ASSESSMENT OF WATER AVAILABILITY, DRAINAGE AND IRRIGATION PROBLEMS IN SOME SELECTED LOCATIONS OF PABNA DISTRICT

By

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Submitted to the Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka
in partial fulfillment for the requirement of degree
of

MASTER OF ENGINEERING IN CIVIL ENGINEERING
(ENVIRONMENTAL)

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

May 2012

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ACKNOWLEDGEMENT

First of all the author wishes to express her deepest gratitude to the Almighty Allah for giving her this opportunity and for enabling her to complete the thesis successfully.

The author wishes to express her profound gratitude and sincerest appreciation to her supervisor Dr. Md. Delwar Hossain, Professor, Department of Civil Engineering, BUET for his constant supervision, hearty support, continuous guidance and encouragement at every stage of the work.

The author is highly grateful to Professor Dr. Monwar Hossain, Executive Director, Institute of Water Modelling (IWM), Dhaka, Bangladesh to allow using the data and other facilities from IWM for developing the model and other analysis for this study. The author is highly indebted to Wahid Palash, Associate Specialist, Flood Management Division, IWM, for his cordial cooperation and guidance during data collection, processing and development of Models.

Finally, the author expresses her thanks to his family and friends for their continuous encouragement and support.

ABSTRACT

The present study area Pabna sadar and Sujanagar upazilas of Pabna district which are not covered by the BWDB catchment delineation and there are no hydrological stations within this area. People of this area faces various problems like water logging, crop loss, drainage congestion, irrigation problems, scarcity of water during dry season etc. since several decades. Therefore, there is need to conduct studies on water availability, drainage and irrigation condition. The study tried to assess water availability, drainage and irrigation problems based on recent and available data in a simple as well effective method.

Assessment of surface water availability has been carried out by developed a rainfall-runoff and hydrodynamic model by using MIKE 11 for the period of 2001-2009. The overall model has been developed considering historical rainfall data of 5 stations within the study area and 3 hydrological stations on Padma and Jamuna River. At the outset MIKE 11 rainfall-runoff model has been calibrated by observed and simulated ground water depth for the year 2004 and hydrodynamic model by 2004 flood satellite image. The people of the area are dependent on the ground water for their domestic and irrigation purposes. CROPWAT 8.00 has been utilized to carry out the total present irrigation water requirement of the study area. Utilizing evapotranspiration (ET_0), effective rainfall, precipitation, crop coefficient and cropping pattern, the field irrigation water requirement (FIWR) for each crop was calculated. ET_0 has been estimated by 30 years average weather data. On the basis of population projection by geometric progression method and per capita water demand, the domestic and municipal water requirement has been estimated. Abstraction was calculated on the basis of irrigation, domestic and municipal water requirement. Using the water-table fluctuation (WTF) method the groundwater recharge of the study area was estimated. Estimating the water-level rise and specific yield, the recharge was calculated.

Most of the study area is surrounded by embankment/highway. The drainage congestion within the area is fully due to very low drainage capacity of channels/khals caused by sedimentation and anthropogenic interventions. Usable surface water is not available during monsoon as well as dry season. There is no provision of surface water so irrigation is solely depending on ground water. The total water requirement is more at Sujanagar upazila though it has less population than that of Pabna sadar. Abstraction is increasing day by day which clearly show increasing dependency on ground water. Recharge in Sujanagar is more due to Beel Gaznar and other beels. Abstraction and recharge reached almost same level in 2009 which points to is a major concern for the future.

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ABBREVIATIONS AND ACRONYMS

ADC	Agricultural Development Corporation
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
BTM	Bangladesh Transverse Mercator
BWDB	Bangladesh Water Development Board
CAD	Command Area Development
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DPHE	Department of Public Health Engineering
DTW	Deep Tube well
FAO	Food and Agriculture Organization
FAP	Flood Action Plan
FCDandI	Flood Control Drainage and Irrigation
FFWC	Flood Forecasting and Warning Centre
FIWR	Field Irrigation Water Requirement
GIS	Geographic Information System
GWL	Ground Water Level
GWT	Ground Water Table
ha	hectare
HD	Hydrodynamic
IWM	Institute of Water Modelling
IWR	Irrigation Water Requirement
Km	Kilometer
LLP	Low Lift Pump
m	Meter
NAM	Nedbør-Afstrømnings-Model (Rainfall-Runoff Model)
NWMP	National Water Management Plan

NWRM	North West Region Model
PIRDP	Pabna Irrigation and Rural Development Project
SIWR	Seasonal Irrigation Water Requirement
SRDI	Soil Research Development Institute
SWMC	Surface Water Modelling Center
SWR	Scheme Water Requirement
UNDP	United Nations Development Programme
WARPO	Water Resources Planning Organization
WTF	Water Table Fluctuation

CHAPTER ONE

INTRODUCTION

1.1 General

Water occurs on the earth in all its three states i.e. liquid, solid and gaseous, and in various degrees of motion. Evaporation of water from water bodies such as oceans and lakes, formation and movement of clouds, rain and snowfall, stream flow and groundwater movement are some example of the dynamic aspects of water (Subramanya, 2003). Water is a precondition for human, animal and plant life as well as an indispensable resource for the economy. Water also plays a fundamental role in the climate regulation cycle (ec.europa.eu/environment/water). Depending on the sources water is found in two forms in nature: Surface water and Ground water.

Surface water is the vital source of water for irrigation and domestic use so as to preserve ground water for drinking. Various studies have been shown that ground water is seriously vulnerable to depletion in some places. Because of this threat, it is important to assess the availability of surface water sources.

Now a days these assessment are done by: (1) Field investigation, (2) Model development and (3) Data collection from secondary sources. But field investigation and data collection is not always possible for financial and managerial constraints. Conceptual and Computational Models describe advances in both conceptual and numerical modeling. It gives insights into the interpretation of field information.

Drainage is the natural or artificial removal of surface and sub-surface water from an area. Many agricultural soils need drainage to improve production or to manage water supplies (http://en.wikipedia.org/wiki/Drainage). This is done by developed a proper and effective drainage system. Bangladesh is not properly facilitating with this system. And being a riverine country, every year she suffers from flood and drainage problem. To mitigate the problems it is important to identify the extent of problems. Computational models based on analytical and numerical techniques are a widely used method to focus on the assessment of prevailing drainage and flood condition.

Groundwater comes from rain, snow, sleet, and hail that soak into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock until it reaches a depth where the ground is filled, or saturated, with water. The area that is filled with water is called the saturated zone and the top of this zone is called the water table. (http://www.groundwater.org/kc/whatis.html). Ground water abstraction is the burning issue for the entire world as ground water table deepening downward for over abstraction of water for human activities. All human activities are more or less related to water. To fulfill this huge need most of the areas of the world is depend on ground water rather than surface water. In order to assess the water availability of an area, investigation of availability of ground water is vital. And it is done by historical data analysis and also by recharge calculation. Recharge means the replenishment of groundwater storage that is depleted by withdrawal through artificial and natural processes (Akram, 2008). Groundwater is recharged naturally by rain and snow melt and to a smaller extent by surface water (rivers and lakes).

The sustainable use and management of surface and groundwater is now a great challenge for the national water agencies of Bangladesh. A number of studies have been done to assess the water availability, drainage and flooding condition in different areas of Bangladesh. Modeling has been an effective way to perform these jobs in many countries of the world. MIKE 11, a one-dimensional river modelling system, developed by DHI Water and Environment, Denmark is being used to carry out research in the field of water resources, flood and drainage problem.

The Pabna Sadar and Sujanagar upazilla are the concerned area of the study. These two upazillas are located at the confluence of two major rivers named the Padma and the Jamuna of Bangladesh. A various number of beels is enriching its ecological and environmental condition. The environmental, social, economic condition and also lifestyle, food culture is closely related to the rivers/khals and various beels. The main river named Badai drains about 45,700 ha area through the sluice at Talimnagar. The

Basin of Badai River is surrounded by Pabna-Nagarbari highway in the north, Nagarbari-Talimnagar-Sujanagar flood control embankment to the east, Sujanagar-Bharara flood control embankment to the south and Bharara-Pabna road to the west. This enclosed condition of the area creates the major problem of the study area and that is drainage congestion. But the drainage problem is extensive as the khals are silted up by seasonal flooding. And most of the area is surrounded by national highways/embankments so monsoon rain overflows the khals/channels and also trapped within the embankment/ highways. Drainage facilities have not been implemented yet as to drain out the surface runoff created within the surrounded area.

But at the dry period unavailability of surface water increase the dependency on ground water for both irrigation and domestic uses. This situation is continuing going on for some previous decades which make a vulnerable condition for ground water resources. Ground water abstraction is increase day by day due to human activities and population growth which leads to ground water table declination. Therefore abstraction and recharge estimation is very important for the wellbeing of environment as well as human.

1.2 Objectives of the Study

The main objective of the study is to improve the socio-economic condition of the area by increasing agricultural production through removing drainage congestion and providing irrigation in about 27,900 ha irrigable area.

The specific objectives are:

- Assessment of availability of surface water in Pabna Sadar and Sujanagar Upazillas using Mathematical Modelling by Hydrodynamic module of MIKE 11.
- Assessment of existing flooding and drainage problems in the study area using MIKE 11 GIS.
- Estimation the irrigation water requirement of the total study area by using CROPWAT 8.0 by analyzing 30 years weather data.
- Estimation domestic water requirement based on the population projection.

- Assessment of total water requirement of the two upazillas.
- Estimation of Upazilla wise abstraction.
- Ground water recharges calculation by using Water-Table Fluctuation (WTF) Method.
- Development of relationship between abstraction and recharge.

1.3 Scope of Works

The scopes of the works under the proposed study are as follows:

- This study can provide a guideline for implementation of drainage and irrigation facilities.
- The drainage model can be updated by extensive field survey to identify the inflow/outflow/actual path of the existing rivers/khals/channels.
- Abstraction and recharge can be utilized for water balance study of the area.
- Seasonal decadal variation map of GW depth of two upazillas.
- Identification of scopes for groundwater irrigation expansions, determination of optimum number of irrigation wells.
- Upazilla-wise assessment of groundwater resources and potential recharge.

1.4 Structure of the Report

The report represents the total achievement carried out under the study. It is comprised of six chapters and a list of mentioned references in the report.

Chapter 1: Focuses on the study, general information of the study, brief description of the existing problems and bottlenecks, its objectives, scopes and the structure of the study.

Chapter 2: Describes the literature review, working principles of MIKE 11, MIKE 11 GIS and CROPWAT 8, presents the brief summary of the previous studies related to this study.

Chapter 3: Gives the physical setting of the study that includes description of the study area; it's geo-morphological and hydrogeological setting, drainage and river system, agricultural and irrigation conditions.

Chapter 4: Presents the general approach and methodology that has been applied during the modelling works, different methods calculation. It deals with data requirement, data collection from secondary sources, data analysis and processing for model input. It provides the various activities of modelling study as well as methods.

Chapter 5: Reflects the result and analysis of the modelling works, drainage condition, water demand, abstraction, and recharge and groundwater resource assessment.

Chapter 6: Presents the conclusions and recommendations that have been found during the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Water is a finite resource, and in the case of surface water, its quantity is not distributed uniformly throughout the year (Cooper, 2002). Stream flow is typically highest in monsoon when demand is low and lowest in summer when demand is high. In most area of the country, summer stream flows often are not sufficient to meet all demands.

Surface water is water collecting on the ground or in a stream, river, lake, wetland, or ocean; it is related to water collecting as groundwater or atmospheric water. Surface water is naturally replenished by precipitation and naturally lost through discharge to evaporation and sub-surface seepage into the ground. In Bangladesh use of surface water for irrigation and domestic purpose is limited only in the urban areas whereas rural people are fully dependent on ground water resources for agriculture and daily use (http://en.wikipedia.org/wiki/Surface_water).

Ground water is water located beneath the ground surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called 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 wetlands. In Bangladesh Groundwater withdrawn for agricultural, municipal and industrial use is a general practice (http://en.wikipedia.org/wiki/Groundwater).

Water covers 70.9% of the Earth's surface, and is vital for all known forms of life. On Earth, 96.5% of the planet's water is found in oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation. Only 2.5% of the Earth's water is fresh water, and 98.8% of that water is in ice and groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products.

Water on earth moves continually through the hydrological cycle of evaporation and transpiration (evapotranspiration), condensation, precipitation and runoff usually reaching the sea. Evaporation and transpiration contribute to the precipitation over land.

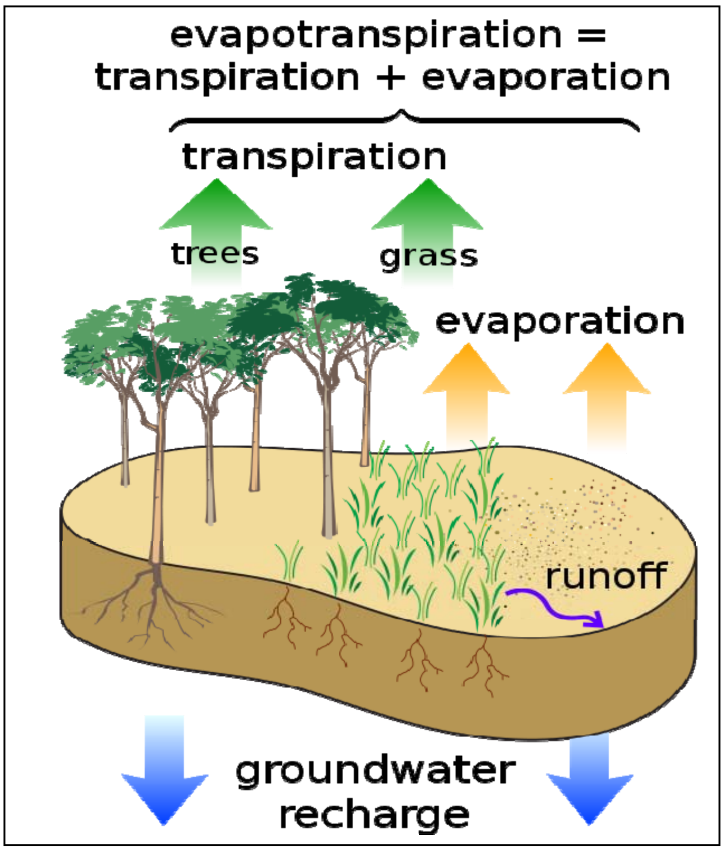


Figure 2.1: Water Cycle on Earth (http://en.wikipedia.org/wiki/Water)

Water abstraction, water extraction, or groundwater abstraction is the process of taking water from any source, either temporarily or permanently. Most water is used for irrigation or treatment to produce drinking water.

Depending on the environmental legislation in the relevant country, controls may be placed on abstraction to limit the amount of water that can be removed. Over abstraction can lead to rivers drying up or the level of groundwater aquifers reducing unacceptably (http://en.wikipedia.org/wiki/Water_abstraction).

Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface .Recharge occurs both naturally (through the water cycle) and anthropologically (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface.

Groundwater is recharged naturally by rain and snow melt and to a smaller extent by surface water (rivers and lakes). Recharge may be impeded somewhat by human activities including paving, development, or logging. These activities can result in enhanced surface runoff and reduction in recharge. Use of ground waters, especially for irrigation, may also lower the water tables. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged (http://en.wikipedia.org/wiki/Groundwater_recharge).

In both the NJDEP Storm water Management Rules and this manual, groundwater recharge is defined as "precipitation that infiltrates into the soil and is not evapotraspired. Instead, the infiltrated precipitation moves downward to a depth below the root zone of the surface vegetation, where it cannot be removed by that vegetation through uptake and evapotranspiration.
(http://www.nj.gov/dep/stormwater/bmp_manual/NJ_SWBMP_6%20print.pdf)

2.2 Working Principles of MIKE 11 and MIKE 11 GIS

2.2.1 Mathematical Modelling

MIKE 11, a one-dimensional river modelling system, developed by DHI Water and Environment, Denmark has been used in this study to compute water level and discharge in the rivers, *khals*/*charas* inside the study area and in its periphery. After a successful calibration of the model, model results for base and for study conditions have then been post-processed using MIKE 11 GIS inundation modelling system to develop flood/inundation maps and impact maps that are used for the assessment of the study benefit.

Working principle of MIKE 11

Computation in the MIKE 11 modelling system takes place in two steps:

- Computation of the rainfall runoff by MIKE 11 NAM module; and
- Computation of the river flows and water level by MIKE 11 HD module.

2.2.2 MIKE 11 NAM Model

Hydrologic information, by means of the MIKE 11 NAM (Rainfall-Runoff) Model, developed by DHI Water and Environment, Denmark requires input data such as rainfall, evaporation etc. The Rainfall-Runoff Model is applied to estimate the runoff generated from rainfall occurring in the catchment by NAM method. NAM is a lumped conceptual model that simulates continuous runoff, base and interflow by simple water balance approach for various land cover types for a continuous period of precipitation record. The model incorporates infiltration, interflow, depression storage, soil storage, overland flow, evapotranspiration, and changes in antecedent soil moisture in determining rainfall-runoff. Thus NAM hydrological model simulates rainfall-runoff processes occurring at the catchment scale and forms Rainfall-Runoff (RR) module of the MIKE 11 River Modelling system. Hence, the resulting output from MIKE 11 NAM is a continuous time series file (TSF) of runoff for every sub-basin been modelled in response of meteorology (rainfall, evaporation) gauges and soil-moisture content, characteristics of agro-geological land cover covering the whole model domain area. The catchments of the rainfall runoff model are delineated according to the topographic barriers/water shed boundaries, roads and river networks (DHI, 2007).

2.2.3 MIKE 11 HD Model

Hydraulic analyses are achieved using MIKE 11 Hydrodynamic module (HD). MIKE 11 HD uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. MIKE 11 HD model is applied to compute water level, discharge and flow velocity at every model grid points (water level, discharge /velocity point). The MIKE11 HD solves the vertically integrated equations of conservation of energy and momentum called the 'Saint Venant Equation' that describe the flow dynamic in a river system. The Model takes into account the river connectivity, river cross-sections, flood plain level and observed discharge at inlet and stage at outlet locations of the modelled river network. The observed discharge and stage applied respectively at the inlet and outlet are called boundary of the model. The runoff generated in the NAM model from rainfall occurring inside the basin is taken care of as inflows into the river system. Historical rainfall and stream flow data along with computer modeling are used to evaluate the flooding scenario of the study area. The Hydrodynamic (HD) Model takes into account schematized rivers/khals/chars of the area. The connectivity of the river systems and influence of other rivers outside the model area is identified from the river network maps. The external boundary conditions are specified to the model from catchment runoff simulated by NAM and water level data. River slope and flow direction is computed in the model by considering cross sections and tail water conditions. The flood plain depression within the model area is defined as flood cell/storage cell (DHI, 2007).

2.2.4 MIKE 11 GIS

Generations of flood inundation maps /data are carried out using MIKE 11 GIS. MIKE 11 GIS is an advanced tool for the spatial presentation and analysis of one-dimensional (1D) flood model results for use in the flood and drainage control, management planning process. The MIKE 11 GIS system integrates the MIKE 11 river and floodplain modeling technologies with the spatial analysis capabilities of the ArcView Geographic Information System (GIS). At its most basic level, MIKE 11 GIS requires information from a MIKE 11 model (river network), MIKE 11 flood simulations and a Digital Elevation Model (DEM). Hence, based on the discrete information from MIKE 11, MIKE 11 GIS constructs a grid based water surface and compares this data with the already available DEM to produce flood depth and duration mapped surfaces. For this study, cell size of grids of DEM as well as flood inundation maps is 50m X 50m.

Flood maps have been generated with the model results for different 9 years (2001-2009). MIKE 11 GIS facilities with land level data from Digital Elevation Model (DEM) have been used to develop flood maps. DEM of 300 m grid resolution for whole

Bangladesh (except the Sundarban Forest) was developed under FAP 19. The depth, duration and extent of flooding found in the MIKE 11 GIS maps for option scenario have been assessed to find out the possible implication of the proposed intervention in the study area in terms of its flooding and drainage scenario.

2.3 Working Principles of CROPWAT 8.0

CROPWAT 8.0 has been developed by Joss Swennenhuis for the Water Resources Development and Management Service of FAO. CROPWAT 8.0 is based on the DOS versions CROPWAT 5.7 of 1992 and CROPWAT 7.0 of 1999. CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements (CWR) and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

Rainfall data are also needed, and are used by CROPWAT to compute effective rainfall data as input for the CWR and scheduling calculations. Finally, crop data (dry crop or rice) are needed for the CWR calculations and soil data if the user also wants to calculate irrigation schedules (dry crop or rice).

Whereas CROPWAT normally calculates CWR and schedules for 1 crop, it can also calculate a scheme supply, which is basically the combined crop water requirements of multiple crops, each with its individual planting date (a so-called cropping pattern).

2.4 Use of MIKE 11 and CROPWAR 8.0

MIKE 11 and CROPWAT 8.0 are used in IWM for the study of many projects. Some of them are listed below:

Use of MIKE 11 (Source: IWM):

- Sirajganj Flood Index model.
- Indian River Linking Project.
- Regional model of Bangladesh (NWRM, NCRM, NERM, SWRM, SERM, EHRM-2005 to 2011).

- Assistance to Climate Change Adaptation and Disaster Risk Reduction in the NE region of Bangladesh.
- Gungaijuri Haor Flood Control Drainage Irrigation Project.
- Morphological study of the selected off take in connection with the Buriganga augmentation project.

