)	Duration (month)	Permanent		Temporary					Water use in month(Liter)	Total price of poultry (Tk)	Production of eggs (per day)
			No of labour	Labour wage/ month (Tk)	No. of male labour	No. of female labour	No. of days /month	Avg. wage of male/ day (Tk)	Avg. wage of female / day (Tk)			
Jarip poultry farm	12	12	1	3,000	0	1	30	0	80	3900	300000	725
Bhai Bhai Agro poultry farm	150	12	4	4,500	2	0	30	120	0	54000	1400000	3555
Khan poultry farm	100	10	2	5,000	1	1	30	150	100	2415	562500	1600
Lal Miah poultry farm	5	9	1	3,500	1	1	29	100	90	3420	116000	Broiler
Parul poultry farm	6	10	1	5,000	0	1	29	0	85	2000	60000	Broiler

Table C-12: Details of surveyed growth centre

Name	Types	Area (ha)	No. of Shops	Average employee/shop	Average wage/person (Tk/month)	Average population gather/day	Sale/day
Kamarbari Bazar, Dewanganj	Regular	0.13	24	30	2,000	500-700	80,000
Maulvibazar, Dewanganj	Regular	0.13	32	40	3,000	1,200	50,000
Fulkocha Bazar, Melandaha	Regular	0.27	30	44	3,500	1,000	100,000
Adra Bazar, Melandaha	Regular & Weekly	0.81	50	65	3,000	900	100,000
Gabergram Bazar, Madarganj	Regular & Weekly	0.95	30	50	3,500	1,000	1000,000
Amritala Bazar, Madarganj	Regular	0.41	25	35	3,000	500	400,000

Table C-13: Cropping pattern wise area, production, financial gain, fertilizer use and employment statistics in 2001

Cropping Pattern	Area (ha)	Production (M.Ton)				Financial Gain (Million Tk)	Fertilizer use (M. Ton)	Employment (Man-Year)
		Rice	Wheat	Jute	Sugarcane			
Aman-Boro	18,414	102,379				997	10,267	16,124
Jute- Aman-Rabi (Wheat)	3,073	9,403	9,218	5,224		204	1,529	3,823
Boro-Jute	529	2,647		900		26	302	560
Boro	7,245	36,227				164	3,260	3,716
Sugarcane	3,005				120,200	120	902	1,637
Aman-Rabi	3,495	10,695	10,485			140	1,320	2,444
Jute-Rabi	4,734		14,203	8,048		165	1,846	4,173
Boro-Mustard/ Valued Crop	1,993	9965				101	1,096	1,405
Aus-Aman-Rabi	0	-	-			-	-	-
Total	**42,488**	**150,656**	**9,218**	**6,124**	**120,200**	**1,510**	**16,260**	**33,882**

Table C-14: Cropping pattern wise area, production, financial gain, fertilizer use and employment statistics in 2008

Cropping Pattern	Area (ha)	Production (M.Ton)				Financial Gain (Million Tk)	Fertilizer use (M. Ton)	Employment (Man-Year)
		Rice	Wheat	Jute	Sugarcane			Rice
Aman-Boro	18,778	105.159				1,007	10,441	16,371
Boro-Jute	524	2,620		891		26	299	554
Boro	10,574	52,871				239	4,758	5,423
Sugarcane	2,330				93,212	93	699	1,270
Jute- Aman-Rabi (Wheat)	3,008	9,205	9,024	5,114		187	1.492	4,908
Aman-Rabi	3,472	10.623	10,415			139	1,311	6,449
Jute-Rabi	1,526		4,577	2,594		53	595	1,345
Boro-Mustard/ Valued Crop	1,899	9,494				96	1,044	1,339
Aus-Aman-Rabi	0	-	-			-	-	-
Total	**42,111**	**169,855**	**9,024**	**6,005**	**93,212**	**1,551**	**17,689**	**37,658**

Table C-15: Cropping pattern wise area, production, financial gain, fertilizer use and employment statistics under option A

Cropping Pattern	Area (ha)	Production (M.Ton)				Financial Gain (Million Tk)	Fertilizer use (M. Ton)	Employment (Man-Year)
		Rice	Wheat	Jute	Sugarcane			Rice
Aman-Boro	18,369	247,982				2,728	9,919	15,308
Boro-Jute	506	4,052		861		51	289	536
Boro	11,812	94,495				869	5,315	6,057
Sugarcane	2,327				93,094	93	698	1,268
Jute- Aman-Rabi (Wheat)	-	-	-	-		-	-	-
Aman-Rabi	2,423	13,326.0	7,269			202	872	1,592
Jute-Rabi	2,753		8,260	4,681		96	1,074	2,427
Boro-Mustard/ Valued Crop	1,781	14,246.41				181	979	1,256
Aus-Aman-Rabi	0	-	-			-	-	-
Total	**39,972**	**374,101**	**15,529**	**5,542**	**93,094**	**4,220**	**19,147**	**28,443**

Table C-16: Cropping pattern wise area, production, financial gain, fertilizer use and employment statistics under option B

Cropping Pattern	Area (ha)	Production (M.Ton)				Financial Gain (Million Tk)	Fertilizer use (M. Ton)	Employment (Man-Year) Rice
		Rice	Wheat	Jute	Sugarcane			
Aman-Boro	24,905	336,218				3,698	13,449	20,754
Jute- Aman-Rabi (Wheat)	2,734	15,038	8,203	4,648		302	1,312	3,286
Boro-Jute	507	4,056		862		51	289	536
Boro	5,295	42,360		-		390	2,383	2,715
Sugarcane	2,338				93,506	93	701	1,274
Aman-Rabi	-	-	-			-	-	-
Jute-Rabi	2,992		8,976	5,086		104	1,167	2,637
Boro-Mustard/ Valued Crop	1,718	13,741				175	945	1,211
Aus-Aman-Rabi	-	-	-			-	-	-
Total	**40,489**	**411,413**	**17,179**	**10,596**	**93,506**	**4,813**	**20,246**	**32,414**

Table C-17: Cropping pattern wise area, production, financial gain, fertilizer use and employment statistics under option C

Cropping Pattern	Area (ha)	Production (M.T)				Financial Gain (Million Tk)	Fertilizer use (M. Ton)	Employment (Man-Year)
		Rice	Wheat	Jute	Sugarcane			Rice
Aman-Boro	6.195	83,630				920	3,345	5,162
Jute- Aman-Rabi (Wheat)	6,261	34,435	18,783	10,644		687	3.005	7,525
Boro-Jute	4,559	36,471		7,750		455	2,599	4,822
Boro	9,422	75,377				693	4,240	4,832
Sugarcane	2,442				97,696	97	733	1,331
Aman-Rabi	-	-	-			-	-	-
Jute-Rabi	548		1,644	932		19	214	483
Boro-Mustard/ Valued Crop	7,414	59.313				753	4.078	5,228
Aus-Aman-Rabi	7,969	79.694	23,908			1,035	4,224	9,579
Total	**44,811**	**368,920**	**44,335**	**19,325**	**97,696**	**4,660**	**22,437**	**38,962**

Table C-18: Cropping pattern wise labour distribution throughout the year in 2001

Cropping Pattern	Area (ha)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sugarcane	3005	3,929	809	809	809	809	809	809	809	809	809	809	7,859
Boro-Mustard/ Valued Crop	1993	1,380	2,682	3,679	1,839	1,226	1,226	4,292	-	-	-	2,453	1,533
Boro-Aman	18414	28,045	16,997	11,331	11,331	39,660	-	-	28,045	10,198	8,499	8,499	29,745
Boro-Jute	529	977	902	555	342	1,130	1,087	1,045	3,617	-	-	-	-
Boro	7245	13,376	6,688	4,459	4,459	15,605	-	-	-	-	-	-	-
Aman-Rabi-Jute	3073	3,782	2.364	2,127	7,682	2,955	2,955	10.636	4,680	1,702	1,418	1,418	4,964
Aman-Rabi	3495	4,301	2,688	2,420	4,705	-	-	-	5,323	1,936	1,613	1,613	5,646
Rabi-Jute	4734	5,827	3.642	3,278	6,373	5,463	4,552	4.552	16,388	-	-	-	-
Total	**42,488**	**61,618**	**36,773**	**28,658**	**37,540**	**66,848**	**10,629**	**21,334**	**58,862**	**14,645**	**12,339**	**14,791**	**49,746**

Table C-19: Cropping pattern wise labour distribution throughout the year in 2008

Cropping Pattern	Area (ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sugarcane	2,330	3,047	627	627	627	627	627	627	627	627	627	627	6,095
Boro-Mustard/ Valued Crop	1,899	1.315	2.556	3,505	1,753	1.168	1,168	4,090	-	-	-	2,337	1,461
Boro-Aman	18,778	28,601	17.334	11,556	11.556	40,446	-	-	28,601	10,400	8,667	8,667	30,334
Boro-Jute	524	977	902	555	342	1,130	1,087	1,045	3,617	-	-	-	-
Boro	10,574	19,522	9,761	6,507	6,507	22,775	-	-	-	-	-	-	-
Aman-Rabi-Jute	3,008	3,702	2.314	2,083	7,520	2.892	2,892	10,413	4.582	1,666	1,388	1,388	4,859
Aman-Rabi	3,472	4,273	2,671	2,403	4,673	-	-	-	5,288	1,923	1,602	1,602	5,608
Rabi-Jute	1,526	1.878	1,174	1.056	2,054	1.760	1,467	1,467	5,281	-	-	-	-
Total	**42,111**	**63,315**	**37,338**	**28,293**	**35,033**	**70,800**	**7,242**	**17,642**	**47,996**	**14,617**	**12,285**	**14,622**	**48,357**

Table C-20: Cropping pattern wise labour distribution throughout the year under option A

Cropping Pattern	Area (ha)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sugarcane	2327	3,043	627	627	627	627	627	627	627	627	627	627	6,087
Boro-Mustard/ Valued Crop	1781	1,233	2,397	3,288	1,644	1,096	1,096	3,836	-	-	-	2,192	1,370
Boro-Aman	18369	27,978	16,956	11,304	11,304	39,564	-	-	27,978	10,174	8,478	8.478	29,673
Boro-Jute	506	977	902	555	342	1,130	1,087	1,045	3,617	-	-	-	-
Boro	11812	21,806	10,903	7,269	7,269	25,441	-	-	-	-	-	-	-
Aman-Rabi	2423	2,982	1,864	1,677	3,262	-	-	-	3,690	1,342	1,118	1,118	3,914
Rabi-Jute	2753	3,388	2,118	1,906	3,706	3,177	2,647	2,647	9,530	-	-	-	-
Total	**39,971**	**61,408**	**35,767**	**26,626**	**28,153**	**71,034**	**5,456**	**8,154**	**45,441**	**12,142**	**10,223**	**12,415**	**41,044**