Use of CROPWAR 8.0 (Source: IWM):

- A comparative assessment of groundwater resource and recharge potential in barind area using modflow and mike she models.
- Ground water management and Zoning study for Repair and Rehabilitation of DTW Project in Greater Dinazpur.
- Ground water quality and aquifer vulnerability assessment if several northern districts of Bangladesh.
- Strengthening Barind Multipurpose Development Authority (BMDA) capacity on water resources management.
- GW model study for Rajshahi Barind- Phase-III.

2.5 Previous Studies and Research

To have a preliminary understanding of the previous plans for agricultural and drainage development in the study area, at this stage, a quick review of the previous study has been made. However, an integrated effort would be made to explore the secondary sources of published reports, data, maps, satellite images etc. from relevant organizations and a thorough review of the previous studies and activities would be undertaken to have the clear understanding of the study, performance of past interventions, its problems and prospects. A brief of the present quick review findings are presented below;

M/S Sanyu Consultants International Japan (1968-70): They conducted the Feasibility Study of Pabna Irrigation and Rural Development Project (PIRDP) is the first ever study been carried out to address the issue like drainage congestion in the Gaznar Beel and adjoining areas. In that study, it proposed a drainage sluice along with a pump station at Talimnagar on the Badai River for improvement of drainage congestion.

The Agricultural Development Corporation (ADC) of Korea (1978): This Corporation reassessed and updated the previous feasibility study in 1978 where drainage improvement of the Badai River basin was also suggested through construction of a sluice along with a pump station at Talimnagar on the Badai River.

In 1980s, flood control embankment along with a six vent sluice at Talimnagar on the Badai River, a two vent regulator at Sujanagar and a three vent regulator at Khalilpur on branches of the Badai River have been implemented under Phase-I of PIRDP. As a result, drainage congestion of the Badai River basin including Beel Gaznar was improved only partially since the proposed pump station at Talimnagar as specified in the feasibility study has not yet been implemented.

Previous study was based on the the Badai river and Gaznar beel. Moreover out coming results of those study was not fully implemented. Therefore, it is necessary to study drainage and irrigation condition of the region for the welfare of the people.

CHAPTER THREE

STUDY AREA

3.1 Geographical Location

The study area is two upazillas of Pabna district situated in the North western part of Bangladesh. The one upazilla is Pabna sadar another is Sujanagar is the main concerned area of the study. The study area is located at the confluence of two major river of Bangladesh Ganges (Padma) and Jamuna. A distributary named Ichamati is flowing within the Pabna sadar upazilla. But now a days it dried up. Whole Sujanagar upazilla and 30% of Pabna sadar upazilla is surrounded by national highways at northside and embankment at south side. The figure below shows the location of the study area.

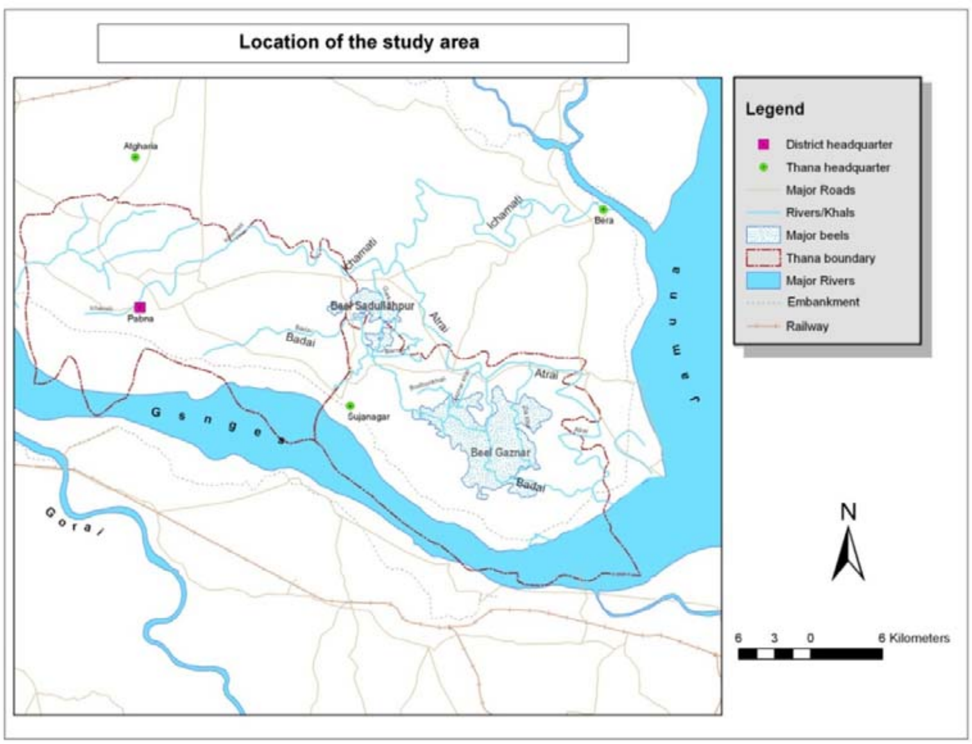


Figure 3.1: Location of the Study area

3.2 Climate

The study area has a typical monsoon climate with a warm and dry season from March to May followed by a rainy season from June to October and a cool period from

November to February. The temperature varies from 25˚ C to 40˚C in summer and from 10˚ C to 24˚ C in winter. Evaporation rates exceed the rainfall rates from November to May. The mean annual rainfall in the area is nearly 1800 mm, which gradually decreases to about 1600 mm in the north western part (NWMP). Almost 80% of the annual rainfall occurs during the period June to September. Annual dependable dry period, November to May, rainfall lies within 250mm. Maximum evaporation during the dry period, November to May lies between 400 to 600 mm.

3.3 Topography of the Study Area

The land elevation of the study area varies from 5m to 13m. The elevation data collected from the recent IWM field topographic survey (Field Topographic Survey for Beel Gaznar Flood Control, Drainage and Irrigation Project by IWM, 2011). The data has been processed by the ArcView GIS and 50m X 50m cell size DEM has produced. The Pabna sadar upazilla is comparatively high land area with an elevation of 13m- 9m. On the other hand Sujanagar upazilla is a low lying area where elevation varies from 9m-5m.

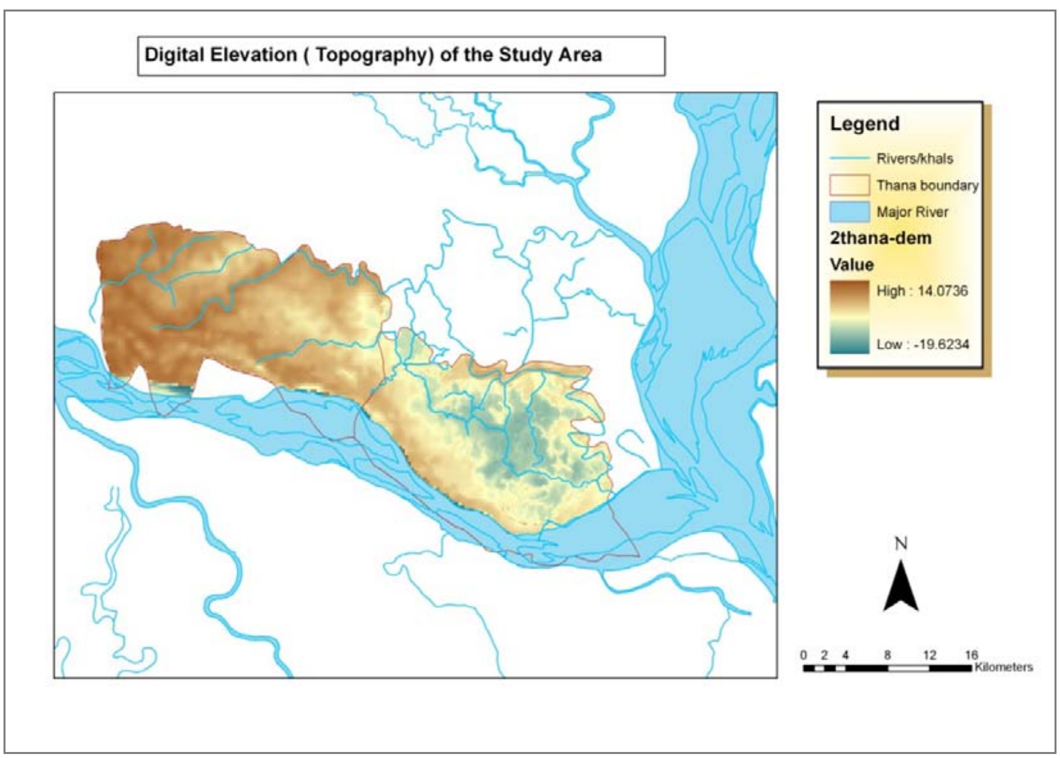


Figure 3.2: Topography of the Study area

3.4 Physiography and Landform

The study area is formed by calcareous dark grey floodplain soils and calcareous brown floodplain soils mainly dark grey or brown clays with dark grey flood coating, some calcareous throughout, some with seasonally acids topsoil and a calcareous substratum within 4feet. Brown loaming soils on highest ridges and near river banks. The area is mixed highland, shallow flooded and deeply flooded in nature. The figure 3.3 shows the physiography of the study area.

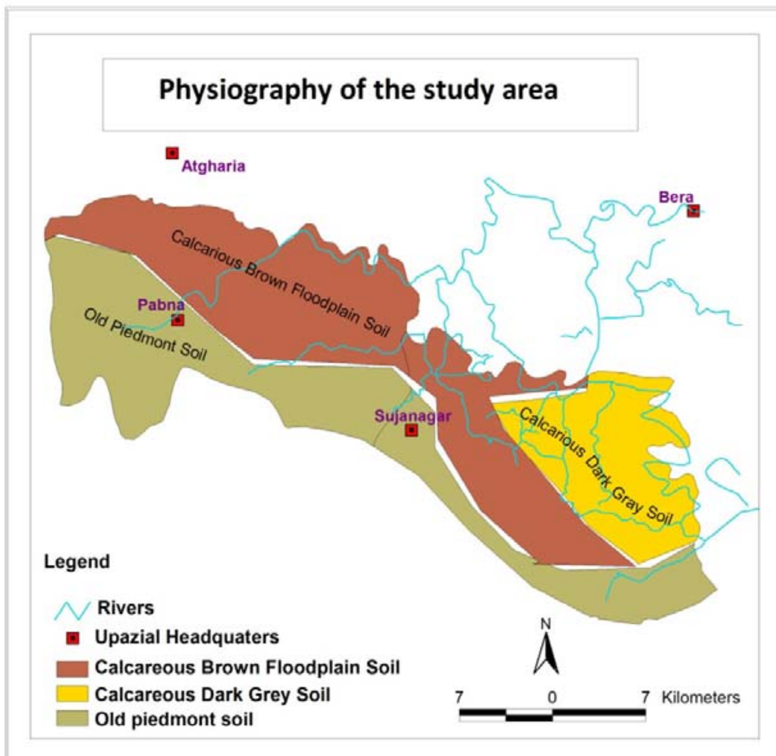


Figure 3.3: Physiography of the Study area

3.5 Geology

An understanding of geological environment is essential in evaluating the geometry of the formation and deposition of sediment which form the major water bearing deposits. As per 'Geological Map of Bangladesh (1990)' the surface geology of the study area is composed by deposits of lower Ganges and lower Atrai flood plain. Bore logs of DTWs have indicated that the average thickness of the top layer is more than 5m. Variations of thickness occur and locally clay can be over 10m thick. Sand strata dominate from 20m and continuous up to drilled depth of 80m. The Ganges flood plain covers about 65% of the area and the surface deposit are mainly silt mixed with fine sand. Sand contents increase with depth which may continue up to 300m or more. Aquifer characteristics are semi-confined (MPO, 1989). More exploratory holes need to be drilled to know the potential of the aquifer up to 300m in details.

3.6 River Systems, Beels, Baors and Ponds

Hydrology of the study area is mainly governed by local rainfall runoff and flow from Atria River. There are some internal rivers, most important one the Badai River but most of them are ephemeral. The Badai River is 50.5km long besides, the Badai River has 114.0km branch channels. The Badai River originates from the Ganges at Bharara regulator of Pabna Sadar Upazilla and falls into the Gaznar Beel flowing about 10 km east of Pabna town. The river then meets the Jamuna River flowing through Talimnagar of Sujanagar Upazilla. The Badai River drains about 45,700 ha area through the sluice at Talimnagar. There is a number of beels within the area among them beel Gaznar and beel Sadullapur is important. The Badai River including its branches have presently lost their drainage capacity due to deposition of sediments took place over the several decades, which has enhanced the drainage congestion in the Gaznar Beel and adjoining areas. Here some pictures of Atrai river and Beel Gaznar collected from the field survey of IWM.

Figure 3.4: View of Atrai River

Figure 3.5: View of Gaznar Beel

3.7 Agricultural Practice

SRDI (Soil Research Development Institute), Ministry of Agriculture developed a Land Use map showing the land use pattern of Bangladesh. Using that map and information a land use map for the study area is developed which illustrate the land use and agricultural practice. Moreover from recent field survey conducted by IWM also gives a present real field condition of land use pattern.

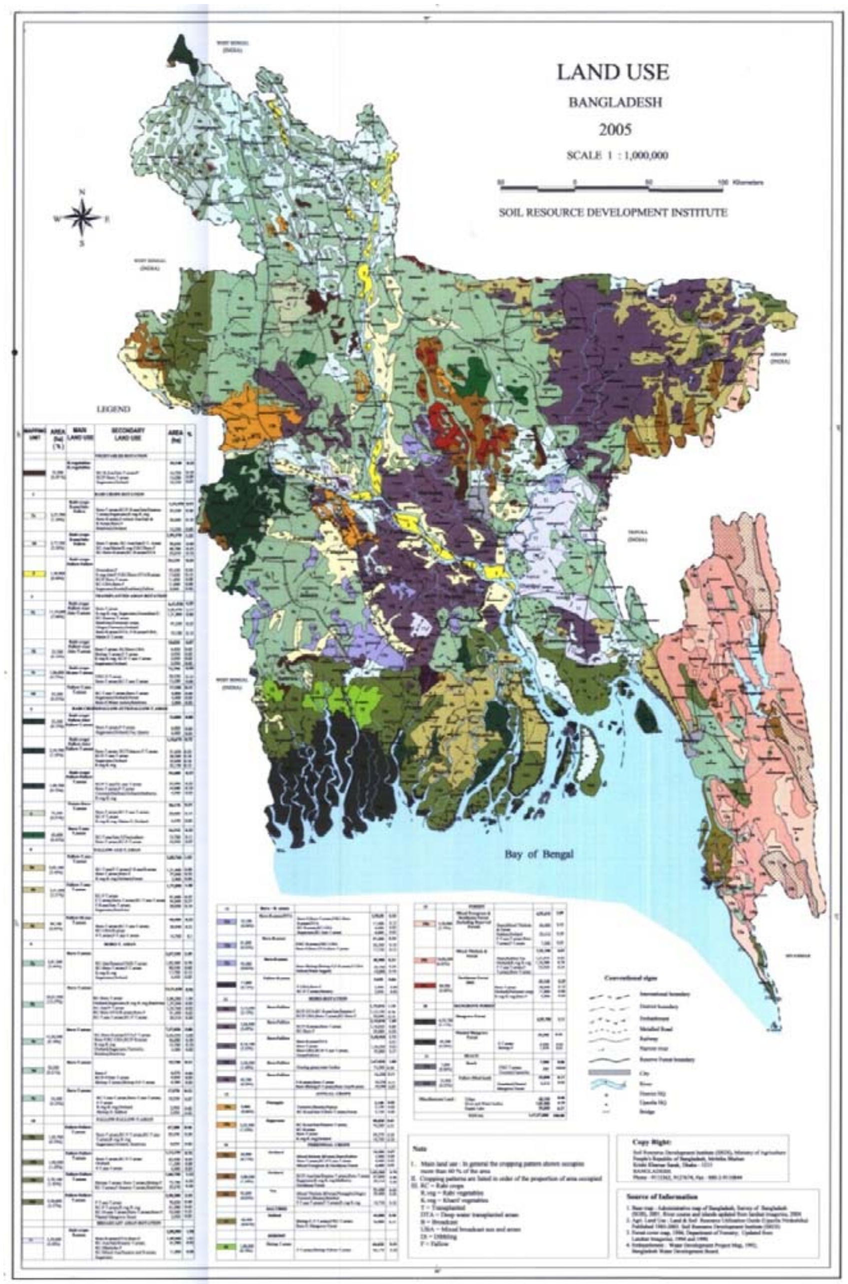


Figure 3.6: SRDI Land use map of Bangladesh

In the study area, main crops are rice-paddy, wheat, potato, onion, oilseeds and variety of vegetables and they grow in rain fed and irrigated condition. Boro, Wheat, potato, oilseeds and winter vegetables are the main Rabi (November to March) crops, while Kharif-I (April to June) crops are HYV Aus, summer vegetables and Kharif-II (July to October) grow HYV Aman and rainy season vegetables. Sugarcane grows in very small scale. Nowadays some fruit trees are also growing. Figure 3.7 shows the land use pattern of the study area:

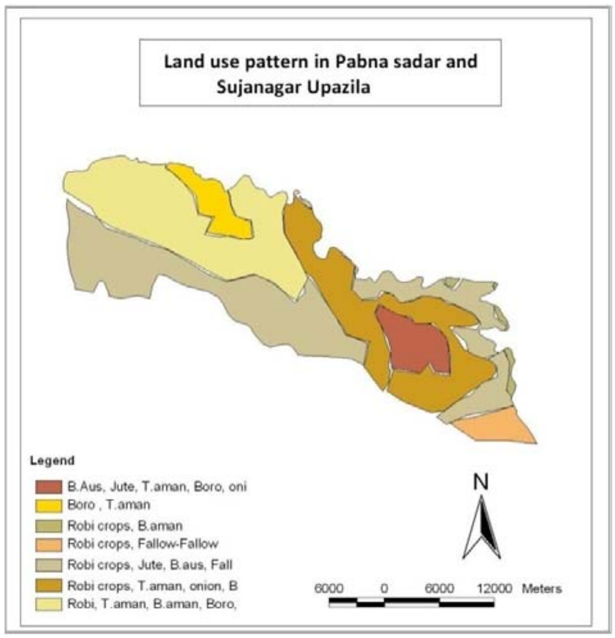


Figure 3.7: Land use pattern of the Study area

The area is facing several problems that include:

- The study area suffers frequent crop losses due to occurrence of drought not only in dry season, but also in Kharif season.
- Presently irrigation is solely dependent on groundwater without having its proper assessment of annual recharge and consequences, of continuing trend of expansion, on safe yield, drinking water supply, and effect on river flows during dry period and on the wider environments including fish resources. Moreover groundwater irrigation is expensive compared to surface water irrigation.
- Existing Khals and drainage channels inside the study area are being silted up causing drainage congestion from local rainfall and upstream runoff. Drainage

congestion mainly occurs around Gaznar Beel area. The situation gets aggravated if water level in the Jamuna remains high and will further be aggravated if surface water system is developed without investigating the drainage and irrigation system in an integrated way.

- The drainage capacity of the Badai River including its branches has been extensively reduced by sedimentation, took place over the several decades. The anthropogenic intervention to the natural drainage system like small khals and channels including Badai River itself also exaggerate this congestion problem.
- Drainage congestion is observed in many places which impedes agricultural production and deteriorates socio-economic as well as environmental condition.
- Insufficient water in dry season irrigation, farming and household uses. As a result, cultivation in about 7,900 ha area is extensively hampered causing deterioration of socio-economic and environmental condition;
- Fisheries resources have been reduced and migration of fishes is restricted due to sedimentation and embankment.
- Available water in the rivers could not be utilized to irrigate high areas for non-availability of storage reservoir and require large pumping plant with second lift.
- Inadequate power supply is another problem for the smooth operation of DTWs.

CHAPTER FOUR
METHODOLOGY AND DATA PROCESSING

4.1 Introduction

Different methodologies have been used to find out the drainage condition, irrigation requirements, abstraction and recharge of the study area. Drainage condition based on the flood mapping and flood depth calculation is the output of mathematical modeling resulting from the availability and quality of data, hydrological understanding. And the irrigation requirements, abstraction are the combined output of various available data like agricultural practice, population, geology, weather condition and so on. The water table fluctuation method has been used to estimate the annual recharge rate of some ground water wells which directly contribute to the recharge of the study area. This chapter contains these different methodologies and available data processing.

4.2 Development of Mathematical Modelling

It is evident that the irrigation system that would be proposed and the existing drainage system in the study are interlinked with various hydrological, hydraulic and environmental aspects both inside and outside the study area. An optimum solution to the problems can only be achieved through a detailed and integrated study of the entire systems. The impacts of the study and the interdependency of the irrigation and the drainage network and associated structures are too complex for traditional methods of analysis. Such a study can only be carried out realistically by a well calibrated mathematical model of the flow systems (irrigation and drainage) in the area. Figure 4.1 outlines the sequence of mathematical modelling study.

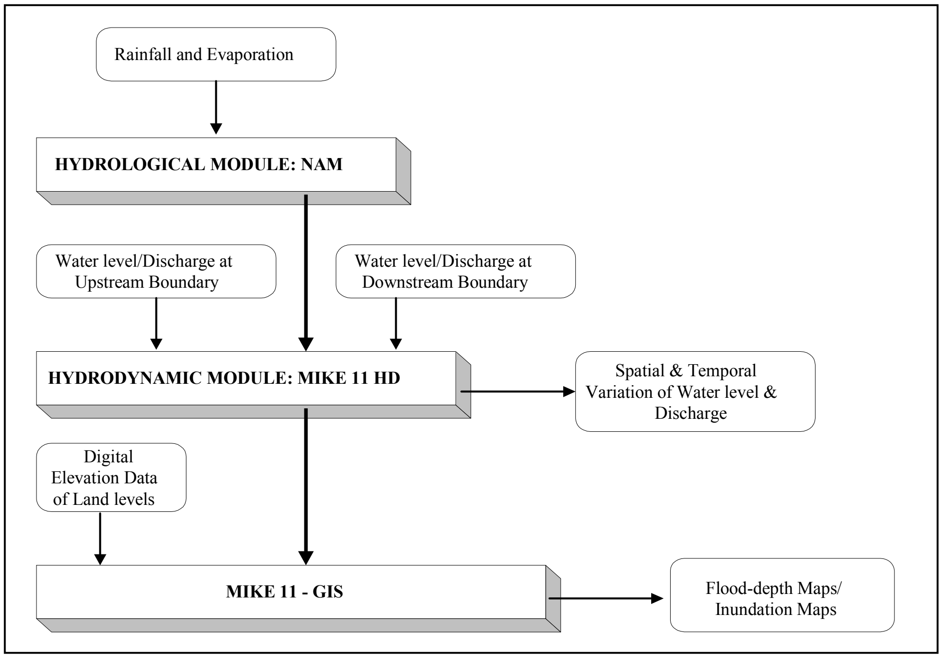


Figure 4.1: Sequence of Mathematical Modelling

4.3 Data Collection and Processing

Data collection and processing are required to understand the physical characteristics of the area and development of model. Major portion of the historical hydrometric data has been taken from the central database of IWM.The data used in this study was checked for quality and consistency and then processed in the required format of the model. In addition to the data quality checking, data analysis has also been carried out for estimation of different model parameters. For the model development using MIKE 11, the following data were required:

4.3.1 Rainfall and Evaporation data

Six BWDB rainfall stations (Table 4.1) have influenced the study area. Daily data was collected for the year 1980 to 2009. Missing data are filled up by taking average of the surrounding stations data. It is assumed that the normal rainfalls of surrounding stations are within 10 to 12% of that concerned station (Subramanya, 2003). Quality checking of rainfall data includes visual inspection of plots, estimation of yearly mean values, and comparison of monthly values. The available rainfall stations in the study area and their data availablity are shown in table 4.1.

Table 4.1: BWDB rainfall stations

Sl. No.	Station Name	Data Type	Station ID	Data Availability
1	Atgharia	Daily	R 001	1980-2009
2	Banwaripara		R 012	1980-2009
3	Bera		R 004	1980-2009
4	Pabna		R 025	1980-2009
5	Sujanagar		R 038	1980-2009
6	Daulatpur		R 010	1986-2009

BWDB maintains only one evaporation station in the study area i.e. Pabna station (Table 4.2). It has been seen that there is relatively little variation of evapotranspiration between the study area and outside the study area. It is due to the fact that important parameters such as temperature and sunshine hours are largely similar across the area. As such, data from this one station has been used for the whole study area. Pan coefficient of 0.7 has been used to calculate open water evaporation from pan evaporation data of the station. Evaporation values outside the range of 2.0-7.0 mm have been rejected.

Table 4.2: BWDB Evaporation data

Station Name	**Data availability**
Pabna sadar	1970-2009

4.3.2 Water level and Discharge

Discharge data used for model inflow boundary and water level data used for outflow boundary of study area. Bahadurabad and Hardinge Bridge are the major inflow boundary as BWDB regular measurement and observation gauge are installed there. The installed discharge and water level stations and their data availability are shown in the table 4.3.

Table 4.3: BWDB Discharge and Water level stations

Sl. No.	Station Name	Ownership	Data Availability		Remarks
1	Sirajganj	BWDB	1964-1999	Daily	Discharge
			1993-2008	Hourly	
2	Hardinge Bridge		1963-1998	Daily	Discharge
			1991-2008	Hourly	
3	Gorai		1945-1996	Daily	Water Level
			1990-2008	Hourly	
4	Aricha		1964-2000	Daily	Water Level
			1990-2008	Hourly	

4.3.3 NAM Development

Maximum part of the study area is located at catchment NW-40 of NWRM of BWDB catchment delineation. Small southern part of Sujanagar upazilla is outside the catchment. As our study area is small compared to the catchment NW-40, new catchment delineation is necessary for small rivers and khals which is actively contributed to the drainage and irrigation system of the study area.

4.3.3.1 Avswat-X for assessment of catchment contribution

As a part of the study area (full Sujanagar upazilla and half part of Pabna upazilla) is surrounded by the embankment, so, there is no flow contribution within the area rather than rainfall contribution. So catchment delineation is a significant factor in this regard. Catchment contribution to a specific river/khal is very important for accurate calculation of rainfall runoff. Avswat-X is ArcView based software which delineates catchments in a small scale extent based on DEM (Digital Elevation Model) and river/khal data. DEM is updated by previous and new surveyed topographic data. Though our main concern is concentrated on Sujanagar and Pabna Sadar upazilla, some small area of Santhia and Bera upazilla is also included within it. Upstream part of Atrai River is within Santhia upazilla and eastern part of the study area is within the Bera upazilla. So, four upazillas have been selected for catchment delineation. Inlet and outlet of each river/khal has been selected on the basis of DEM and survey information. Around 87 catchments have been created by Avswat-X among which 47 were utilized for deliberating catchment contribution (Fig: 4.2). Catchment selection is done by the area of influence of a specific river/khal.

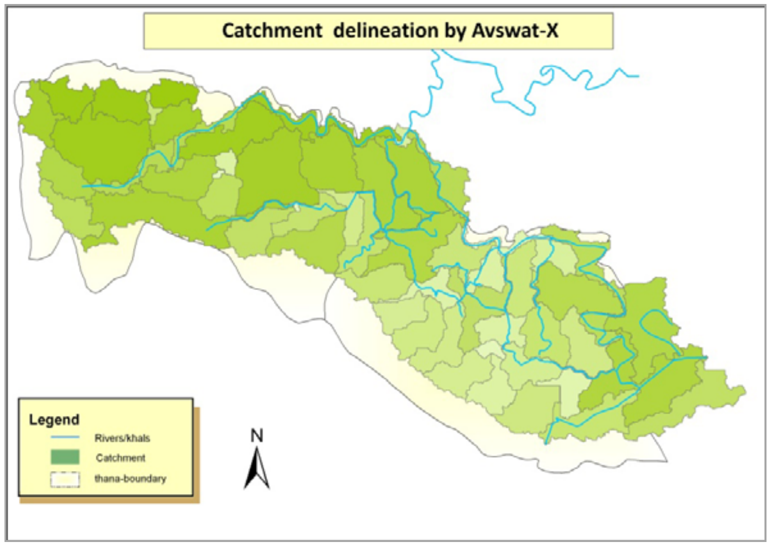


Figure 4.2: Catchment delineation by Avswat-X

4.3.3.2 Calculation of Influential Area of RF Stations

Rainfall stations represent only point sampling of the areal distribution. However, hydrological analysis requires knowledge of the rainfall over an area, such as over a catchment. To convert the point rainfall values at various stations into an average values over a catchment Thiessen-polygon method is applied. It is mentioned earlier that 6 rainfall stations are available in and around the study areas. To account for the spatial variation in rainfall, the time series data for each station has been assigned to Thiessen Polygon as shown in Figure 4.3.

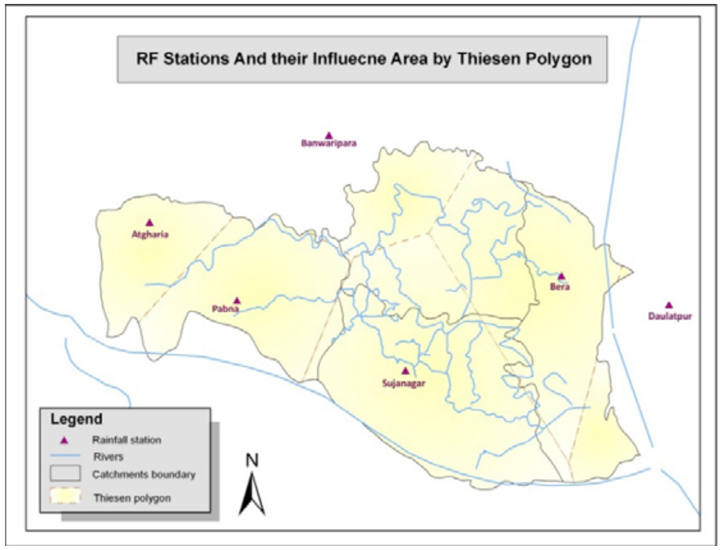


Figure 4.3: RF station and their influential area in the study area

4.3.4 HD Development

4.3.4.1 River Network and cross-section data

The river flow assessment model has been developed to assess the water availability in peripheral and internal rivers using MIKE-11 modelling system. The model comprised of the Jamuna, Ganges, Atrai, Badai and other significant river/khals of the study area. Surveyed cross-sections of river and khals of the study area have been incorporated.

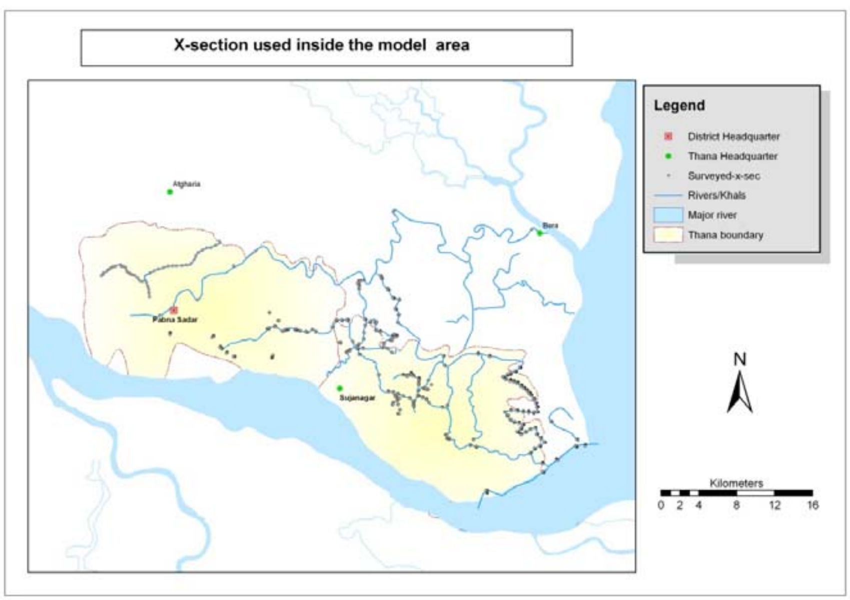


Figure 4.4: The river network and cross section of the study area

Table 4.4: Name, Length and No. of available cross-sections of the rivers in the study area

Sl. No.	River name	Total Length (km)	Surveyed Length (km)	Non-surveyed Length (km)	No. of cross-section surveyed
Main Rivers /*Khals*					
1	Badai River	57	12500	0	51
2	Atrai River	46	8500	0	22
Rivers/Khals					
6	Garka khal	9.8	9.8	0	13
7	Barnai-1	4.8	4.8	0	6
8	Barnai-2	2.5	2.5	0	7
9	Barnai-3	5.8	5.8	0	3
10	Branch9	3	3	0	7
11	Bodhonkhali	4.8	4.8	0	11
12	Gaznar khla	5	2.5	2.5	5
13	Branch of Gaznar khal	0.6	0.6	0	3
14	Branch6	4.8	0.3	4.5	3
15	Zia khal	12	0.4	11.6	1
16	Khanpura khal	7.6	3.9	3.7	2

4.3.4.2 Boundary Condition

Two upstream boundaries were selected, one at Hardinge Bridge and Bahadurabad (both WL and Q stations). Hardinge Bridge is located 35km downstream of Ganges River and Bahadurabad is located 84.5km downstream of Jamuna river from upstream point of Bangladesh border. Time-series rated / observed flow will be used for model simulation. In downstream, the boundary is at Baruria on Padma River. Time-series observed water level will be used as boundary data.

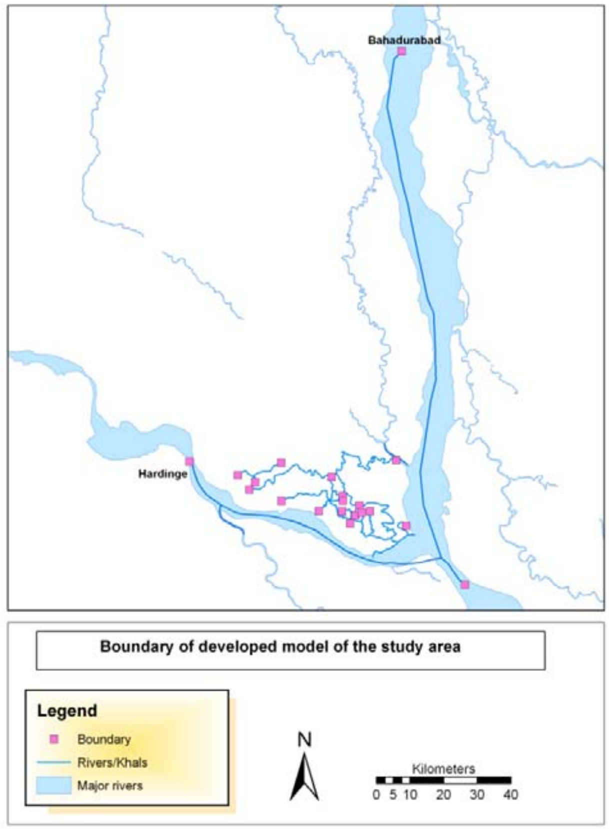


Figure 4.5: Boundary used in HD model

4.3.5 River Flow Model

Hydrodynamic Model routes the channel and floodplain flows and includes storage computation in flood cells. The primary inputs in the model are bathymetry of routing channels, topography of floodplains and flood cells, information of infrastructures, local catchments runoff (Output of Rainfall-Runoff Model) and peripheral water mass that enters into or leave the system. The key parameter, that highly influence the routing, is resistance arisen from channel surfaces which can be incorporated in the model through Manning's M /n or Chezy's C. The performance of the hydrodynamic model is evaluated through comparison of simulated outputs with measured events (usually water level, velocity and discharge) at different points within the river network wherever observation is available.

4.3.5.1 Development of Drainage River Flow Model

The drainage model would be developed to device solution of the existing drainage congestion as well as likely effect of proposed irrigation network on drainage system. The main drainage model would be developed for the entire drainage system of present study area using the updated cross-sections and drainage catchments to be obtained from the updated survey data. Drainage catchments would be delineated from the updated topographic survey data. The model would be calibrated against water level and discharge for the monsoon period as that of the flow assessment model. This model would be specifically used to identify the drainage congested area under the existing and future condition; drainage problematic areas to be identified, based on modelling results, would also be verified through field visits or from the satellite images.

4.3.6 Flood Mapping and Impact Assessment

Flood maps have been generated with the model results for different years (2001-2009). MIKE 11 GIS facilities with land level data from Digital Elevation Model (DEM) have been used to develop flood maps. Nine different flood maps have been developed to find out the flooding and drainage scenarios of these two low lying upazillas at the confluence of Padma and Ganges.

4.3.7 Flood Phase Calculation

To find out the percentage of area inundated flood phase calculation has been utilized. Flood phase calculation is an ArcView script developed in IWM. The main purpose of this script is to calculate the no. of grid (cell) that has been inundated. Depending on the flood depth IWM classified the flood in five classes that is F_0, F_1, F_2, F_3, and F_4. These flood phases is used by FFWC (Flood Forecasting and Warning Center) of Bangladesh Water Development Board for their daily flood bulletin during monsoon. Finally the no. of grid is multiplied by the size of each grid to find out the area inundated.

Phase	Flood depth(mm)
F_0	0-300
F_1	300-900
F_2	900-1800
F_3	1800-3600
F_4	>3600

4.4 Crop water Requirement Calculations by CROPWAT 8.0

Evapotranspiration and effective rainfall of the study area have been estimated by analyzing 30 years average weather data (Temperature, Wind speed, Humidity and Sunshine hours). Necessary information about crop and soil has to be incorporated to compute the crop water requirement (CWR) of the study area. Steps involved in determining the CWR are shown in figure 4.6:

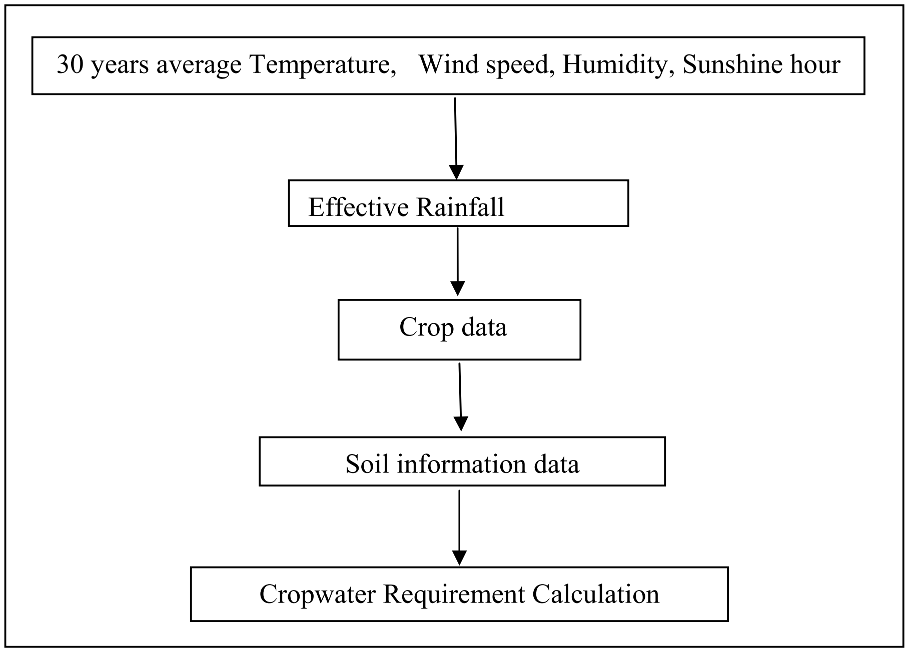


Figure 4.6: Sequence of Cropwat 8.0 (Windows version)

4.4.1 Field Irrigation Water Requirement

(http://www.fao.org/docrep/X0490E/X0490E00.htm)

Crop Water Requirement (CWR) is the potential evapotranspiration of a reference crop (ET_0) multiplied by the crop coefficient (Kc). It is the requirement of a crop for its full development without any water stress condition.

Crop water requirement is important factor for calculating total amount of water to be abstracted for irrigation. If required quantity of water is supplied to the crop at right time corresponding to the stages crop growth, maximum crop production will be achieved. Field Irrigation Water Requirement (FIWR) of a given crop $FIWR_i$ is calculated by subtracting effective rainfall from the sum of FIWR and percolation rate as shown below:

$$FIWR_i = \sum_{t=0}^{T} \left(Kc_i \cdot ET_{0_i} + P - R_{eff} \right)$$

Where, Kc - Crop coefficient; ET_0 - Potential evapotranspiration (mm/day);
P – Percolation (mm/day); R_{eff} – effective rainfall (mm/day).

FIWR is the net irrigation requirement that normally represents as depth unit (mm), while Scheme Irrigation Water Requirement (SIWR) is the gross irrigation requirement represents as volume or flow rate (l/s) at source of supply. SIWR is calculated from FIWR by dividing with the overall irrigation efficiency.

Field Irrigation Water Requirement (FIWR) and unit Scheme Irrigation Water Requirement (SIWR) have been computed using CROPWAT, (FAO, 1992) version 8 considering following assumptions:

- Percolation loss during dry period 5.0 mm/day (details are given Chapter 3)
- Percolation loss during wet period 3.0 mm/day
- Water requirement for land preparation for dry period is 180 mm
- Water requirement for land preparation for wet period is 100 mm
- Conveyance loss is 10% as the scheme is fed by tube well, canals are lined and small.

FIWR and SIWR have been computed for consideration of existing mixed mode of cropping. Crop water requirement is very important factor to know the total amount of water to be abstracted for irrigation. If actual water requirement of crop is supplied to the crop at right time corresponding to the stage of development the production will be maximum.

Crop water requirement depends on several factors. Some of those-

- Potential Evapotranspiration,
- Rainfall,
- Percolation,
- Land use,
- Cropping pattern,
- Soil type etc.

4.4.1.1 Rainfall

For the calculation of effective rainfall an average value of rainfall should be needed. Most of the cases a long period of rainfall of the study area have to be analyzed. In this study an average value 30 years rainfall has taken. Based on 30 years available data of IWM, average rainfall has been estimated (Data source: BWDB). Average maximum, minimum and mean of rainfall data of different stations are presented in Figure 4.7 to Figure 4.8.