Table C-21: Cropping pattern wise labour distribution throughout the year under option B

Cropping Pattern	Area (ha)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sugarcane	2,338	3,057	629	629	629	629	629	629	629	629	629	629	6,114
Boro-Mustard/ Valued Crop	1,718	1,189	2,312	3,171	1,586	1,057	1,057	3,700	-	-	-	2,114	1,321
Boro-Aman	24,905	37,932	22,989	15,326	15,326	53,642	-	-	37,932	13,794	11,495	11,495	40,231
Boro-Jute	507	936	468	312	312	1,677	488	488	1,755	-	-	-	-
Boro	5,295	9,775	4,888	3,258	3,258	11,405	-	-	-	-	-	-	-
Aman-Rabi-Jute	2,734	3,365	2,103	1,893	6,836	2,629	2,629	9,465	4,164	1,514	1,262	1,262	4,417
Aman-Rabi		-	-	-	-	-	-	-	-	-	-	-	-
Rabi-Jute	2,992	3,682	2,302	2,071	4,028	3,452	2,877	2,877	10,357	-	-	-	-
Total	**40,489**	**59,937**	**35,691**	**26,661**	**31,975**	**74,491**	**7,680**	**17,158**	**54,838**	**15,937**	**13,386**	**15,500**	**52,083**

Table C-22: Cropping pattern wise labour distribution throughout the year under option C

Cropping Pattern	Area (ha)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sugarcane	2,442	3,194	658	658	658	658	658	658	658	658	658	658	6,388
Boro-Mustard/ Valued Crop	7.414	5,133	9,981	13,688	6,844	4,563	4,563	15,969	-	-	-	9,125	5,703
Boro-Aman	6,195	9,435	5,718	3,812	3,812	13,343	-	-	9,435	4,765	4,765	4,765	10,007
Boro-Jute	4,559	8,416	4,208	2,805	2,805	15,079	1,087	4,384	15,781	-	-	-	-
Boro	9,422	17,395	8,697	5,798	5,798	20,294	-	-	-	-	-	-	-
Aman-Rabi-Jute	6,261	7,706	4,816	4.335	15.653	6,020	6,020	21,673	9,536	4,816	4,816	3,612	10,114
Rabi-Jute	548	674	422	379	738	632	527	527	1,897	-	-	-	-
T.Aus-T.Aman-Rabi	7,969	4,598	13,793	12,874	5,211	5,517	19,311	31,194	2.575	6,130	6,130	25,747	4,598
Total	**44,811**	**56,551**	**48,293**	**44,349**	**41,518**	**66,106**	**32,164**	**74,404**	**39,881**	**16,369**	**16,369**	**43,907**	**36,810**

Table C-23: Per capita daily normative calorie requirements and the cost needed to meet the requirement

Items Included in the Minimum Consumption Bundle	Per Capita Daily Normative Calorie Requirements		Cost	
	Gm	Kilocalorie	Price (Tk/Kg)	Price of the Required Amount
Rice	397	1,386	25	9.9
Wheat	40	139	24.43	1.0
Pulses	40	153	110	3.0
Oil	20	180	85	1.7
Potato	27	26	15	0.4
Sugar	20	82	55	0.8
Meat	12	14	157.25	1.9
Fish	48	51	120	5.8
Milk	58	39	36	2.1
Vegetables	150	36	15	2.3
Fruits (1 Banana/day)	20	6	3.5 (1 piece)	2.0
Total		**2,112**		**30.8**

Annex D

User Manual of Decision Support Framework

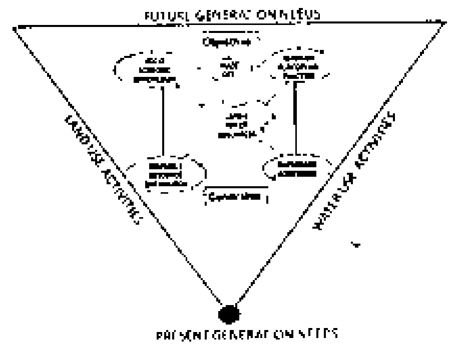
A Decision Support Framework for Sustainable Land and Water Management in a Floodplain

Institute of Water and Flood Management (IWFM)
Bangladesh University of Engineering and Technology (BUET)