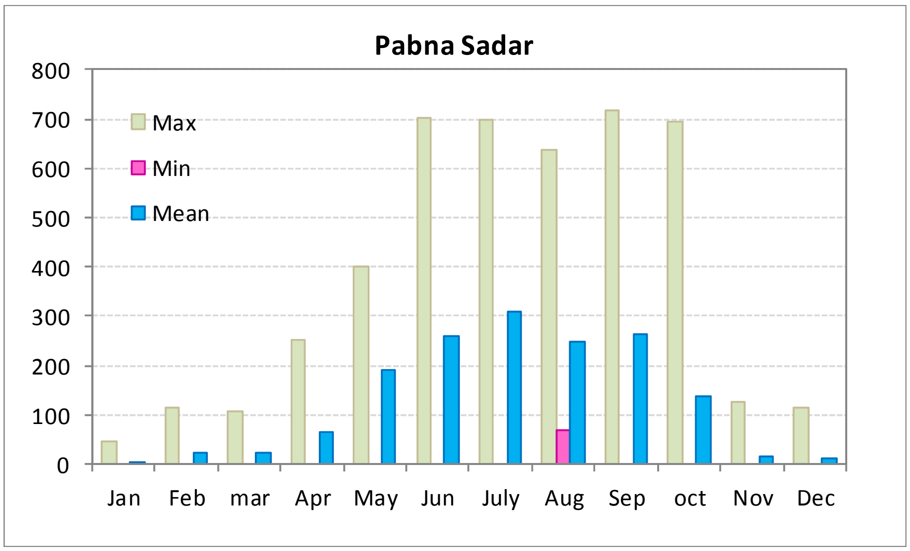


Figure 4.7: 30 years average maximum, minimum, mean RF of Pabna sadar

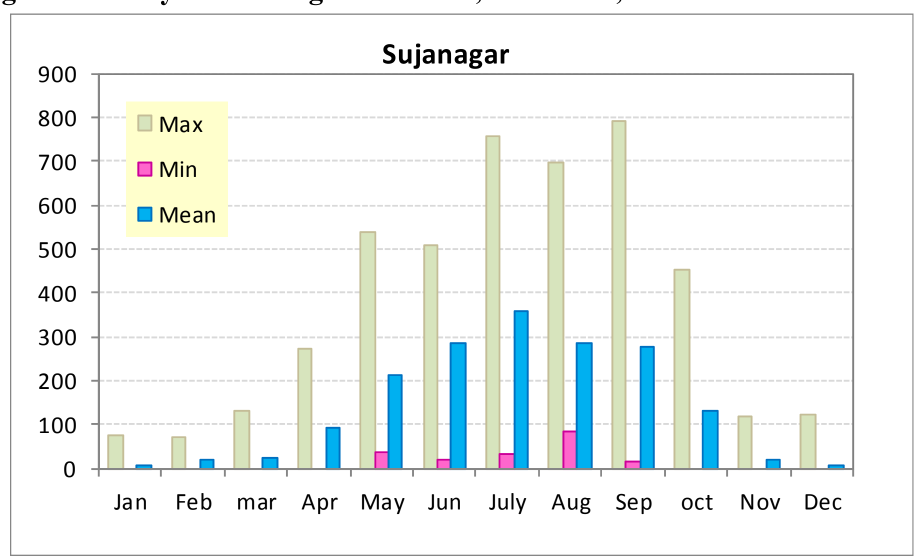


Figure 4.8: 30 years average maximum, minimum, mean RF of Sujanagar

4.4.1.2 Effective Rainfall (R_{eff})

This is an important parameter for estimation of CWR. Effective rainfall is the portion of the rain that effectively stored in root zone. The method of computing effective rainfall as per United States Department of Agriculture (USDA), by this CROPWAT 8.0 is given as;

$$R_{eff} = R_{mean}(125 - 0.2*R_{mean})/125 \quad \text{when } R_{mean} < 250 \text{ mm/month} \quad \ldots\ldots\ldots(2)$$

$$R_{eff} = 125 + 0.1*R_{mean} \quad \text{when } R_{mean} > 250 \text{ mm/month} \quad \ldots\ldots\ldots(3)$$

In the study equation no (2) is used at CROPWAT 8.0 for effective rainfall calculation (Table 4.5). R_{eff}

Table 4.5: Effective rainfall calculation by CROPWAT 8.0 for the study area

Month	Rainfall (30 years average)		Effective Rain-fall(Pabna)	Effective Rain-fall(Sujanagar)
	Pabna	Sujanagar		
Jan	7.13	7.19	7.00	7.1
Feb	24.98	22.84	24.00	22
mar	26.32	29.22	25.20	27.8
Apr	70.74	91.84	62.70	78.3
May	193.26	227.42	133.10	144.7
Jun	267.71	297.00	151.30	154.7
July	314.12	368.84	156.50	161.9
Aug	241.06	279.73	147.30	153
Sep	292.27	312.00	153.30	155.8
oct	148.67	135.65	110.70	108.8
Nov	16.68	22.71	15.70	22.6
Dec	11.58	9.18	11.00	9.4

4.4.1.3 ET_0Estimation

Potential Evapotranspiration (ET_0) depends on four factors namely-

- Temperature
- Relative Humidity,
- Wind Speed,
- Daily Sunshine Hours

These four factors have been analyzed on the basis of the 30 years weather data. Data was collected from the website www.wunderground.com. These available data have been downloaded and processed to get the 30 years average value of these four factors.

Table 4.6: 30 years average Meteorological data and ET_0 estimation of Pabna Sadar

Month	Mean Daily Temperature ^oC	Relative humidity (%)	Wind speed (km/day)	Sunshine hours	ET_O mm/day	Remarks
January	18.24	73.41	55.02	7.49	2.24	Minimum
February	21.02	61.67	66.23	8.05	2.99	
March	25.82	67.34	105.19	8.27	4.22	
April	29.09	66.01	173.70	8.21	5.43	
May	29.40	75.15	181.18	7.18	5.1	Maximum
June	29.30	82.84	167.70	4.89	4.15	
July	28.86	85.57	154.52	4.03	3.7	
August	28.97	84.85	136.50	4.63	3.78	
September	28.86	105.92	105.56	5.04	3.26	
October	27.50	80.39	62.02	7.19	3.55	
November	23.71	75.76	49.15	7.82	2.87	
December	19.57	74.89	49.97	7.70	2.29	

(Source: www.wunderground.com.)

Table 4.7: 30 years average Meteorological data and ET_0 estimation of Sujanagar upazilla

Month	Mean Daily Temperature ^oC	Relative humidity (%)	Wind speed (km/day)	Sunshine hours	ET_O mm/day	Remarks
January	18.31	73.61	54.30	7.44	2.24	Minimum
February	21.11	62.81	65.91	7.99	2.96	
March	25.84	67.81	105.47	8.18	4.22	
April	28.94	67.40	172.95	8.12	5.4	
May	29.24	76.00	176.50	7.08	5.04	Maximum
June	29.20	83.23	164.79	4.81	4.13	
July	28.80	85.68	152.64	4.02	3.74	
August	28.93	84.93	134.89	4.62	3.8	
September	28.82	104.27	104.34	5.01	3.59	
October	27.53	80.55	61.81	7.14	3.55	
November	23.77	76.00	48.77	7.76	2.89	
December	19.64	75.18	48.26	7.66	2.3	

(Source: www.wunderground.com.)

4.4.1.4 Crop Coefficient (Kc)

There is an influence of the crop type and growth stage on crop water needs. The relationship between the reference grass crop and the crop actually grown is given by the **crop co-efficient,** Kc, as shown in the following formula:

ETo × Kc = ET crop

with ET crop = crop evapotranspiration or crop water need (mm/day)

Kc = crop co-efficient

ETo = reference evapotranspiration (mm/day)

Both ET crop and ETo are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month.

The crop factor, Kc, mainly depends on:

- the type of crop
- the growth stage of the crop
- the climate

Kc and the type of crop

Fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop: Kc, maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop: Kc, cucumber is less than 1.

Kc and the growth stage of the crop

A certain crop will use more water once it is fully developed, compared to a crop which has just recently been planted.

Kc and the climate

The climate influences the duration of the total growing period and the various growth stages. In a cool climate a certain crop will grow slower than in a warm climate.
Thus, to determine the crop co-efficient Kc, it is necessary, for each crop, to know the total length of the growing season and the lengths of the various growth stages.

Per crop, four crop co-efficient have to be determined: one crop factor for each of the four growth stages. (http://www.fao.org/docrep/S2022E/s2022e07.htm)

Example of crop coefficients of Different crops for different growth stages and growth period are given in Table 4.8 and 4.9.

Table 4.8: Crop co-efficient for different crops

Stage	Onion		Wheat		Vegetable		Mustered		Potato	
	Length (days)	Crop Co-efficient(Kc)	Length (days)	Crop Co-efficient(Kc)	Length (days)	Crop Co-efficient(Kc)	Length (days)	Crop Co-efficient(Kc)	Length (days)	Crop Co-efficient(Kc)
Initial (A)	25	0.5	30	0.3	20	0.7	15	0.4	25	0.5
Development (B)	30	0.5	30	0.3	30	0.7	15	0.4	30	0.5
Mid-season (C)	35	1.05	40	1.15	30	1.05	40	1.15	45	1.15
Late season (D)	15	0.85	30	0.3	15	0.95	15	0.5	30	0.75

However there are some crops that do not directly fit this model: their crop co- efficient Kc is determined in a different way. Paddy/Rice is such type of crop which needs another two stages: 1) Nursery, 2) Land Preparation. The crop co-efficient of rice is given at table 4.9.

Table 4.9: Crop co-efficient for Rice

Stage	Boro		T. Aus	
	Length (days)	Crop Coefficient	Length (days)	Crop Coefficient
Nursery	25	1.1	20	1.1
Land preparation	20	1.1	10	1.1
Initial (A)	15	1.1	30	1.1
Development (B)	25	1.2	30	1.35
Mid-season (C)	35	1.2	30	1.35
Late season (D)	20	1.2	10	1.35
Total	140		130	
Nursery area	10%		10%	
Land Preparation by puddling	180 mm (for a period of 20 days)		180 mm (for a period of 20 days)	
Percolation and Seepage loss	5 mm/day		5 mm/day	

4.4.1.5 Round the year Cropping Patter

The present cropping practice in the study area is mixed mode. Table 4.10 and 4.11 shows the percentage of area under each crop. FIWR and SIWR have been computed for the mixed crop. From the recent field survey conducted by IWM has been recommend that at Pabna sadar and Sujanagar upazilla Boro and Kharif-2 cultivation is being practiced.

The irrigation water requirement of the study area has been calculated considering round the year irrigation for Mixed Cropping Pattern cultivation in Rabi, Kharif-I and Kharif-II seasons. Boro, Aus and Aman cultivation is being practiced in the study area during Rabi, Kharif-I and Kharif-II seasons respectively. From the field survey conducted by IWM it is found that at Sujanagar upazilla two seasonal crops Rabi and kharif-2 are cultivated. For Rabi crops percentage of area under each crop is same as Pabna sadar. It differs for kharif-2 season as major beel Gaznar is inundated during monsoon due to monsoon flood. The total irrigable land for Pabna sadar is 23220 ha and for Sujanagar is 21505 ha. Percentage of area of cultivation under each crop for Boro and kharif-2 at decadal basis of the study area are shown in Appendix B and Appendix C.

Table 4.10: Cropping pattern for Pabna Sadar upazilla

Sl No.	Crop type	Area under each crop	% of area under each crop
1	T.Aman	2500	10.77
2	HYV Boro	2280	9.82
3	T. Aush	1325	5.25
4	Onion	4534	17.98
5	Mustered	1072	4.25
6	Wheat	9463	37.52
7	Rabi Vegetables	935	3.71
8	Potato	1072	4.25
9	Summer vegetables	39	0.15

Table 4.11: Cropping pattern for Sujanagar upazilla

Sl No.	Crop type	Area under each crop	% of area under each crop
1	T.Aman	3750	17.44
2	HYV Boro	5050	23.48
3	Onion	7500	34.88
4	Mustered	1072	4.98
5	Wheat	2960	13.76
6	Rabi Vegetables	539	2.51
7	Potato	95	0.44
8	Summer vegetables	539	2.51

4.4.2 Total Present Irrigation Water Requirement for the Study Area

The total irrigation water requirement for the present condition for the entire area depends mainly on the cropping pattern, type of crop, growing season of the crop and crop water requirement and area under each crop. Cropping pattern for the present situation is obtained from the field investigation and secondary sources which is shown in Table 4.10 and 4.11. However, the crops that require significant amount of irrigation and/or have large crop coverage are considered for the present water requirement estimation. CROPWAT 8.00 gives Net Irrigation Requirement (NIR) per decade. These NIR is converted to daily irrigation requirement, and then Monthly irrigation requirement is calculated simply multiplying the daily requirement by the number days in the months. The irrigation requirement for the entire growing season of each crop is calculated by summing up the monthly requirements. The volume of water requirement of each crop is obtained by multiplying the seasonal irrigation requirement by the crop coverage. Crop coverage under each crop for entire area is estimated from the Upazilla wise area weighted average crop coverage. Finally total irrigation water requirement for the entire study area is obtained by summing up the water requirement of all the crops and depth of water requirement is calculated by dividing volume of water by the total cultivable area of the study. The crop wise water requirement for the study area is shown in Appendix B and Appendix C.

4.5 Domestic and Municipal Water Requirement

In Bangladesh, about 97% of total potable water is met up from groundwater sources. It is understood from the field survey that domestic and municipal water source of the study area is solely groundwater based. Therefore, assessment of domestic and municipal water requirement is important to see the abstraction effect on groundwater table.

Estimation of the present population and projected population is necessary for assessing the present and future domestic and municipal water demand. The Per Capita water demand is the annual average water consumption of one person daily. Thus average daily demand over a year means the annual average daily demand. The total quantity of water required by the community can be computed using the following equation.

$$Q = P \times q$$

Where, Q is the present or projected quantity of water required by the community per day, P is the present or projected population and q is the rate of water consumption per capita per day.

4.5.1 Population Assessment

In Bangladesh, the population census is carried out in ten years interval. Last population was enumerated in the year 2001 and published by the BBS which is the only sources of population data. The average population growth rate as stated in the CIA website is 1.58% (www.cia.gov/library/publications/the-world-factbook/geos/bg.html). From the 2001 population data, projected population for the year 2002-2009 is estimated.

Table 4.12: From BBS Population for this two upazilla

Thana Name	Male	Female	Total
Pabna Sadar	247,601	229,331	476932
Sujanagar	130,757	120,435	251192

In our study area there is a portion of urban area in Pabna Sadar upazilla i.e some water supply system as well as industrial and commercial demand have within the Upazilla , but the water supply system of whole Sujanagar upazilla is nature depended i.e this upazilla is considered as rural areas.

Table 4.13: The rural people of Pabna Sadar upazilla

Upazilla Name	In Urban area	In Rural area	Total
Pabna Sadar	95360	381572	476932

The projected population is estimated by the Geometric Progression method (Ahmed et al, 2003):

$$P_p = P_b(1+r)^n$$

Where P_p = projected population in the year n

P_b = Base population

r = rate of natural increase of population per year

n = number of years being considered.

The calculated projected population in rural and urban areas of the study area is given in the Appendix D.

4.5.2 Computation of Domestic and Municipal Water Requirement

The unit of domestic and municipal water demand is usually expressed as liters per capita per day (lpcd). Several factors influence the per capita water demand such as:

- Size of the town and coverage with piped water supply and sewerage facilities,
- Accessibility of water and quality of services as well as the standard of living of the consumers,
- Climatic conditions of the area,
- Income and affordability of the consumer and habitats of the people
- Quality and quantity of water supplied,
- Development of sewerage system, types of sanitary latrine and flushing system of the latrine,
- Water supply pattern-whether the supply is continuous or intermittent
- Wastage and system losses- leakage in the distribution system

According to the NWMP report, per capita gross water demand for municipal town and rural areas are 166 lpcd and 30 lpcd respectively. The gross water demand of municipal town includes 119 lpcd net domestic water demand, 20% of it as a system loss, 10% as gross commercial demand and 15% as industrial demand. On the other hand it has 50%

returned flow from the commercial demand and 75% returned flow, thus the net water demand for municipal town becomes 76 lpcd. The gross water demand for rural areas doesn't include any loss and commercial and industrial demand. Thus the net water demand for rural areas is same as the gross water demand.

Upazilla wise projected population and year wise water demand for rural areas is given in Table 4.14 and projected population along with water for municipal town under the study area is given in Table 4.15.

Table 4.14: Domestic Water Demand of Rural areas for two Upazilla

Year	Future Population (P_p)		Dmomestic Water Demand			
			(l/c/day)		(m3/day)	
	Pabna	Sujanagar	Pabna	Sujanagar	Pabna	Sujanagar
2001	381572	251192	11447160.00	7535760.00	11447.16	7535.76
2002	387601	255161	11628025.13	7654825.01	11628.03	7654.83
2003	393725	259192	11811747.93	7775771.24	11811.75	7775.77
2004	399946	263288	11998373.54	7898628.43	11998.37	7898.63
2005	406265	267448	12187947.84	8023426.76	12187.95	8023.43
2006	412684	271673	12380517.42	8150196.90	12380.52	8150.20
2007	419204	275966	12576129.60	8278970.01	12576.13	8278.97
2008	425828	280326	12774832.44	8409777.74	12774.83	8409.78
2009	432556	284755	12976674.80	8542652.23	12976.67	8542.65

Table 4.15: Municipal Water Demand of Urban areas for Pabna Sadar Upazilla

Year	Future Population (Pp)	Water Demand			
		(l/c/day)			(m3/day)
		Gross	Returned	Net Demand	Net demand
2001	95360	15829760.00	8582400.00	7247360.00	7247.36
2002	96867	16079870.21	8718001.92	7361868.29	7361.87
2003	98397	16333932.16	8855746.35	7478185.81	7478.19
2004	99952	16592008.29	8995667.14	7596341.14	7596.34
2005	101531	16854162.02	9137798.68	7716363.33	7716.36
2006	103135	17120457.78	9282175.90	7838281.87	7838.28
2007	104765	17390961.01	9428834.28	7962126.73	7962.13
2008	106420	17665738.19	9577809.86	8087928.33	8087.93
2009	108102	17944856.86	9729139.26	8215717.60	8215.72

4.6 Abstraction

4.6.1 Different Irrigation facilities

Irrigation in study area is provided by different methods. According to BBS various methods of irrigation facilities provided both in Pabna and Sujanagar upazilla is shown in Tabulated form in table 4.16 and table 4.17:

Table 4.16: Different Irrigation methods provided at Pabna Sadar Upazilla

SL no	Name of method (Items)	No of Items	Irrigated area(Acre)
1	Deep Tube Well (DTW)	358	25933
2	Shallow Tube Well (STW)	855	27244
3	Low Lift Pump (LLP)	232	2696

Table 4.17: Different Irrigation methods provided at Sujanagar Upazilla

SL no	Name of method (Items)	No of Items	Irrigated area(Acre)
1	Deep Tube Well (DTW)	13	2720
2	Shallow Tube Well (STW)	2277	48060
3	Low Lift Pump (LLP)	42	440

4.6.2 Running Time

The time of an Irrigation facilities means the total running hour that it supply service throughout the season or the year. In our study we consider the whole year for abstraction calculation as it gives the overall and actual view of water balance condition of the two upazillas. Various irrigation facilities are used at various durations in different upazillas. But for simplicity of calculation we consider same duration for same facilities. The actual scenario will be little bit different than that used. Here a tabulated form which describe the total running hour of the different facilities used in these two upazilla is given in table 4.18.

Table 4.18: Running Time for calculation of Abstraction

Month	Daily Running Time			Monthly Running Time		
	DTW	**STW**	**LLP**	**DTW**	**STW**	**LLP**
Dec	6	4	5	186	124	155
Jan	8	6	6	248	186	186
Feb	6	4	4	168	112	112
Mar	6	6	5	186	186	155
Apr	3	3	2	90	90	60
May				0	0	0
Jnue						
July	6	5	3	186	155	93
Total				1064~ 1000	853~ 800	761~ 700

4.6.3 Abstraction due to Irrigation water demand

Irrigation in study area is provided either by DTWs or STWs or LLPs. Under the present situation, DTWs are of different capacities while STWs are mainly of same capacity. Most of the DTWs are of 2 cusec and some are of 1 cusec, STWs are of 1 cusec and LLPs are 0.3 cusec. Abstraction due to irrigation carried out for the year 2001 based on available data and the other remaining years (2002-2009) has been determined by utilizing the percentage at which the domestic and municipal water demand is increased. The Abstraction of two upazilla is given in table 4.19 and table 4.20.

Table 4.19: Present Abstraction (for irrigation) condition in Pabna sadar upazilla

Name Irrigation Facilities	No. of Irrigation Facilities	Irrigated Area in (acre)	Irrigated Area in ha.	Abstraction in m^3	**Abstraction** in mm/season	**Abstraction** in mm/month
Deep Tube Well (DTW)	358	25933	10499.19	60202175	301.77	60.34
Shallow Tube Well (STW)	855	27244	11029.96	52283250		
Low Lift Pump (LLP)	232	2696	1091.50	3724035		

Table 4.20: Present Abstraction (for irrigation) condition in Sujanagar upazilla

Name Irrigation Facilities	No. Irrigation Facilities	Irrigated Area in (acre)	Irrigated Area in ha.	Abstraction in m^3	**Abstraction** in mm/season	**Abstraction** in mm/month
Deep Tube Well (DTW)	13	2720	1101.21	2186112.50	380.45	76.09
Shallow Tube Well (STW)	2277	48060	19457.49	139238550.00		
Low Lift Pump (LLP)	42	440	178.14	674178.75		

4.6.4 Abstraction due to Domestic and Municipal water demand

Abstraction due to domestic and Municipal requirement is calculated by per capita consumption of present and future population condition which is done in the water demand calculation at para 4.5.2. Total abstraction due to domestic and municipal water demand is given in table 4.21 and table 4.22.

Table 4.21: Total Abstraction in Pabna Sadar Upazilla

Year	Yearly Irrigation Water Requirement		Domestic and MW Water Requirement			Total	Total
	mm/ha	Mm^3	m^3/day	mm/ha	Mm^3	mm/ha	Mm^3
2001	319.49	177.46	18694.52	17.72	6.82	337.21	184.29
2002	324.54	179.93	18989.89	18.00	6.93	342.54	186.86
2003	329.67	182.91	19289.93	18.28	7.04	347.95	189.95
2004	334.88	190.07	19594.71	18.57	7.15	353.45	197.23
2005	340.17	197.86	19904.31	18.87	7.27	359.03	205.13
2006	345.54	206.28	20218.80	19.16	7.38	364.71	213.66
2007	351.00	215.76	20538.26	19.47	7.50	370.47	223.26
2008	356.55	224.49	20862.76	19.77	7.61	376.32	232.10
2009	362.18	249.43	21192.39	20.09	7.74	382.27	257.17

Table 4.22: Total Abstraction in Sujanagar Upazilla

Year	Yearly Irrigation Water Requirement		Domestic and MW Water Requirement			Total	Total
	mm/ha	Mm^3	m^3/day	mm/ha	Mm^3	mm/ha	Mm^3
2001	387.82	152.79	7535.76	7.36	2.75	395.18	155.54
2002	393.94	154.91	7654.83	7.48	2.79	401.42	157.71
2003	400.17	157.48	7775.77	7.60	2.84	407.77	160.32
2004	406.49	163.65	7898.63	7.72	2.88	414.21	166.53
2005	412.91	170.36	8023.43	7.84	2.93	420.75	173.28
2006	419.44	177.60	8150.20	7.96	2.97	427.40	180.58
2007	426.06	185.76	8278.97	8.09	3.02	434.16	188.79
2008	432.80	193.28	8409.78	8.22	3.07	441.02	196.35
2009	439.63	214.76	8542.65	8.35	3.12	447.98	217.87

4.7 Water-Table Fluctuation (WTF) Method

The water-table fluctuation (WTF) method provides an estimate of groundwater recharge by analysis of water-level fluctuations in observation wells. The method is based on the assumption that a rise in water-table elevation measured in shallow wells is caused by the addition of recharge across the water table.

Recharge by the WTF method is estimated as

$$R(t_j) = Sy^* DH(t_j)$$

Where, $R(t_j)$ (cm) is recharge occurring between times t_0 and t_j, Sy is specific yield (dimensionless), and $DH(t_j)$ is the peak water level rise attributed to the recharge period (cm).

Although simple in theory, some key assumptions and critical issues inherent in the WTF method have great bearing on its successful application: (1) the observed well hydrograph depicts only natural water-table fluctuations caused by groundwater recharge and discharge; (2) Sy is known and constant over the time period of the water-table fluctuations, and (3) the pre-recharge water-level recession can be extrapolated to determine $DH(t_j)$.

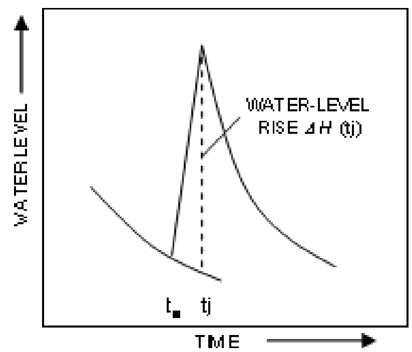
Application of the method WTM involves two steps:

- Estimating the water-level rise $DH(t_j)$
- Estimating specific yield Sy

Because of the simplicity of the method and wide availability of water-level hydrographs from observation wells, the WTF method has been used for many years (http://water.usgs.gov/ogw/gwrp/methods/wtf/).

4.7.1 Estimating the Water-Level Rise (*DH*(t_j))

The water-level rise *DH*(t_j) is estimated as the difference between the peak of a water-level rise and the value of the extrapolated antecedent recession curve at the time of the peak. The recession curve is the trace that the well hydrograph would have followed had there not been any recharge. Extrapolation of the recession curve is not always straightforward (http://water.usgs.gov/ogw/gwrp/methods/wtf/).



Determination of water-level rise.

4.7.2 Ground Water level Analysis

There are 14 ground water level (GWL) stations within the study area. 12 GWL stations are selected depending on the data availability. The station list is given at table 4.23.

Table 4.23: 12 GWL stations at Pabna sadar and Sujanagar upazilla

Upazilla Name	Union Name	GW Station
Pabna Sadar	Maligacha	PAB022
	Dapunia and Hemayetpur	PAB023
	Bharara	PAB024
	Sadullapur	PAB025
	Dogachi	PAB026
	Ataikula	PAB027
Sujanagar	Manikhat	PAB030
	Sujanagar	PAB031
	Hatkkhali	PAB032
	Dulai	PAB033
	Nazirganj	PAB034
	Satbaria	PAB035

GWL data from the year 2001 to 2009 has been analyzed. The maximum and minimum GWL value has been processed for each year as also for each station. The maximum and minimum value has been taken as the whole year maximum and minimum value for each station. Then each year maximum and minimum value of each upazilla has been found by averaging the maximum and minimum values of all 6 GW stations. The GWL rise thus has been calculated by subtracting these average max and average min GWL data. ALL data processing related to GWL has shown in Appendix E and F. As mentioned previous at chapter named 'methodology' by WTF method the Recharge have been calculated by using following method:

$$\text{Recharge} = \Delta l \text{ (GWL difference)} * Sy \text{(specific yield)}$$

The Specific Yield (Sy) of these two Upazilla is collected from (IWM, 2008). Here for example one GWL analyzed data (Maximum and Minimum) of Pabna Sadar upazilla named Bharara (PAB024) have been tabulated for beter understanding. Maximum and Minimum GWL data was extracting by processing whole the year GWL data.

4.7.3 Specific Yield

Laboratory test and field survey by IWM in a study (IWM, 2008) in collaboration with BWDB, WARPO, BMDA, DPHE' get the specific yield for the study area. Table 4.24 shows the specific yield of the study area.

Table 4.24: Specific yield of the study area

Upazilla name	Specific yield(Sy)
Pabna Sadar	0.08
Sujanagar	0.09

4.7.4 Recharge

After processing all stations maximum and minimum value only one data is taken by averaging all 6 stations value. Then rise of ground water level(Δl) is get by subtracting minimum value from the maximum value. Then ground water recharge is obtained by multiplying the Δl with the specific yield:

$$\text{Recharge} = \Delta l * Sy$$

The whole calculation procedure has been shown below for both Pabna Sadar and Sujanagar upazilla from table 4.25 to 4.30.

Table 4.25: Year wise Maximum value of all six stations GWL data of Pabna sadar upazilla

Station ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB22	6.85	7.9	8.6	7.4	7.56	7.64	7.54	8.31		8.25
PAB23	10.9	10.41	10.99	11.27	11.85	10.56	9.52	11.65	11.35	10.38
PAB24	11.7	11.71	11.62	11.67	11.62	8.78	8.99	11.91	11.07	10.85
PAB25	8.35	9.1	8.19	9.02	8.95	9.55	8.67	9.01		9.16
PAB26			5.72	5.58	5.09	4.48	5.81	5.56		5.55
PAB27	6.25	6.9	6.7	6.2	7.31	7.01	8.01	5.16	6.91	7.61

Table 4.26: Year wise Minimum value of all six stations GWL data of Pabna sadar upazilla

Station ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB22	0.35	1.1	0.25	0.6	1.5	1.64	1.84	0.64		-
PAB23	3.84	3.24	3.78	4.09	3.15	3.43	3.15	2.89	2.88	2.93
PAB24	5.02	4.85	5.32	5.21	3.96	4.01	4.56	3.91	5.11	5.04
PAB25	2.72	3.21	2.9	2.93	0.33	2.32	3.74	6.49		2.62
PAB26			1.26	1.29	0.56	1.51	3.03	4.51		2.26
PAB27	2.55	3.05	2.6	0.95	0.86	1.76	4.01	2.21	1.61	3.86

Table 4.27: Recharge calculation of Pabna Sadar upazilla by WTF method

Field	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average of Max GWL	8.81	9.20	8.64	8.52	8.73	8.00	8.09	8.60	7.33	8.63
Average of Min GWL	2.90	3.09	2.69	2.51	1.73	2.45	3.39	3.44	2.40	3.86
WL Difference (Δl)(cm)	591.40	611.40	595.17	601.17	700.33	555.83	470.17	515.83	493.25	477.50
Specific yield (Sy)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Recharge(cm)= Δl*Sy	47.31	48.91	47.61	48.09	56.03	44.47	37.61	41.27	39.46	38.20

Table 4.28: Year wise Maximum value of all six stations GWL data of Sujanagar upazilla

Station ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB30					9.27	8.52	9.09	9.19	8.81	9.36
PAB31	5.28	5.98	5.48	5.43	6.61	6.5	6.75	6.81	6.61	6.79
PAB32	6.8		6.65	7.8	6.49	6.67	5.91	5.91	7.09	5.41
PAB33					7.59	6.87	7.86	8.21	7.61	8.1
PAB34	9.84	9.18	8.66	9.13	8.87	5.97	7.62	8.47	7.52	8.57
PAB35	3.18	3.78	3.73	3.48	4.74	4.89	4.74	4.49	5.71	6.19

Table 4.29: Year wise Minimum value of all six stations GWL data of Sujanagar upazilla

Station ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB22	0.35	1.1	0.25	0.6	1.5	1.64	1.84	0.64	0	6.44
PAB23	3.84	3.24	3.78	4.09	3.15	3.43	3.15	2.89	2.88	2.93
PAB24	5.02	4.85	5.32	5.21	3.96	4.01	4.56	3.91	5.11	5.04
PAB25	2.72	3.21	2.9	2.93	0.33	2.32	3.74	6.49		2.62
PAB26			1.26	1.29	0.56	1.51	3.03	4.51		2.26
PAB27	2.55	3.05	2.6	0.95	0.86	1.76	4.01	2.21	1.61	3.86

Table 4.30: Recharge calculation of Sujanagar upazilla by WTF method

Field	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average of Max GWL	8.81	9.20	8.64	8.52	8.73	8.00	8.09	8.60	7.33	8.63
Average of Min GWL	2.90	3.09	2.69	2.51	1.73	2.45	3.39	3.44	2.40	3.86
WL Difference (Δl)(cm)	591.40	611.40	595.17	601.17	700.33	555.83	470.17	515.83	493.25	477.50
Specific yield (Sy)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Recharge(cm)= Δl*Sy	47.31	48.91	47.61	48.09	56.03	44.47	37.61	41.27	39.46	38.20

CHAPTER FIVE
RESULTS AND DISCUSSIONS

5.1 Introduction

The drainage model would be developed to device solution of the existing drainage congestion as well as likely effect of proposed irrigation network on drainage system. The main drainage model developed for the entire drainage system of present study area using the updated cross-sections and drainage catchments to be obtained from the updated survey data. Flood maps have been generated by using the model results for different years (2001-2009) with MIKE 11 GIS. And flood phase calculation used to indicate the percentage of area inundated. Reliable assessment of groundwater resource is essential for effective irrigation management and protection of environment. Accordingly, groundwater resource of the study area has been assessed based on abstraction and recharge from 2001-2009 periods.

This chapter contains the whole output of the study which give us a concept of present drainage and irrigation condition and also on the available ground water resources.

5.2 Calibration of the Model

The process in which by changing parameters the simulated results are matched with observed value is known as calibration. In the study for the overall assessment of water availability ground water and surface water availability is done. As the water availability of the whole study area is more or less depending upon the rainfall-runoff of the surrounding area. So, water availability, drainage and irrigation problems are closely related to the complex relation of flooding condition, duration and extension of flood, ground water depth, availability and recharge. For the level of accuracy of model the calibration is done for both ground and surface water. For ground water calibration is done by NAM calibration and surface water calibration is done by HD calibration.

5.2.1 NAM Calibration

In the NAM model the parameters and variables represent average values for the entire catchment. While in some cases a range of likely parameter values can be estimated, it is not possible, in general, to determine the values of the NAM parameters on the basis of the physiographic, climatic and soil physical characteristics of the catchment, since most of the parameters are of an empirical and conceptual nature. Thus, the final parameter estimation must be performed by calibration against time series of hydrological observations. Thus in the study the parameters and variables average value are set by comparing the ground water depth data simulated vs. observed. These average values of parameters and variables is obtained by a number of model run till a good agreement between the average simulated and observed ground water depth data. Hence, the best way to calibrate NAM model is by comparing the runoff generated from the model with that observed at the outlet of the catchment. However, for the catchments in plain land like the lower half of this study area, it is not possible to identify the single outlet of the catchment or isolate one catchment from the influence of other catchments. At the same time, it is not possible to observe discharge at the outlet of the catchment due to lack of regular measurement activities and other reasons. Under such conditions, the NAM model is indirectly calibrated against observed groundwater data with the groundwater levels simulated by the model. Figure 5.1 shows such type of comparison obtained by model calibration.

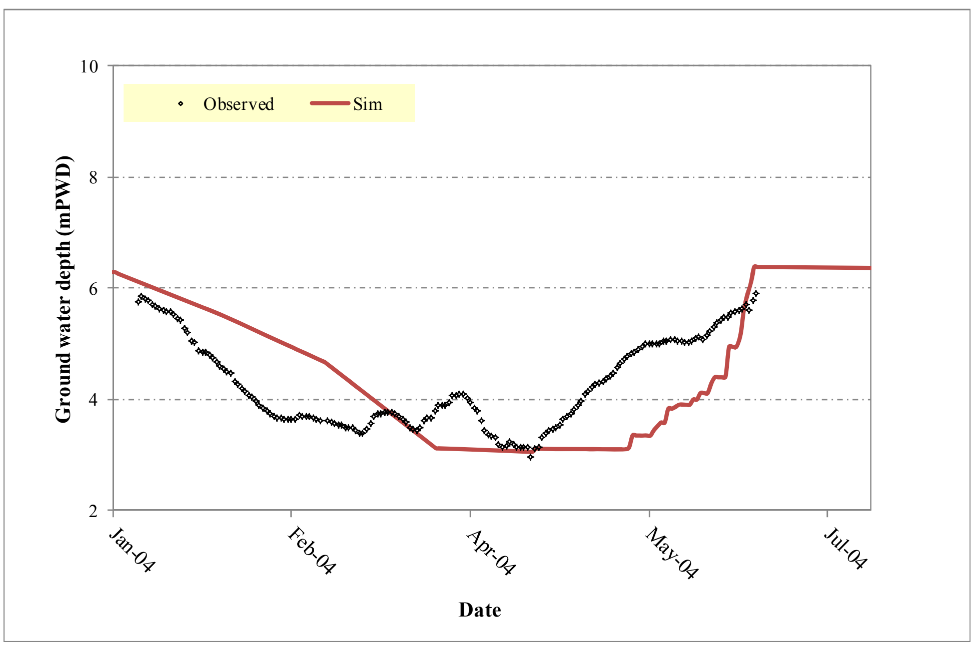
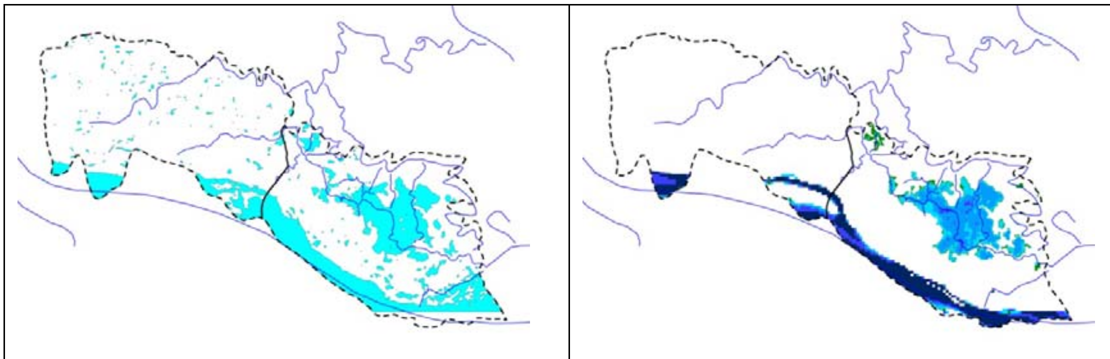


Figure 5.1: Calibration of NAM model

5.2.2 HD Calibration

Hydrodynamic model calibration is done to check out however the developed simulated model conveys the actual scenario of real field. Most of the time model has been calibrated against the water level data recorded at regular monitoring stations installed by different agencies like BWDB, BIWTA etc. But in this study there is no water level station within the study area. So comparison of simulated and observed water level data is not possible due to unavailable observed data. So calibration of the study is done by comparing simulated flood map with the actual flood image obtained by Landsat of the flood year 2004. As the 2004 flood is the most devastating flood year within the study period (2001-2009) and flood image is available for the year 2004. Thus the calibration is done within a great extent and hence the model is calibrated. Figure 5.2 shows the calibration for flood year 2004.



Flood image from Landsat (Source: IWM) | Model output flood image

Figure 5.2: Actual satellite flood image and Model output flood image

5.3 Output from Model

One of the major objective and output of this study, as it was mentioned earlier is to figure out the existing flooding and drainage problems for the Pabna Sadar and Sujanagar upazilla. Development and output of hydrodynamic model is that it produce yearly monsoon flooding scenario of the study area. This Model and its output then would be used for the assessment of drainage and flooding problems which leads to understand the extension of flooded area and drainage condition. From this model study percentage of area inundated is extracted using the utility tools of ArcView software. This study would be leads to find out the major devastating flood corresponding to flooding area and drainage congestion.

After development of hydrodynamic model, yearly maximum flood depth data /maps during monsoon season (June to October) for the period of 2001 to 2009 have been produced. Figure 5.3 to Figure 5.11 show some floodmaps during monsoon of 2001 to 2009. Overall spatial extension of floodmap includes whole Pabna Sadar Sujanagar upazilla, administrative boundary of which falls at both the Padma and Jamuna River.

It would be worthy to mention that 50m X 50m grid based daily flood depth data are produced in Bangladesh Transverse Mercator (BTM) co-ordinate projection system.