A Decision Support Framework for Sustainable Land and Water Management in a Floodplain

developed by

Ahmadul Hassan



Front End: Visual Basic 6

Back End: MS Access

Input Data: Model Result

Output Data: MCA Scorecard and Chart

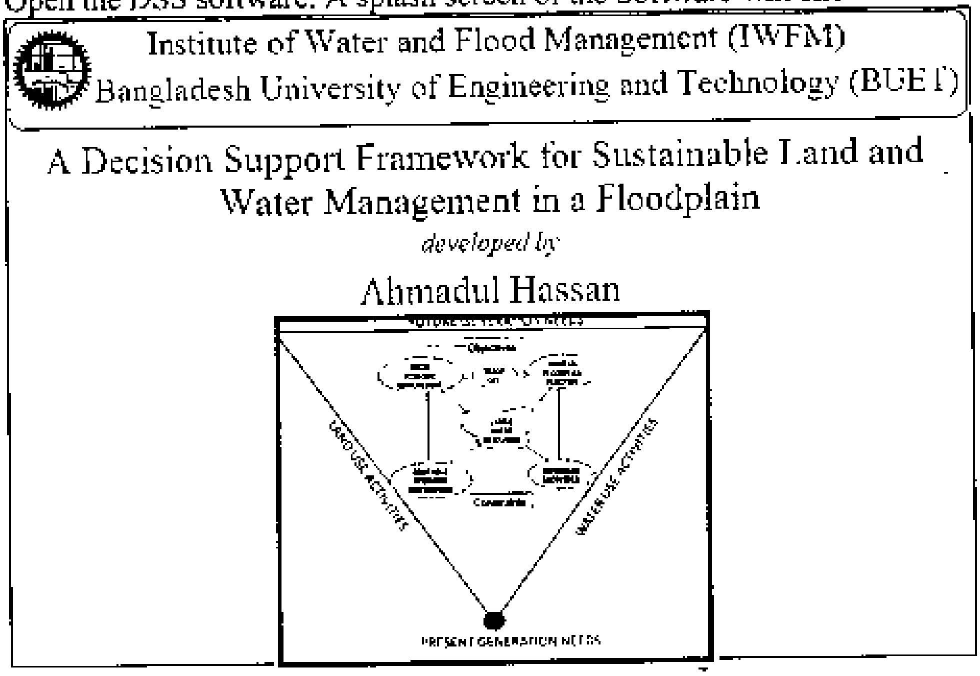
Export: MCA Scorecard can be exported to MS Excel and Chart can be Exported in various Picture Format

Space required: Minimum 200 MB (or Higher)

Screen Resolution: 1280 x 1024

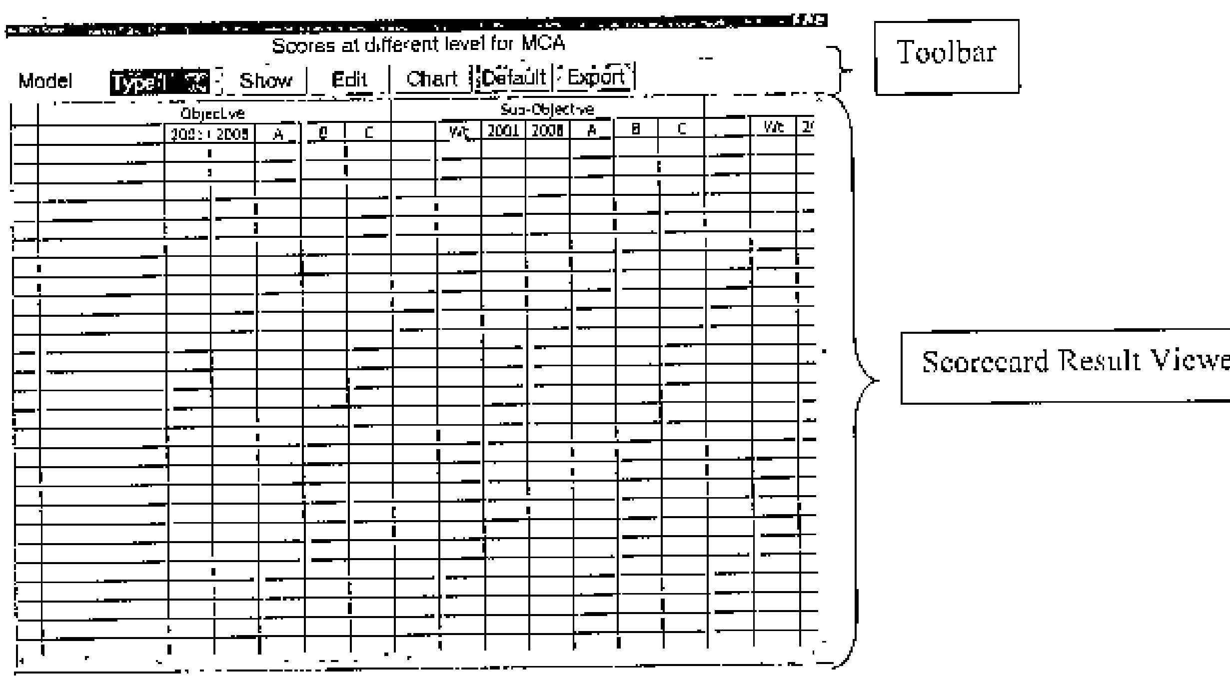
Starting DSS

Open the DSS software. A splash screen of the Software will shown on the Screen.



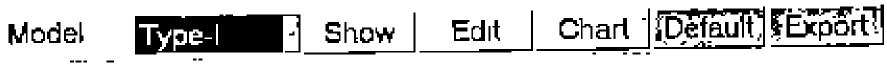
Scorecard Viewer:

Click on the Framework Picture to open the DSS main window. Then the DSS score viewer will be open on the screen shown as below.