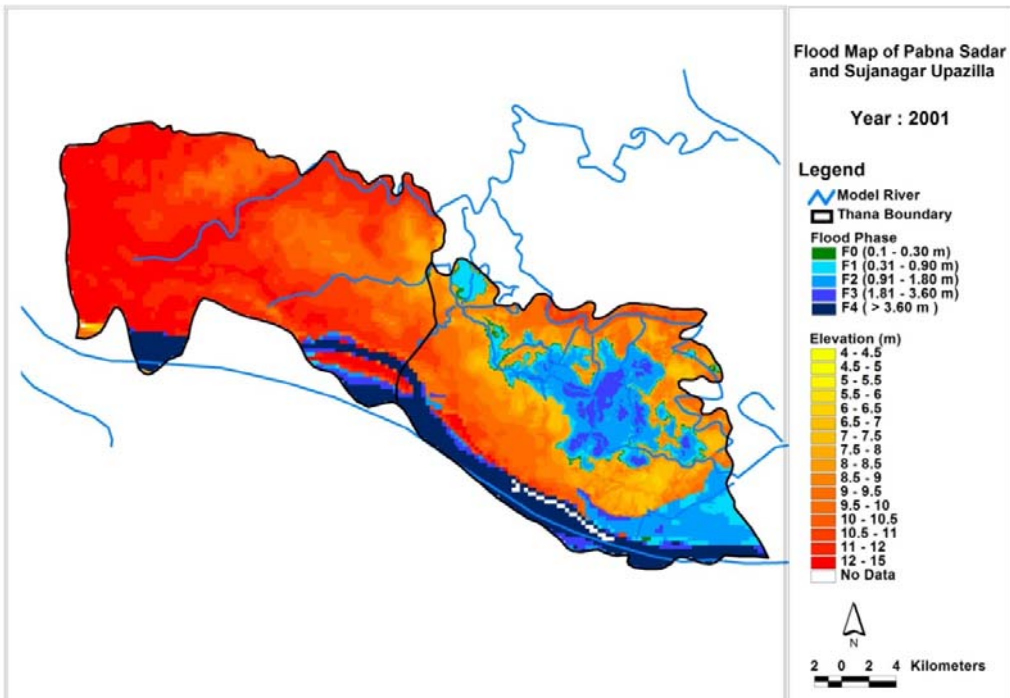


Figure 5.3: Flood inundation map of the study area for the year 2001

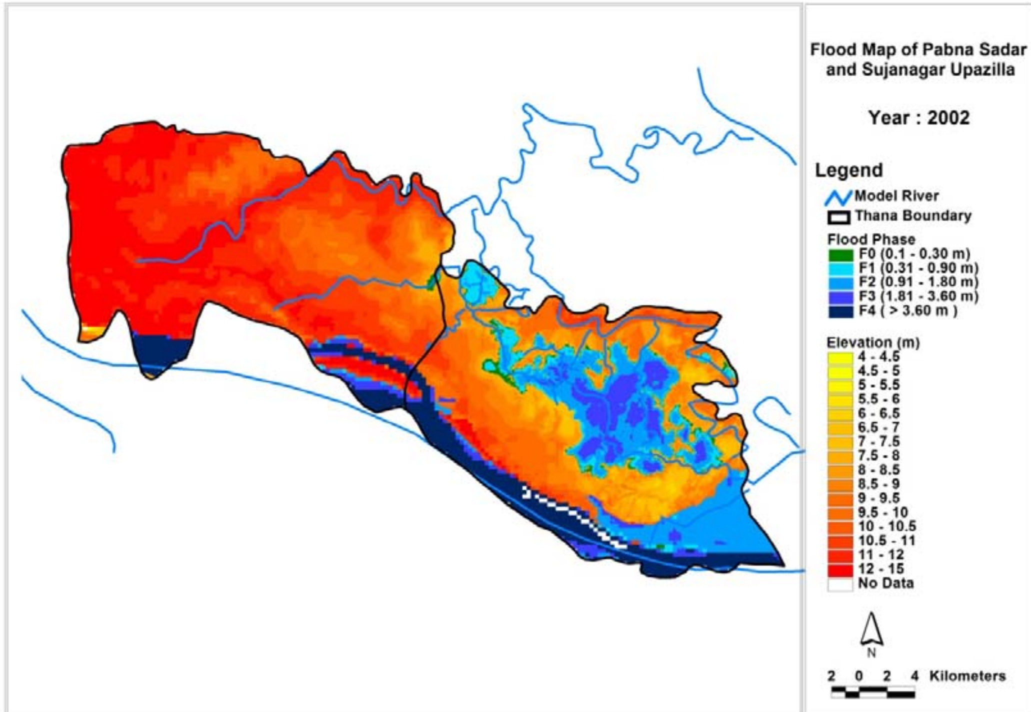


Figure 5.4: Flood inundation map of the study area for the year 2002

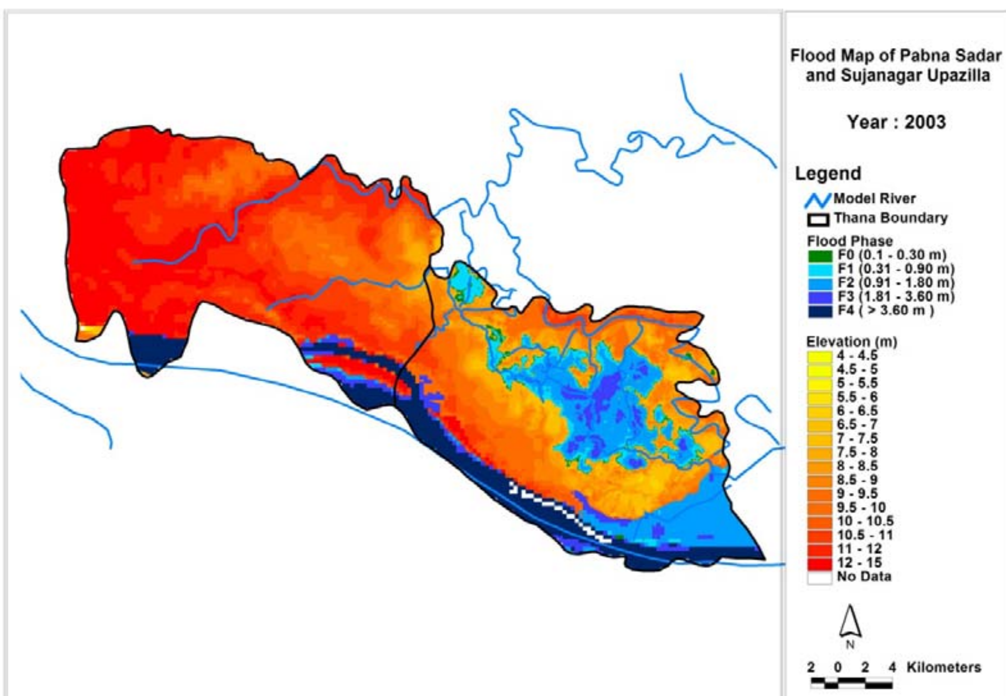


Figure 5.5: Flood inundation map of the study area for the year 2003

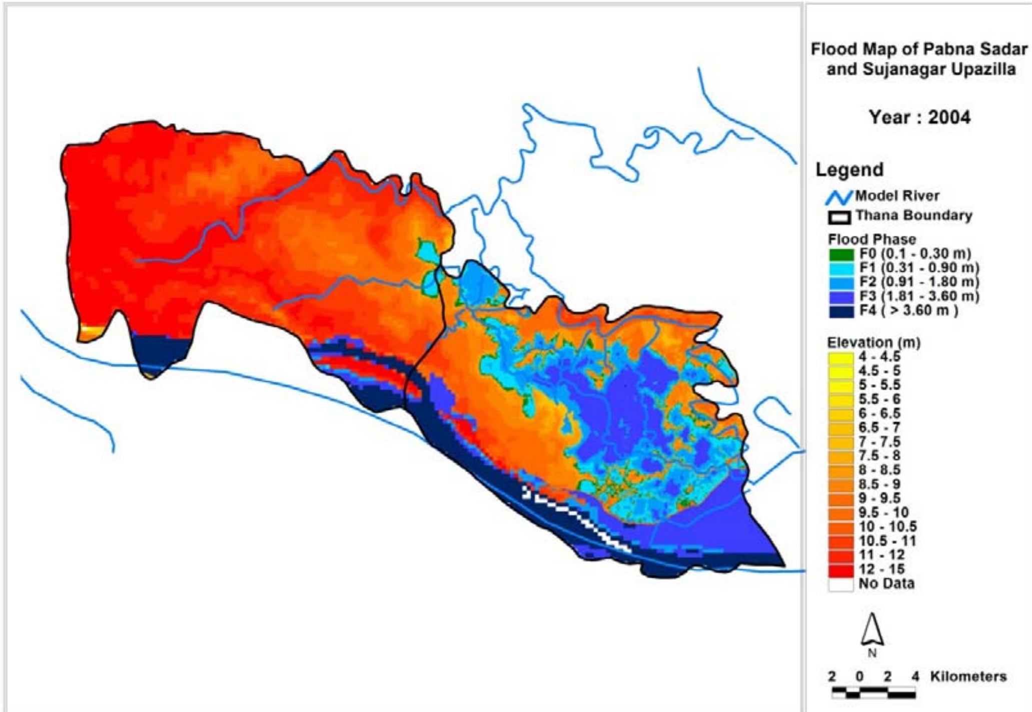


Figure 5.6: Flood inundation map of the study area for the year 2004

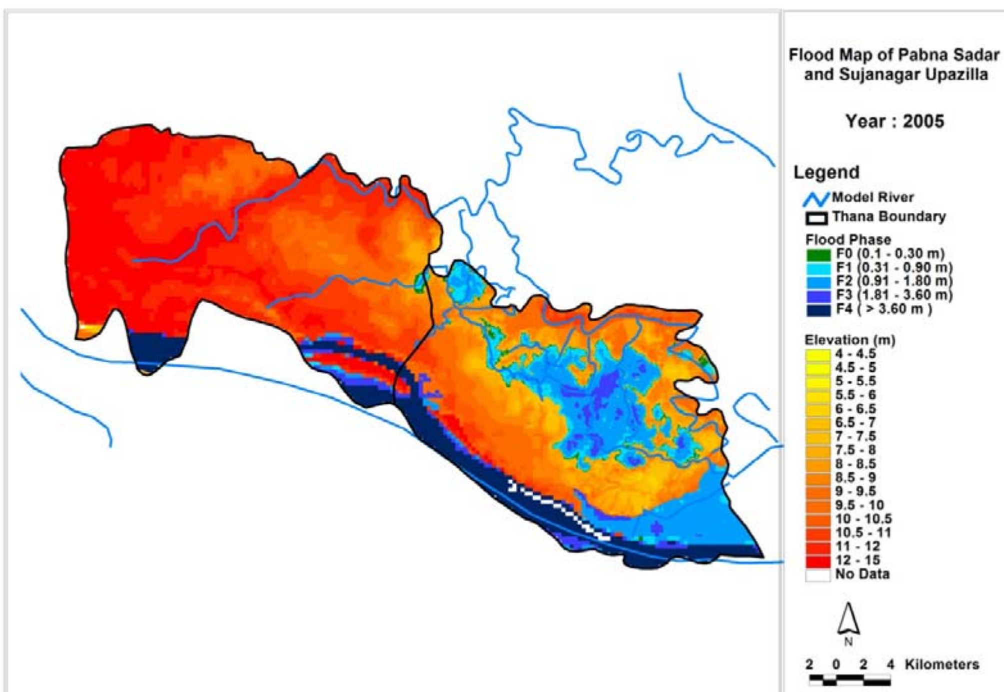


Figure 5.7: Flood inundation map of the study area for the year 2005

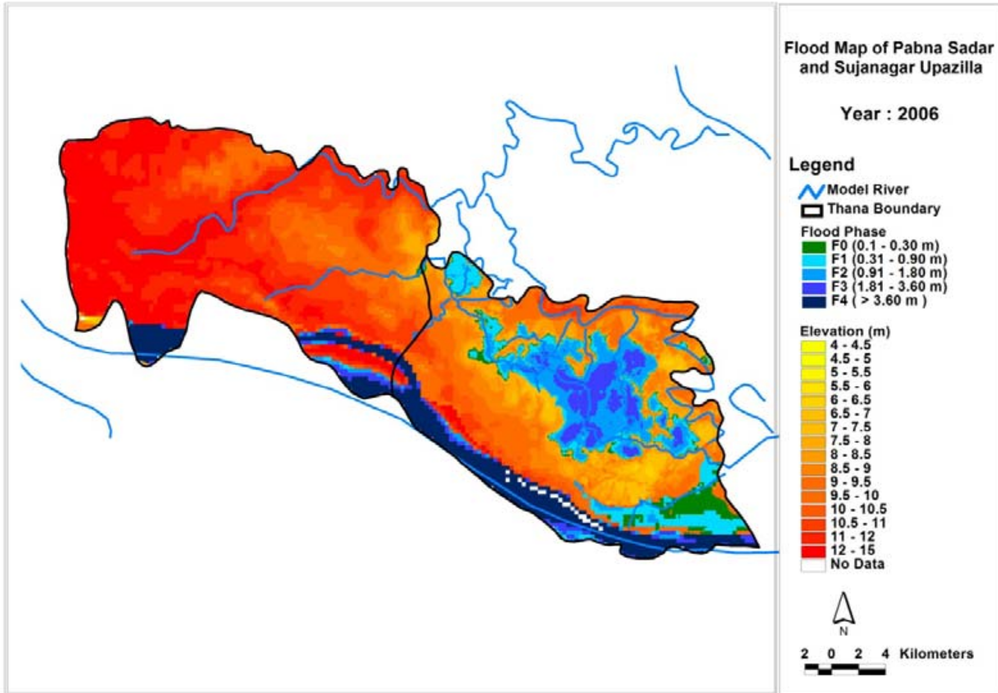


Figure 5.8: Flood inundation map of the study area for the year 2006

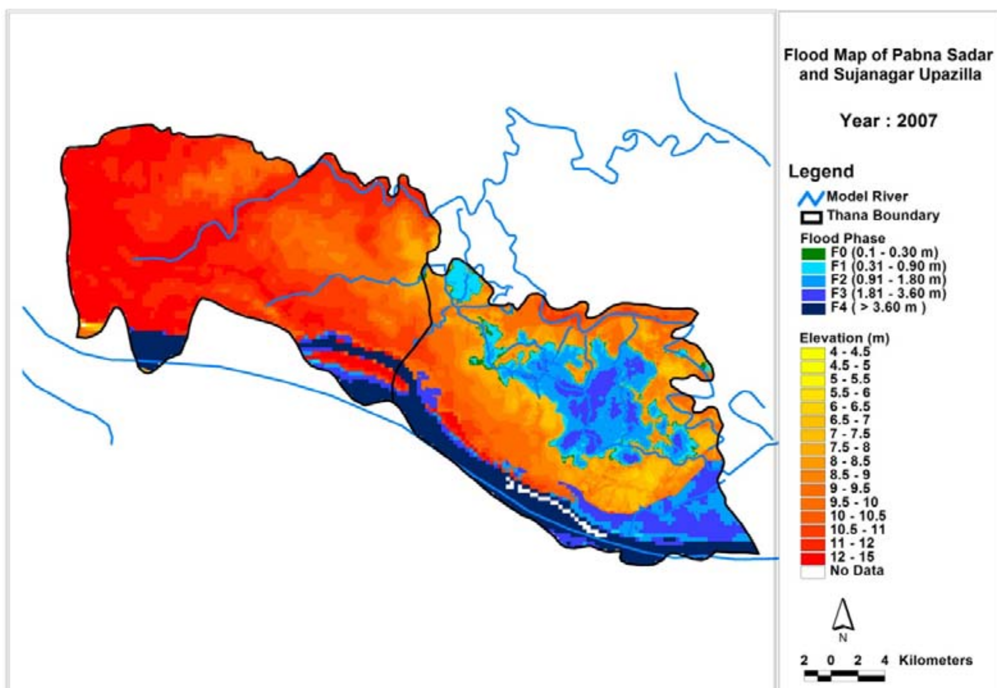


Figure 5.9: Flood inundation map of the study area for the year 2007

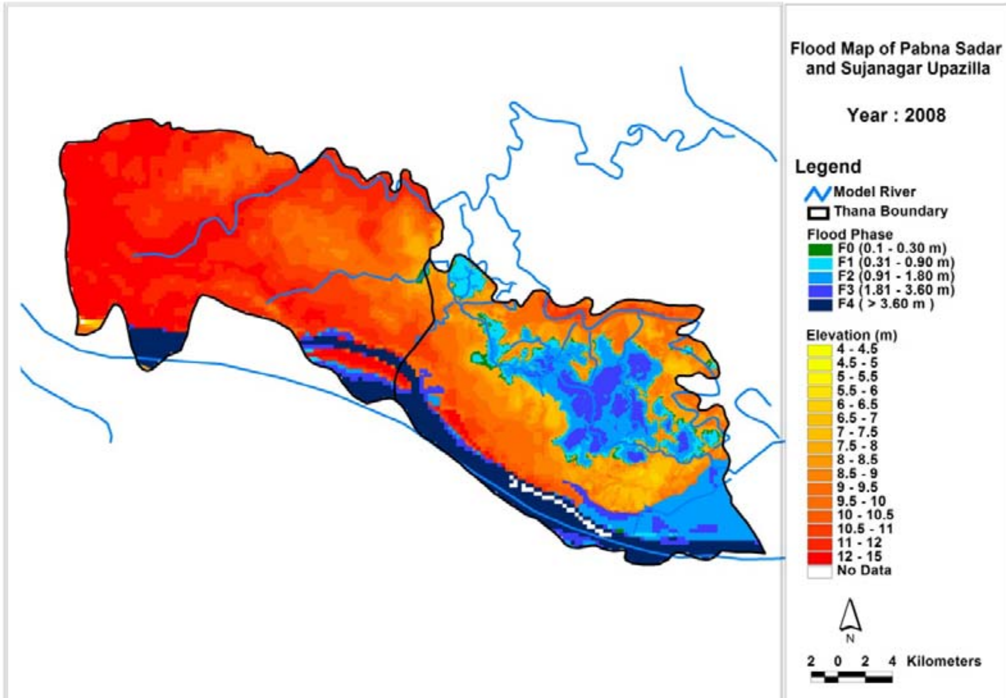


Figure 5.10: Flood inundation map of the study area for the year 2008

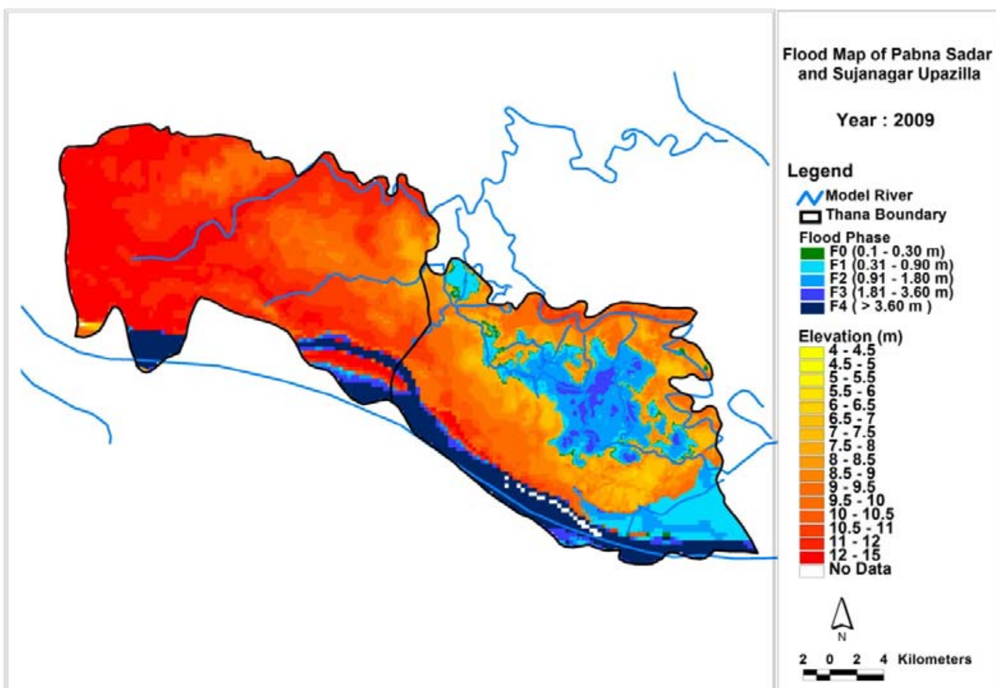


Figure 5.11: Flood inundation map of the study area for the year 2009

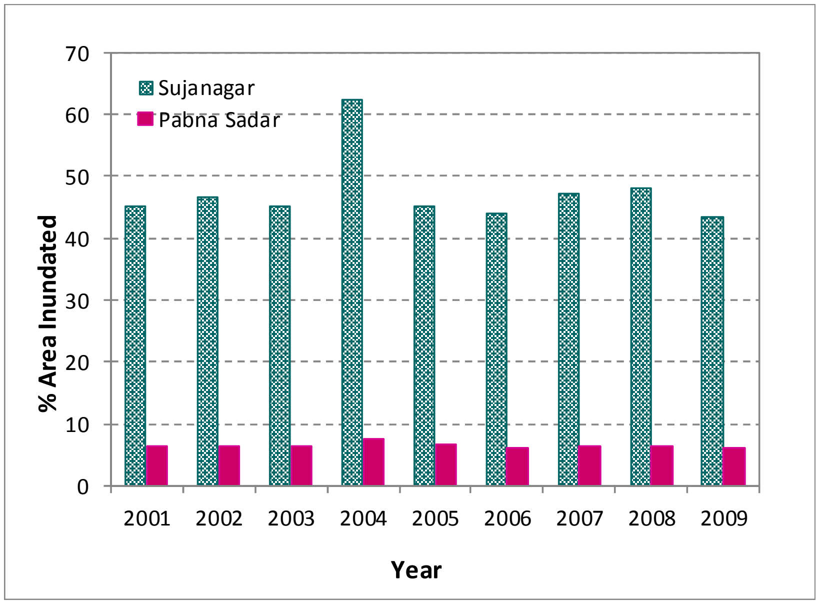


Figure 5.12: Percentage of total area inundated of study area in different years

From the above figures the following findings have arisen:

- The drainage problem at Pabna Sadar upazilla is negligible in comparison with Sujanagar upazilla as maximum and average elevation of Pabna sadar is higher than that of Sujanagar upazilla.
- The drainage congestion is higher at the adjoining area of beel Gaznar and beel Sadullahpur and also at the south-eastern part of the upazilla.
- There is a number of small khals/channel in the Sujanagar upazilla which in general sense can convey the storm water but in the real field they cannot.
- The major as well as small khals/channels are silted up as the whole upazilla is surrounded by Highways/embankment so they cannot transmit the storm water rather than inundated.
- At major flood like 2004 and 2007 the flood map shows that the 50% of the total Sujanagar upazilla was inundated. And about 25% area is under depth of 1.81m to 3.6m.

5.4 Irrigation Water Requirement (Mixed Mode Cropping Pattern)

The present cropping practice in the study area is mixed mode FIWR and SIWR have been computed for the mixed crop. It is found that for this option maximum FIWR for

Pabna and Sujanagar upazilla are 0.958 and 0.60 l/s/ha that occur in January. The SIWR are 1.06 and 0.66 l/s/ha. Table 5.1 and 5.2 shows the values of FIWR and SIWR. The Tables also shows the water requirements for Paddy, Onion, Mustered, Wheat, Vegetables, Potato, T.Aman, T.Aush. However, in reality, farmers do not apply the exact requirement to the crop due to various reasons such as higher cost of irrigation in case of STW, disruption of constant electricity for DTW and other administrative complicacy with the irrigation providing authority. During the discussion with the farmers, it was understood that in Wheat, Maize and Other crops farmers usually apply half of the required amount and they do not apply any irrigation during June and July in T. Aman. Therefore the applied amount of irrigation for T.Aman, T.Aush and summer vegetables are much less than that of calculation. The maximum water requirement is considered for the critical condition so maximum mm/month is enlisted on the table. The total irrigation water applied in the field round the year under the present situation is 966 mm for Pabna Sadar and 772 for Sujanagar upazilla. It is worth mentioning that recycling of irrigation water is not considered in present irrigation water requirement estimation as mentioned in Table 5.1 and 5.2. Crop-wise irrigation water requirement of the study area is given in Appendix B and Appendix C. Monthly max crop water requirement and FIWR for the whole study area are given below in the tabular form.

Table 5.1: Monthly crop water requirements of the study area

Sl No.	Upazilla	Crop water Requirement (mm)								
		Month	Jan	Feb	Mar	Apr	May	Jun	July	Dec
1	Pabna Sadar	Max mm/month	256.65	74.50	230.18	242.94	60.48	115.99	74.92	98.01
		FIWR (l/s/hec)	0.96	0.31	0.86	0.94	0.23	0.45	0.28	0.37
2	Sujanagar	Max mm/month	159.65	79.68	134.54	90.42	0.00	13.74	125.34	158.82
		FIWR (l/s/hec)	0.60	0.33	0.50	0.35	0.00	0.05	0.47	0.59

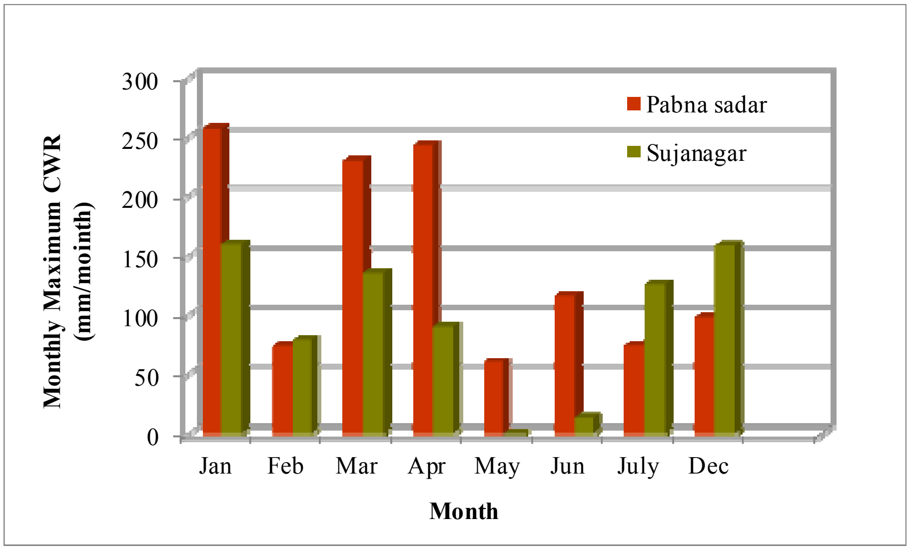


Figure 5.13: Monthly crop water requirements of the study area

From the above analysis the findings are:

- The Paddy requires maximum amount of water than that of all other crops for upazillas.
- At the month of January Irrigation water requirement is maximum.
- At the month of the May the CWR at Sujanagar upazilla is minimum because at season of kharif-I no crops is cultivated.

5.5 Gross Domestic and Municipal Water Demand

Gross Domestic and Municipal Water Demand for the study area are presented in table 5.2. The table gives us the idea that:

- Domestic and Municipal Water Demand for Pabna Sadar is greater than that of Sujanagar as the population of Pabna sadar is more and there also has municipal water supply systems which increase the water demand.
- It also illustrates that the water demand is increasing year to year for both upazilla.

Table 5.2: Gross Domestic and Municipal Water Demand of the Study Area

Year	Domestic and Municipal Water Demand(m^3/day)		Domestic and Municipal Water Demand(mm)		Domestic and Municipal Water Demand(Mm^3)	
	Pabna	Sujanagar	Pabna	Sujanagar	Pabna	Sujanagar
2001	18694.52	7535.76	17.72	7.36	6.82	2.75
2002	18989.89	7654.83	18.00	7.48	6.93	2.79
2003	19289.93	7775.77	18.28	7.60	7.04	2.84
2004	19594.71	7898.63	18.57	7.72	7.15	2.88
2005	19904.31	8023.43	18.87	7.84	7.27	2.93
2006	20218.80	8150.20	19.16	7.96	7.38	2.97
2007	20538.26	8278.97	19.47	8.09	7.50	3.02
2008	20862.76	8409.78	19.77	8.22	7.61	3.07
2009	21192.39	8542.65	20.09	8.35	7.74	3.12

5.6 Abstraction

From the study it is obtained that

- The Irrigation water demand of Sujanagar upazilla is more than that of Pabna sadar upazilla as maximum number of khals/channels are silted up. Therefore, there is no provision of surface water utilization.
- Sujanagar upazilla uses more number of tube wells than that of Pabna Sadar upazilla to meet irrigation water demand thus creating more abstraction.
- The total amount of irrigation, domestic and municipal water requirement is actually the total abstraction of these two upazilla. In summation the abstraction are tabulated below in table 5.3 and figure 5.14.

Table 5.3: Abstraction of the study area

Year	**Abstraction(mm)**	
	Pabna Sadar	**Sujanagar**
2001	337.21	395.18
2002	342.54	401.42
2003	347.95	407.77
2004	353.45	414.21
2005	359.03	420.75
2006	364.71	427.40
2007	370.47	434.16
2008	376.32	441.02
2009	382.27	447.98

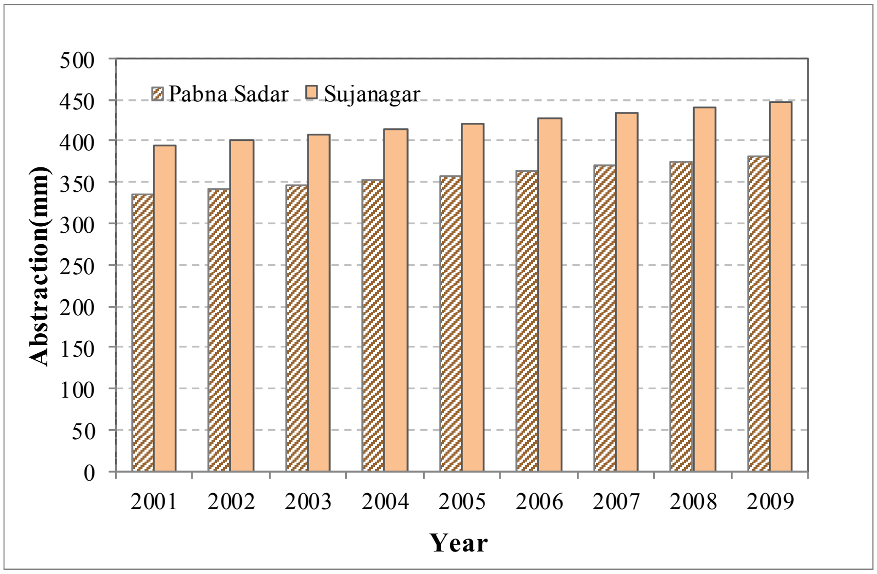


Figure 5.14: Abstraction of the study area

This table reflects a clear view of abstraction of these two upazilla:

- Abstraction of Sujanagar upazilla is higher than Pabna sadar upazilla.
- And the rate of abstraction is increasing year to year.

5.7 Recharge

Understanding the recharge process and its relationship with rainfall is of critical importance to the management of groundwater systems (Wu, J and Zhang, R, 1984). Recharge is summarized below in table 5.4 and presented in figure 5.14 also:

Table 5.4: Recharge of the study area

Thana name	2001	2002	2003	2004	2005	2006	2007	2008	2009
Pabna Sadar	489.1	476.1	480.9	560.3	444.7	376.1	412.7	394.6	382.0
Sujanagar	444.3	422.6	432.0	543.3	500.1	482.9	517.1	505.7	442.7

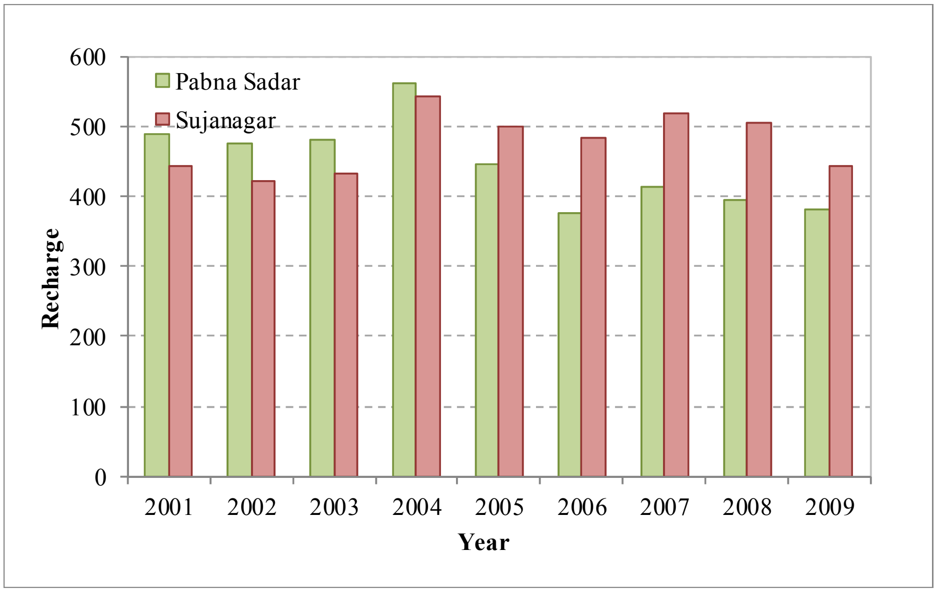


Figure 5.15: Recharge of the study area

From the study it is found that:

- At Pabna sadar upazilla the recharge is decreasing as it is the main town of the Pabna district and the population growth is higher and utilization of GW for all purpose (irrigation, domestic and municipal) is also increasing.
- But at Sujanagar upazilla recharge vary year to year depending upon the flooding condition of the year.
- As the whole Sujanagr upazilla is surrounded by the national highway/embankment around it, the runoff resulting from the rainfall is trapped and infiltrate into the ground just after the rainfall as well as slowly for some days/weeks. For this reason the recharge is more in this upazilla.
- It is also found that during the high flood year like 2004 and 2007 the recharge was much more than the other average flood year.

5.7.1 Abstraction vs. Recharge relationship

The figures below show the relationship between Abstraction and recharge. From the figures the following findings have arisen:

- The abstraction is increasing day by day but the recharge is not increasing simultaneously.

- At Pabna Sadar upazilla first 5 years (2001-2005) recharge was high but last 4 years (2006-2009) it seems to be at same level.
- At Sujanagar upazilla abstraction and recharge was more or less same, except the flooding years (2004 and 2007).
- Abstraction and recharge reached almost same level at 2009 which indicate worse condition for the future.

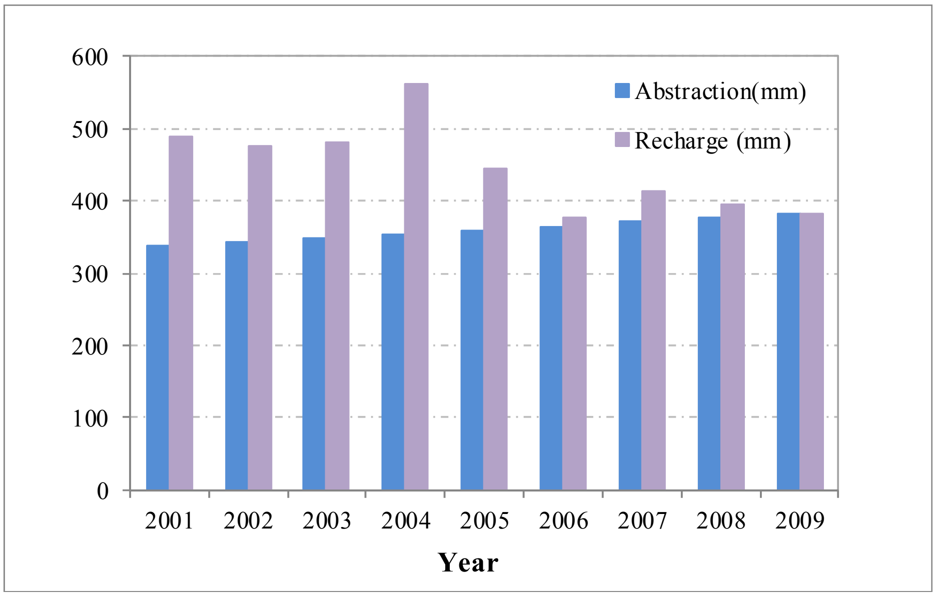


Figure 5.16: Relation between Abstraction and Recharge of Pabna sadar

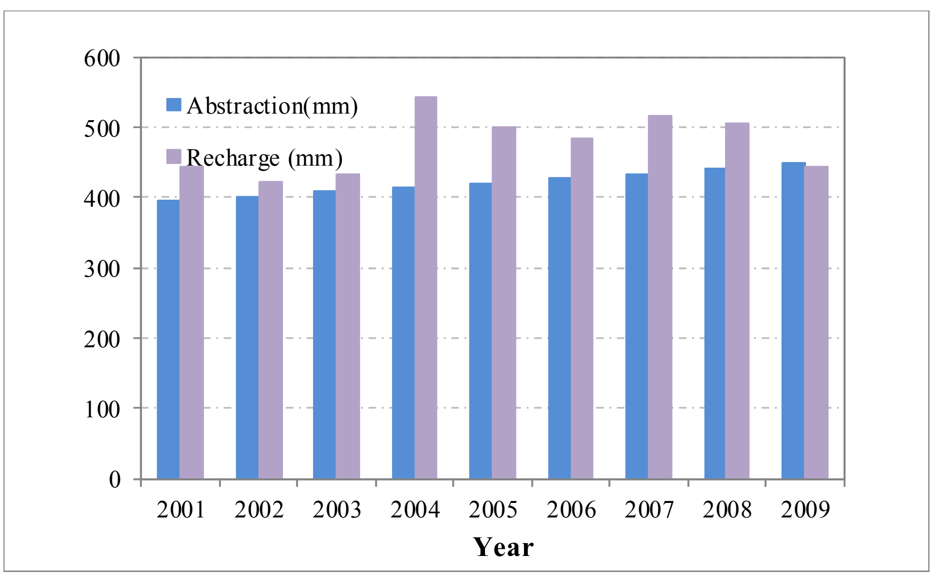


Figure 5.17: Relation between Abstraction and Recharge of Sujanagar

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objectives for the present study were to assess the surface water availability and drainage condition by the mathematical modeling and ground water availability by the water table fluctuation method using existing hydro-geological and meteorological data. Another objective was to estimate the irrigation water requirement to investigate the water demand so as to compare the abstraction vs. recharge.

- From model result it is apparent that the usable surface water is not available during monsoon as well as dry season. The main river Badai and other khals/chnnels are remaining fully or partly dry during dry season. Therefore, lack of irrigation as well as domestic water is a common feature in that area.
- During monsoon khals/channels overflow water due to siltation and caused drainage congestion. Drainage congestion mainly occur at the adjoining area of major beels named Gaznar and Sadullapur and also at the Talimnagar sluice area as it not utilized properly.
- For both upazillas the irrigation water requirement is maximum in the month of January, and also from the 30 years rainfall analysis it is evident that less rainfall occurs at January so there is no provision of surface water irrigation in the critical month which creates more dependency on ground water and more abstraction.
- Though the Pabna sadar has more population but the total water requirement is more at Sujanagar upazilla as it requires more water for irrigation. Hence, abstraction occur more at Sujanagar.
- High Ground Water Level variation occurs in Pabna sadar due to high rainfall at the year 2001-2005 therefore, recharge is considerably high in first 5 years (2001-2005) but at rest of the year it is as close as abstraction. However, at Sujanagar upazilla recharge is not at that alarming level like Pabna sadar as the

cultivable land is much less than Pabna sadar and the upazilla is enriched by some beels. But abstraction scenario is gradually increasing for both the upazillas. At the year 2009 the abstraction and recharge is almost same.

6.2 Recommendations for further studies

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The recommendation from the current study can be synthesized as follows:

- As the field data is not available so the calibration of the model was done by the flood image. Accurate hydrodynamic model can be developed by calibrating the model with the accurate field water level data.
- To provide an appropriate irrigation facility an irrigation model can develop depending on the field survey data.
- As the NAM model is calibrated against ground water level, therefore, groundwater table and quality monitoring should also be done regularly.
- The groundwater systems of the study area are complex and linked with surface water availability in the region. So ground water availability may be assessed by developing a ground water model. And coupling of ground and surface water modeling may be done for overall water assessment of this region.
- For estimation of recharge an appropriate methodology could be established.
- Investigation of field irrigation facilities by extensive survey should be carried out for accurate abstraction estimation.
- This model can be used for various development options in consultation with local stakeholders.
- In future the relation of recharge with rainfall can be developed.

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Appendix- A-1: 30 years average rainfall data

Station	Event	Jan	Feb	mar	Apr	May	Jun	July	Aug	Sep	oct	Nov	Dec
Pabna Sadar	Maximum	45.7	115	109	250.7	400	701.5	699	639	716.5	695	126	115.5
	Minimum	0	0	0	0	0	0	0	67.5	0	0	0	0
	Mean	5.75	23.19	23.49	66.37	191.03	259.75	307.58	249.58	262.07	139.58	14.50	11.47
Sujanagar	Maximum	75.4	72.5	131.4	272.1	536.2	508	755.7	695.4	792.6	453.4	119.5	120.3
	Minimum	0	0	0	0	36	18.28	30.69	83	13.9	0	0	0
	Mean	6.85	21.04	25.67	90.37	210.77	283.58	356.92	283.96	278.75	131.44	20.45	8.12

Appendix-B-1: Percentage of area of cultivation under each crop for Rabi of Pabna sadar

Month	Decade	**Paddy**	**Onion**	**Mustered**	**Wheat**	**Vegetable**	**Potato**
Dec	1st Decade	20%	40%	30%	20%	50%	30%
	2nd Decade	30%	40%	30%	30%	30%	30%
	3rd Decade	30%	10%	20%	30%	10%	20%
Jan	1st Decade	20%	10%	20%	20%	10%	20%

Appendix-B-2: Percentage of area of cultivation under each crop for kharif-1 of Pabna sadar

Month	Decade	Aush	Summar Veg
Mar	2		40%
	3		40%
Apr	1	50%	20%
	2	50%	

Appendix-B-3: Percentage of area of cultivation under each crop for kharif-2 of Pabna sadar

Month	Decade	T.Aman
July	1	50%
	2	50%

Appendix-B-4: Net CWR\Decade for Paddy at Pabna Sadar

Month\Planting Date	Decade	1-Jan	12-Jan	22-Jan	01-Feb	Avg CWR mm/month
Nov	2					
	3					
Dec	1	0.00	0.00	0.00	0.00	
	2	312.17	78.84	1.03	0.00	98.01
	3	0.00	0.00	0.00	0.00	
Jan	1	0.00	0.00	0.00	0.00	
	2	78.12	287.37	341.62	319.51	256.65
	3	0.00	0.00	0.00	0.00	
Feb	1	0.00	0.00	0.00	0.00	
	2	81.20	77.84	71.96	67.01	74.50
	3	0.00	0.00	0.00	0.00	
Mar	1	0.00	0.00	0.00	0.00	
	2	143.43	152.83	154.07	151.69	150.51
	3	0.00	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	0.00	
	2	18.60	70.06	119.25	144.77	88.17
	3	0.00	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	49.29	

Appendix-B-5: Net CWR\ Decade for Onion at Pabna Sadar

Month\Planting Date	Decade	20-Dec	01-Jan	12-Jan	22-Jan	Average CWR mm/month
Nov	2					
	3					
Dec	1	0.00	0.00	0.00	0.00	
	2	10.75	0.00	0.00	0.00	2.68
	3	0.00	0.00	0.00	0.00	
Jan	1	0.00	0.00	0.00	0.00	
	2	37.72	31.00	19.43	9.20	24.33
	3	0.00	0.00	0.00	0.00	
Feb	1	0.00	0.00	0.00	0.00	
	2	55.91	46.11	31.73	22.12	38.96
	3	0.00	0.00	0.00	0.00	
Mar	1	0.00	0.00	0.00	0.00	
	2	108.29	113.56	112.43	104.16	109.61
	3	0.00	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	0.00	
	2	5.27	48.77	88.45	102.71	61.30
	3	0.00	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	33.69	

Appendix-B-6: Net CWR\ Decade for Mustered at Pabna Sadar

Month\Planting Date	Decade	25-Nov	01-Dec	15-Dec	01-Jan	Average CWR mm/month
Nov	2.00	5.68				5.68
	3.00	0.00	0.00			
Dec	1.00	0.00	0.00	0.00	0.00	
	2.00	44.12	25.52	11.16	0.00	20.20
	3.00	0.00	0.00	0.00	0.00	
Jan	1.00	0.00	0.00	0.00	0.00	
	2.00	76.47	76.36	67.99	39.27	65.02
	3.00	0.00	0.00	0.00	0.00	
Feb	1.00	0.00	0.00	0.00	0.00	
	2.00	22.21	46.76	63.37	66.45	49.70
	3.00	0.00	0.00	0.00	0.00	
Mar	1.00	0.00	0.00	0.00	0.00	
	2.00	0.00	0.00	15.71	81.74	24.36
	3.00	0.00	0.00	0.00	0.00	
Apr	1.00	0.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	0.00	
May	1.00	0.00	0.00	0.00	0.00	

Appendix-B-7: Net CWR\ Decade for Wheat at Pabna Sadar

Month\Planting Date	Decade	25-Nov	08-Dec	15-Dec	01-Jan	Average CWR mm/month
Nov	2	0.00				
	3	7.44				7.44
Dec	1	0.00	0.00	0.00	0.00	0.00
	2	12.92	10.02	6.82	0.00	7.44
	3	0.00	0.00	0.00	0.00	0.00
Jan	1	0.00	0.00	0.00	0.00	0.00
	2	60.45	37.41	26.97	15.09	34.98
	3	0.00	0.00	0.00	0.00	0.00
Feb	1	0.00	0.00	0.00	0.00	0.00
	2	65.99	65.61	61.69	36.59	57.47
	3	0.00	0.00	0.00	0.00	0.00
Mar	1	0.00	0.00	0.00	0.00	0.00
	2	78.02	112.43	122.66	127.00	110.02
	3	0.00	0.00	0.00	0.00	0.00
Apr	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	17.46	33.79	89.49	35.19
	3	0.00	0.00	0.00	0.00	0.00
May	1	0.00	0.00	0.00	0.00	0.00