The scorecard viewer contains two part. The upper part of the Screen is the Toolbar and the second part contains the Scorecard Result Viewer.

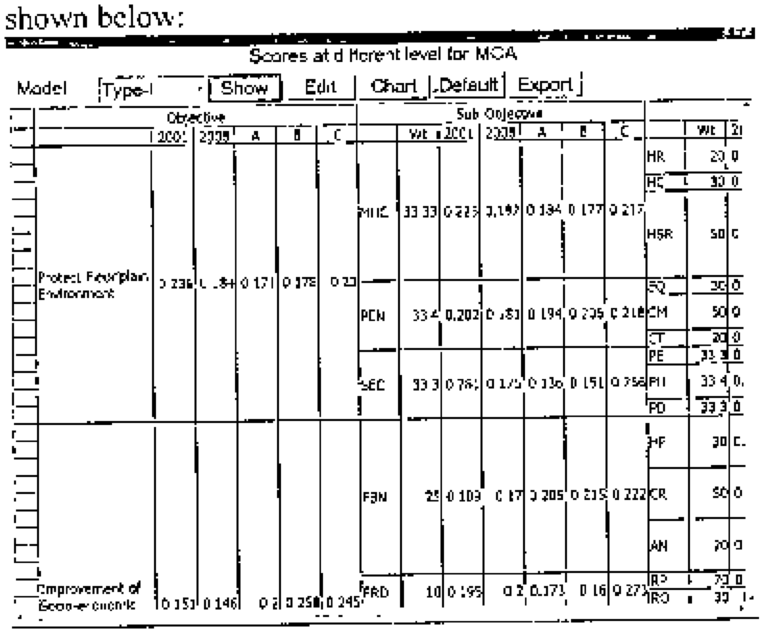
Toolbar:



Model Type-I	Select the Model type. Now here is only one type into the Database.
Show	The Show button will display the Scorecard data depends on the selection of the model type. The result will be shown into the Scorecard Result Viewer (SRV).
Edit	Edit Button is for Editing the Weightage of Objective, Sub-objective, Criteria and Indicators.
Chart	To view chart of the Score Card Result.
Default	The Default button will be set the Weghtage default value.
Export	The Export button is for Export the Scorecard result to MS excel format.

Scorecard Result Viewer:

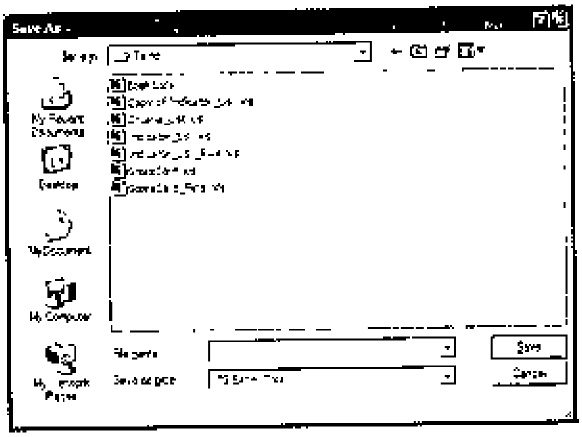
When the user select Model Type and Click on Show button the Scorecard Result Viewer will be filled with the calculated values. A filled Scorecard Result Viewer is shown below:



The full result can't be seen at a time. To view the right portion of the result user has to use Horizontal Scroll bar and to view the bottom portion use Vertical Scroll bar.

Export the Scorecard Result:

User can export the Scorecard Result into MS Excel. To export click on the Export button. A "Save As" screen will be shown on the screen. User has to select the Path and Export File Name. Then click on save button.

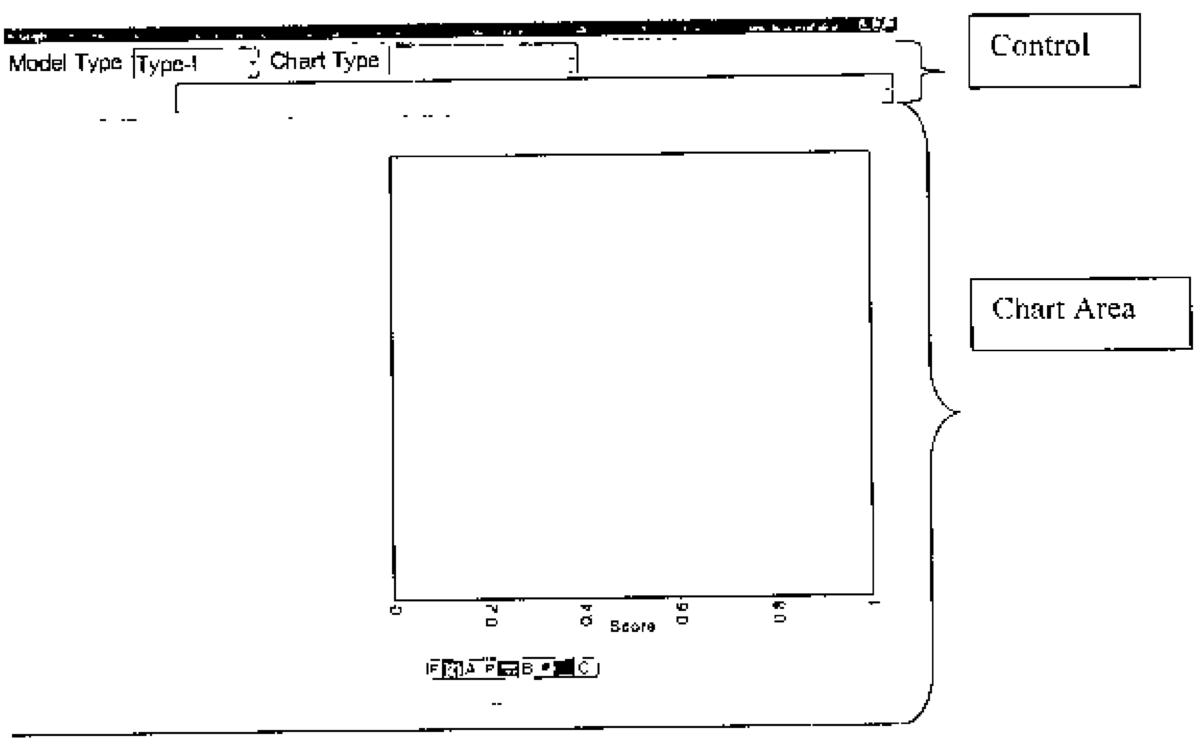


After completion of the Export DSS will be shown Completion Message on the screen.

Chart Viewer:

To view the chart user has to click on Chart button. The Chart Viewer has two parts.

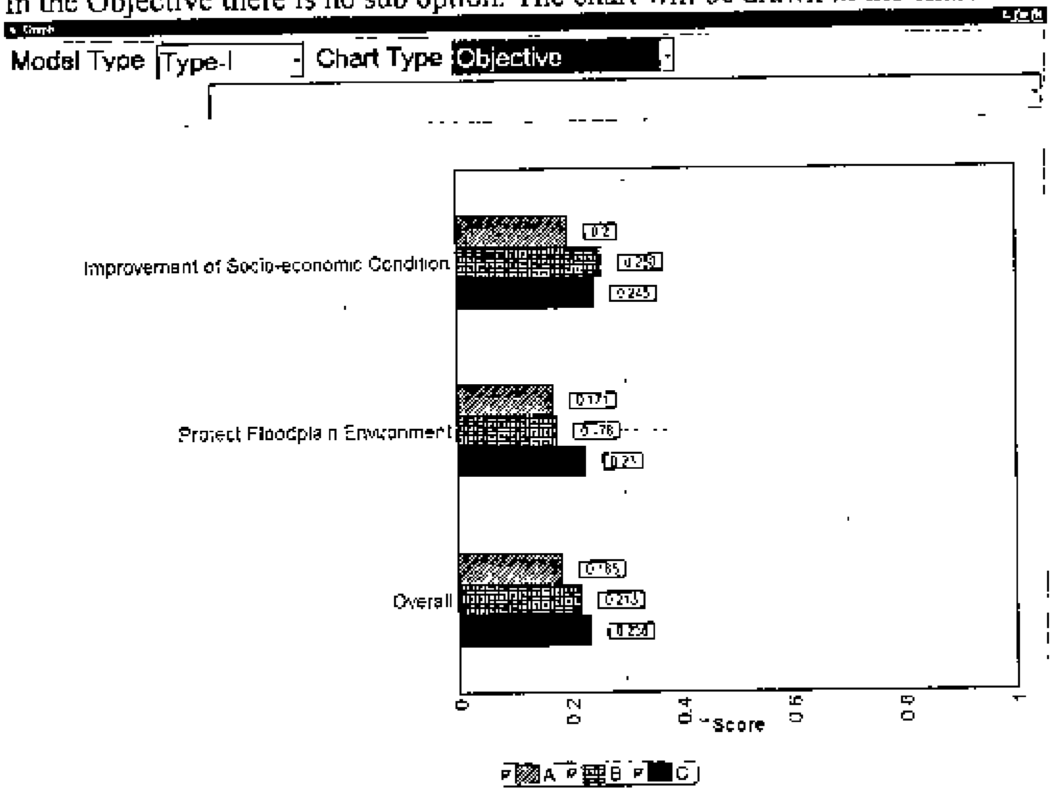
1. Control
2. Chart Area



Select Model Type, then Chart Type. In the Chart Type there is 3 options. 1. Objective, 2. Sub objective and 3. Criteria.

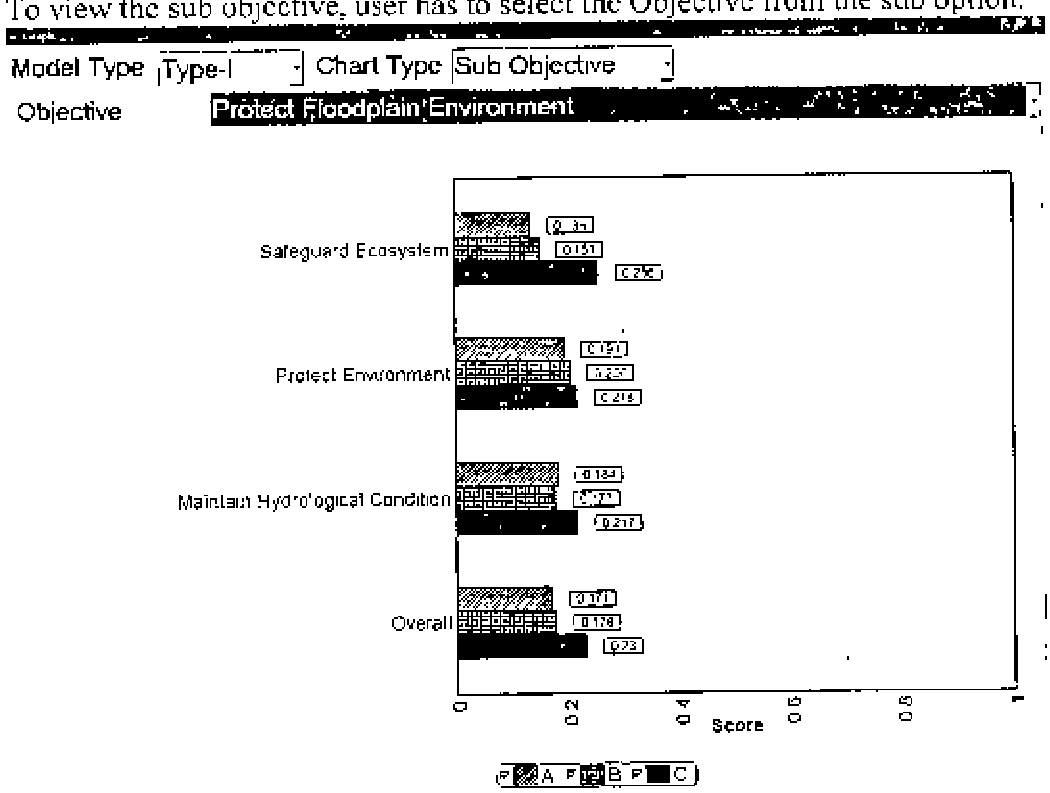
Objective level:

In the Objective there is no sub option. The chart will be drawn in the chart.

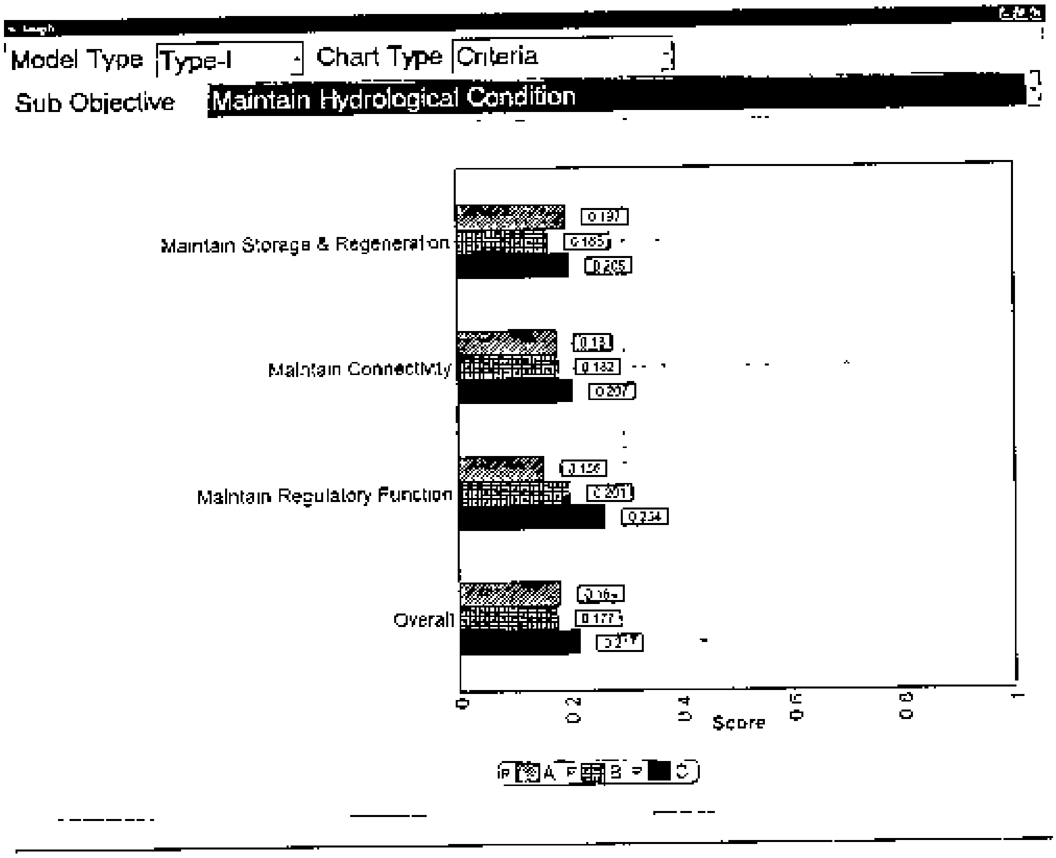


Sub objective level:

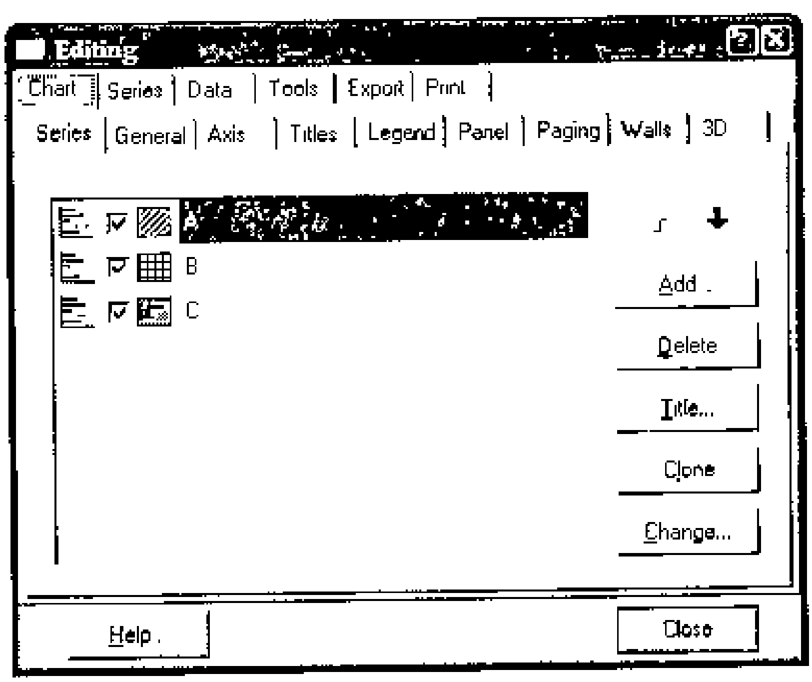
To view the sub objective, user has to select the Objective from the sub option.



Criteria level:
To view the Criteria Chart, user has to select the Sub objective from the sub option.

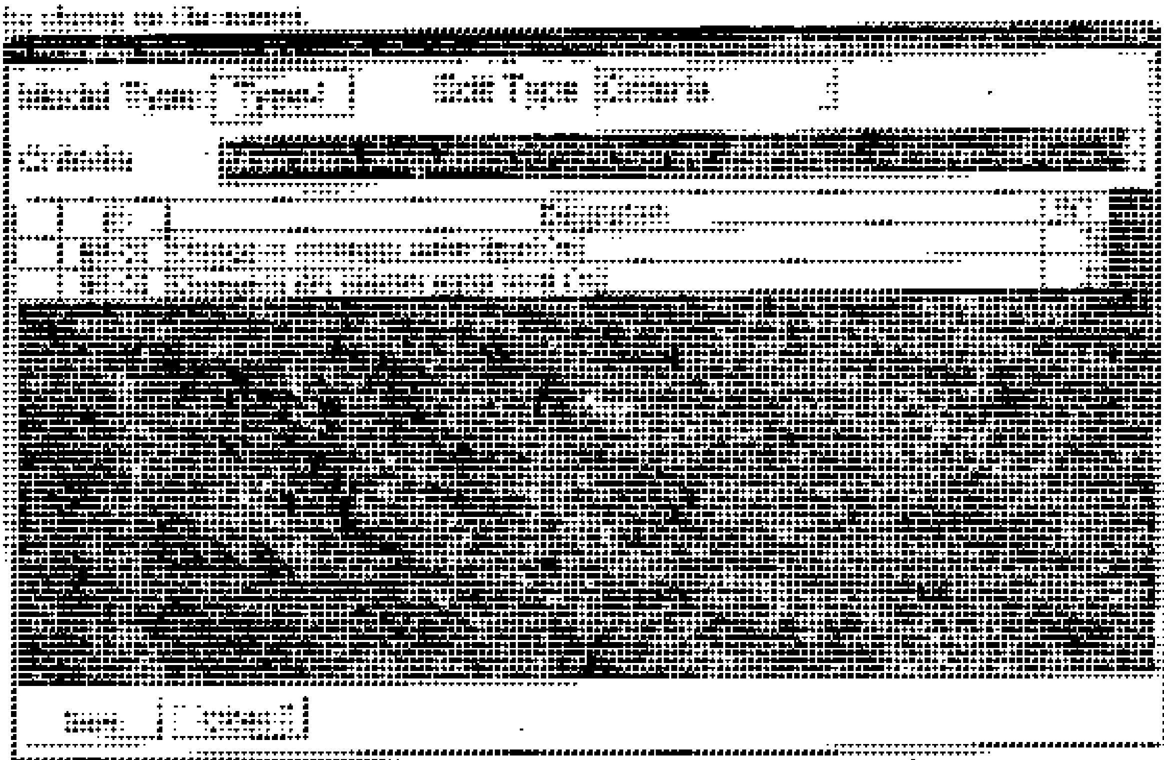


To Edit or Export the Chart User has to "Double Click" on the chart. Then the Chart control window will be shown on the screen.



Edit:

To Edit the Weightage value user has to click on the Edit button. The Editor Screen will



User will select the Edit Type such as Objective, Sub objective, Criteria and Indicator. Then select the respective functions then the current weightage value will be shown on the screen. User can the Edit the value and Click on "Save" button to update the value. Then click on close to back into the Scorecard viewer.