Appendix-B-8: Net CWR\ Decade for Vegetable at Pabna Sadar

Month\Planting Date	Decade	15-Nov	25-Nov	15-Dec	01-Jan	Average CWR mm/month
Nov	2	29.45				29.45
	3	0.00				
Dec	1	0.00	0.0000	0	0.0000	0.00
	2	50.94	45.1567	22.836667	0.0000	29.73
	3	0.00	0.0000	0	0.0000	0.00
Jan	1	0.00	0.0000	0	0.0000	0.00
	2	69.34	67.5800	56.11	46.9133	59.99
	3	0.00	0.0000	0	0.0000	0.00
Feb	1	0.00	0.0000	0	0.0000	0.00
	2	29.87	53.1067	58.893333	54.2267	49.02
	3	0.00	0.0000	0	0.0000	0.00
Mar	1	0.00	0.0000	0	0.0000	0.00
	2	0.00	0.0000	63.446667	112.2200	43.92
	3	0.00	0.0000	0	0.0000	0.00
Apr	1	0.00	0.0000	0	0.0000	0.00
	2	0.00	0.0000	0	16.8433	4.21
	3	0.00	0.0000	0	0.0000	0.00
May	1	0.00	0.0000	0	0.0000	0.00

Appendix-B-9: Net CWR\ Decade for Potato at Pabna Sadar

Month\Planting Date	Decade	25-Dec	05-Jan	15-Jan	01-Feb	Average CWR mm/month
Nov	2					
	3	15.81				15.81
Dec	1	0.00	0.00	0	0.00	0.00
	2	29.86	23.35	14.77	0.00	17.00
	3	0.00	0.00	0	0.00	0.00
Jan	1	0.00	0.00	0	0.00	0.00
	2	69.33	58.38	44.53	31.20	50.87
	3	0.00	0.00	0	0.00	0.00
Feb	1	0.00	0.00	0	0.00	0.00
	2	66.26	66.45	65.52	51.52	62.44
	3	0.00	0.00	0	0.00	0.00
Mar	1	0.00	0.00	0	0.00	0.00
	2	103.43	117.07	124.93	127.20	118.16
	3	0.00	0.00	0	0.00	0.00
Apr	1	0.00	0.00	0	0.00	0.00
	2	3.61	30.27	62.10	106.64	50.66
	3	0.00	0.00	0	0.00	0.00
May	1	0.00	0.00	0	25.93	6.48

Appendix-B-10: Net CWR\ Decade for T.Aman at Pabna Sadar

Month	Decade	1-Jul	12-Jul	Avg CWR mm/month
Jun	1	0.00	0.00	
	2	188.89	43.09	115.99
	3	0.00	0.00	
July	1	0.00	0.00	
	2	0.00	149.83	74.92
	3	0.00	0.00	
Aug	1	0.00	0.00	
	2	0.56	0.47	0.51
	3	0.00	0.00	
Sep	1	0.00	0.00	
	2	0.00	0.00	0.00
	3	0.00	0.00	
Oct	1	0.00	0.00	
	2	0.00	0.00	0.00
	3	0.00	0.00	
Nov	1	0.00	0.00	

Appendix-B-11: Net CWR\ Decade for Summer Vegetables at Pabna Sadar

Month	Decade	15-Mar	25-Mar	1-Apr	Avg CWR mm/month
Mar	1	0.00	0.00	0.00	
	2	39.78	17.46	0.00	19.08
	3	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	
	2	73.78	59.93	54.04	62.59
	3	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	
	2	24.55	19.69	13.35	19.20
	3	0.00	0.00	0.00	
Jun	1	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	
July	1	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	
Aug	1	0.00	0.00	0.00	

Appendix-B-12: Net CWR\ Decade for Aush at Pabna Sadar

Month	Decade	1-Apr	10-Apr	Avg CWR mm/month
Mar	1	0.00	0.00	
	2	366.32	94.03	230.18
	3	0.00	0.00	
Apr	1	0.00	0.00	
	2	122.45	363.42	242.94
	3	0.00	0.00	
May	1	0.00	0.00	
	2	63.37	57.59	60.48
	3	0.00	0.00	
Jun	1	0.00	0.00	
	2	11.16	12.09	11.63
	3	0.00	0.00	
July	1	0.00	0.00	
	2	0.00	0.00	0.00
	3	0.00	0.00	
Aug	1	0.00	0.00	

Appendix-B-13: Crop-wise Present Irrigation Water Requirement for Pabna Sadar

Month	Days	Paddy	Onion	Mustard	Wheat	Vegetable	Potato	T.Aman	T.Aush	Summer Veg	Max mm/month	FIWR l/s/hec	SIWR l/sec/hec	Remarks
Jan	31	256.65	24.34	65.02	34.98	59.99	50.87	0.00	0.00	0.00	256.6	0.9582	1.0647	Max
Feb	28	74.50	38.97	49.70	57.47	49.02	62.44	0.00	0.00	0.00	74.50	0.3080	0.3422	
Mar	31	150.51	109.61	24.36	110.02	43.92	118.16	0.00	230.18	19.08	230.2	0.8594	0.9549	
Apr	30	88.17	61.30	0.00	35.19	4.21	50.66	0.00	242.94	62.59	242.9	0.9373	1.0414	
May	31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.48	19.20	60.48	0.2258	0.2509	
Jun	30	0.00	0.00	0.00	0.00	0.00	0.00	116	11.625	0.00	116	0.4475	0.4972	
July	31	0.00	0.00	0.00	0.00	0.00	0.00	74.92	0.00	0.00	74.92	0.2797	0.3108	
Aug	31	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.513	0.0019	0.0021	
Sep	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0000	0.0000	
Oct	31	0.00	0.00	0.00	0.00	0.00	0.00	9.68	0.00	2.31	9.68	0.0361	0.0402	
Nov	30	0.00	0.00	5.68	7.44	29.45	0.00	0.02	0.00	0.00	29.45	0.1136	0.1262	
Dec	31	98.01	2.69	20.20	7.44	29.73	17.00	0.00	0.00	0.00	98.01	0.3659	0.4066	
Total		667.84	236.90	164.9	252.54	216.3	299.13	201.1	545.22	103.2	667.8			

Appendix-C-1: Percentage of area of cultivation under each crop for Rabi of Sujanagar

Month	Decade	**Paddy**	**Onion**	**Mustered**	**Wheat**	**Vegetable**	**Potato**
Dec	1st Decade	20%	40%	30%	20%	50%	30%
	2nd Decade	30%	40%	30%	30%	30%	30%
	3rd Decade	30%	10%	20%	30%	10%	20%
Jan	1st Decade	20%	10%	20%	20%	10%	20%

Appendix-C-2: Percentage of area of cultivation under each crop for Kharif-2 of Sujanagar

Month	Decade	T.Aman	Summar Veg
July	1	50%	40%
	2	40%	40%
Aug	1	10%	20%

Appendix-C-3: Net CWR\Decade for Paddy at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	
	2	279.93	249.65	104.68	1.03	158.82
	3	0.00	0.00	0.00	0.00	
Jan	1	0.00	0.00	0.00	0.00	
	2	83.39	77.81	201.29	276.11	159.65
	3	0.00	0.00	0.00	0.00	
Feb	1	0.00	0.00	0.00	0.00	
	2	82.97	82.51	79.99	73.27	79.68
	3	0.00	0.00	0.00	0.00	
Mar	1	0.00	0.00	0.00	0.00	
	2	96.82	140.74	149.21	151.38	134.54
	3	0.00	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	0.00	
	2	0.00	16.22	48.36	105.09	42.42
	3	0.00	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	0.00	

Appendix-C-4: Net CWR\Decade for Onion at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	
	2	11.47	0.00	0.00	0.00	2.87
	3	0.00	0.00	0.00	0.00	
Jan	1	0.00	0.00	0.00	0.00	
	2	37.51	30.90	19.22	7.13	23.69
	3	0.00	0.00	0.00	0.00	
Feb	1	0.00	0.00	0.00	0.00	
	2	57.21	47.51	33.32	21.75	39.95
	3	0.00	0.00	0.00	0.00	
Mar	1	0.00	0.00	0.00	0.00	
	2	105.61	110.88	109.74	97.65	105.97
	3	0.00	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	0.00	
	2	3.00	41.02	74.40	87.63	51.51
	3	0.00	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	0.00	

Appendix-C-5: Net CWR\Decade for Soyabean at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	
	2	8.68	0.00	0.00	0.00	2.17
	3	0.00	0.00	0.00	0.00	
Jan	1	0.00	0.00	0.00	0.00	
	2	59.62	38.96	16.22	5.37	30.04
	3	0.00	0.00	0.00	0.00	
Feb	1	0.00	0.00	0.00	0.00	
	2	67.39	67.76	62.44	39.48	59.27
	3	0.00	0.00	0.00	0.00	
Mar	1	0.00	0.00	0.00	0.00	
	2	31.52	79.98	114.80	124.41	87.68
	3	0.00	0.00	0.00	0.00	
Apr	1	0.00	0.00	0.00	0.00	
	2	0.00	0.00	8.27	41.33	12.40
	3	0.00	0.00	0.00	0.00	
May	1	0.00	0.00	0.00	0.00	

Appendix- C-6: Net CWR\Decade for Wheat at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	0.00
	2	5.89	0.00	0.00	0.00	1.47
	3	0.00	0.00	0.00	0.00	0.00
Jan	1	0.00	0.00	0.00	0.00	0.00
	2	21.39	14.98	9.40	3.62	12.35
	3	0.00	0.00	0.00	0.00	0.00
Feb	1	0.00	0.00	0.00	0.00	0.00
	2	58.24	38.08	17.45	4.39	29.54
	3	0.00	0.00	0.00	0.00	0.00
Mar	1	0.00	0.00	0.00	0.00	0.00
	2	123.48	124.31	117.28	90.31	113.85
	3	0.00	0.00	0.00	0.00	0.00
Apr	1	0.00	0.00	0.00	0.00	0.00
	2	37.92	72.64	0.00	105.09	53.91
	3	0.00	0.00	0.00	0.00	0.00
May	1	0.00	0.00	0.00	0.00	0.00

Appendix- C -7: Net CWR\Decade for Vegetables at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	0.00
	2	17.15	0.00	0.00	0.00	4.29
	3	0.00	0.00	0.00	0.00	0.00
Jan	1	0.00	0.00	0.00	0.00	0.00
	2	52.39	46.71	29.04	10.75	34.72
	3	0.00	0.00	0.00	0.00	0.00
Feb	1	0.00	0.00	0.00	0.00	0.00
	2	59.73	55.53	47.69	38.45	50.35
	3	0.00	0.00	0.00	0.00	0.00
Mar	1	0.00	0.00	0.00	0.00	0.00
	2	79.88	109.53	111.39	107.05	101.96
	3	0.00	0.00	0.00	0.00	0.00
Apr	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	14.57	51.56	79.46	36.40
	3	0.00	0.00	0.00	0.00	0.00
May	1	0.00	0.00	0.00	0.00	0.00

Appendix- C -8: Net CWR\Decade for Potato at Sujanagar

Month\Planting Date	Decade	20-Dec	10-Jan	15-Jan	25-Jan	Average CWR mm/month
Dec	1	0.00	0.00	0.00	0.00	0.00
	2	11.47	0.00	0.00	0.00	2.87
	3	0.00	0.00	0.00	0.00	0.00
Jan	1	0.00	0.00	0.00	0.00	0.00
	2	38.96	26.45	19.22	7.13	22.94
	3	0.00	0.00	0.00	0.00	0.00
Feb	1	0.00	0.00	0.00	0.00	0.00
	2	64.49	47.13	36.12	22.40	42.54
	3	0.00	0.00	0.00	0.00	0.00
Mar	1	0.00	0.00	0.00	0.00	0.00
	2	123.90	124.72	122.97	108.50	120.02
	3	0.00	0.00	0.00	0.00	0.00
Apr	1	0.00	0.00	0.00	0.00	0.00
	2	58.69	95.27	102.20	105.50	90.42
	3	0.00	0.00	0.00	0.00	0.00
May	1	0.00	0.00	0.00	0.00	0.00

Appendix- C -9: Net CWR\Decade for T.Aman at Sujanagar

Month	Decade	10-Jul	20-Jul	1-Aug	Max CWR mm/month
Jun	1.00	0.00	0.00	0.00	
	2.00	41.23	0.00	0.00	13.74
	3.00	0.00	0.00	0.00	
July	1.00	0.00	0.00	0.00	
	2.00	59.73	149.32	166.99	125.34
	3.00	0.00	0.00	0.00	
Aug	1.00	0.00	0.00	0.00	
	2.00	0.56	0.00	0.00	0.19
	3.00	0.00	0.00	0.00	
Sep	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	
Oct	1.00	0.00	0.00	0.00	
	2.00	0.00	6.30	22.73	9.68
	3.00	0.00	0.00	0.00	
Nov	1.00	0.00	0.00	0.00	

Appendix- C -10: Net CWR\Decade for Summer Vegetables at Sujanagar

Month	Decade	10-Jul	20-Jul	1-Aug	Max CWR mm/month
Jun	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	
July	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	
Aug	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	
Sep	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	0.00	0.00
	3.00	0.00	0.00	0.00	
Oct	1.00	0.00	0.00	0.00	
	2.00	0.00	0.00	6.92	2.31
	3.00	0.00	0.00	0.00	
Nov	1.00	0.00	0.00	0.00	

Appendix-C-11: Crop-wise Present Irrigation Water Requirement for Sujanagar

Month	Days	Paddy	Onion	Soyabean	Wheat	Vegetable	Potato	T.Aman	Summer Veg	Max mm/month	FIWR l/s/hec	SIWR l/sec/hec	Remarks
Jan	31	159.65	23.69	30.04	12.35	34.72	22.94	0.00	0.00	159.65	0.60	0.66	Max
Feb	28	79.68	39.95	59.27	29.54	50.35	42.53	0.00	0.00	79.68	0.33	0.37	
Mar	31	134.54	105.97	87.68	113.85	101.96	120.02	0.00	0.00	134.54	0.50	0.56	
Apr	30	42.42	51.51	12.40	53.91	36.39	90.41	0.00	0.00	90.41	0.35	0.39	
May	31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Jun	30	0.00	0.00	0.00	0.00	0.00	0.00	13.74	0.00	13.74	0.05	0.06	
July	31	0.00	0.00	0.00	0.00	0.00	0.00	125.34	0.00	125.34	0.47	0.52	
Aug	31	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.18	0.00	0.00	
Sep	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Oct	31	0.00	0.00	0.00	0.00	0.00	0.00	9.67	2.31	9.67	0.04	0.04	
Nov	30	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	
Dec	31	158.82	2.87	2.17	1.47	4.28	2.86	0.00	0.00	158.82	0.59	0.66	
Total		575.12	223.98	191.56	211.12	227.70	278.76	148.95	2.31				

Appendix D-1: Upazilla-wise Projected Population in the rural areas

Year	Increase rate (r)	No. of Year (n)	Present Population (P_b)		Future Population (P_p)	
	r	n	Pabna	Sujanagar	Pabna	Sujanagar
2001	0.0158	0	381572	251192	381572	251192
2002	0.0158	1	381572	251192	387601	255161
2003	0.0158	2	381572	251192	393725	259192
2004	0.0158	3	381572	251192	399946	263288
2005	0.0158	4	381572	251192	406265	267448
2006	0.0158	5	381572	251192	412684	271673
2007	0.0158	6	381572	251192	419204	275966
2008	0.0158	7	381572	251192	425828	280326
2009	0.0158	8	381572	251192	432556	284755

Appendix D-2: Urban Population at Pabna Sadar

Year	Increase rate (r)	No. of Year (n)	Present Population (Pp)	Future Population (Pb)
2001	0.0158	0	95360	95360
2002	0.0158	1	95360	96867
2003	0.0158	2	95360	98397
2004	0.0158	3	95360	99952
2005	0.0158	4	95360	101531
2006	0.0158	5	95360	103135
2007	0.0158	6	95360	104765
2008	0.0158	7	95360	106420
2009	0.0158	8	95360	108102

Appendix-E-1: Maximum round the year GWL at PAB 022 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	5.6	6.3	6.5	6.54	6.79	6.75			
Feb	5.82	7.3	7.1	7.39	7.39	7.39	6.06		
Mar	6.1	7.9	7.4	7.56	7.64	7.54	7.75		7.79
Apr	7.9	8.6	7.15	7	6.14	7.14	8.02		8.25
May	6.4	7.7	6.75	6.64	4.79	5.81	8.31		
jun	4.9	5	5.6	4.5	5.14	4.69	8.04		7.25
July	3.95	2.45	1.25	3.14	2.64	3.92	3.25		
Aug	2.8	1.3	1.85	2.19	3.29	3.14	0.75		
Sep	2	2.9	2.65	2.79	3.04	2.85			
Oct	3.2	3.9	3.55	3.14	3.25	3.75			
Nov	4.3	5.2	4.4	4.29		5.89			
Dec	5.8	5.95	5.5	5.85		6.6			
Maximum	7.9	8.6	7.4	7.56	7.64	7.54	8.31	0	8.25

Appendix-E-2: Minimum round the year GWL at PAB 022 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	4.9	5.9	6.1	6.14	6.14	6			
Feb	5.5	6.4	6.7	5.64	6.89	6.9	5.89		
Mar	5.96	7.6	7.25	7.21	6.69	7.19	7.35		7.35
Apr	6.25	7.9	6.95	6.83	5.75	6.19	7.1		8
May	4.37	5.4	5.75	4.54	4.79	4.94	7.25		
jun	3.9	2.7	0.6	3.39	2.75	4.62	3.39		6.44
July	2.1	0.25	0.7	1.64	1.64	3.29	2.25		
Aug	1.5	0.6	1.4	1.5	3.14	2.89	0.64		
Sep	1.1	1.4	1.95	2.64	2.42	1.84			
Oct	2.3	1.8	2.85	2.39	2.64	2.34			
Nov	3.15	4.2	3.75	3.39		4.75			
Dec	4.8	5.3	4.5	4.64		6.39			
Minimum	1.1	0.25	0.6	1.5	1.64	1.84	0.64	0	6.44

Appendix-E-3: Maximum round the year GWL at PAB 023 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	6.37	6.31	6.25	6.54	6	6.02	5.74	5.92	
Feb	4.93	5.18	5.06	5.58	4.7	4.98	4.4	6.96	4.71
Mar	3.92	4.19	4.6	4.09	4.01	3.77	3.84	3.35	3.64
Apr	3.61	3.9	4.28	3.58	3.85	3.32	3.28	3.22	3.28
May	4.65	5.04	4.56	4.12	4.26	4.11	3.35	3.39	3.44
jun	7.73	8.49	8.32	8.14	5.23	7.96	7.38	4.8	3.89
July	9.24	10.92	11.27	11.85	10.56	9.34	10.9	10.46	7.36
Aug	10.33	10.99	10.26	11.12	10.51	9.19	11.27	10.77	10.38
Sep	10.41	9.93	10.39	10.16	10.24	9.52	11.65	11.35	9.82
Oct	9.76	9.36	9.79	10.23	9.46	9.3	10.44	10.56	9
Nov	8.24	7.78	8.5	8.66	8.92	7.3	7.69	8.15	
Dec	7.03	6.79	7.17	6.59	6.79	6.42	6.65	6.76	
Maximum	10.41	10.99	11.27	11.85	10.56	9.52	11.65	11.35	10.38

Appendix-E-4: Minimum round the year GWL at PAB 023 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	5.29	5.69	5.39	5.92	5.23	5.32	4.63	5.03	
Feb	4.04	4.11	4.47	4.34	3.81	4.05	4.4	6.21	3.73
Mar	3.53	3.78	4.18	3.56	3.5	3.31	3.43	3.35	3.23
Apr	3.24	3.78	4.09	3.18	3.43	3.15	2.89	2.88	2.93
May	3.84	4.28	4.4	3.15	3.81	3.31	2.92	2.89	3.14
jun	5.19	5.22	4.68	4.55	4.34	4.49	3.48	4.65	3.59
July	8.08	8.99	10.3	9.55	6.88	8.25	8.5	8.64	4.65
Aug	9.82	10.36	9.82	9.57	9.59	8.76	10.38	10.34	8
Sep	9.97	8.94	10.09	9.43	9.59	8.89	10.89	11.22	9.05
Oct	8.86	8.11	9.07	9.53	9.3	7.55	8.15	8.3	8.93
Nov	7.24	7.06	7.4	6.86	7.09	6.53	6.92	7.09	
Dec	6.42	6.38	6.61	6.13	6.15	6.15	6.05	6.57	
Minimum	3.24	3.78	4.09	3.15	3.43	3.15	2.89	2.88	2.93

Appendix-E-5: Maximum round the year GWL at PAB 024 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	7.61	8.93	9.3	8.93	8.14	8.78			7.41
Feb	6.31	7.88	7.11	7.24	7.57	6.34	5.78		7
Mar	5.46	6.04	6.09	6.28	6.53	5.58	5.47	6.99	6.2
Apr	5.14	5.36	5.72	5.24	5.54	4.67	4.97		
May	5.08	6.03	5.4	5.23	4.96	5.14	4.75	5.11	
jun	6.86	8.23	8.24	7.68	4.28	7.86	4.96	5.61	5.47
July	10.28	11.62	11.62	11.4	8.68	8.8	11.16		7.58
Aug	10.68	11.52	11.67	11.62	8.78	8.78	11.76	9.82	10.35
Sep	11.54	10.98	11.61	10.52	8.78	8.89	11.91	11.07	10.85
Oct	11.71	10.66	11.03	10.54	5.77	8.99	11.71	9.82	
Nov	10.19	10.41	9.54	9.91	3.76	8.37		10.4	
Dec	9.7	10.36	9.29	8.7	1.73	8.61		10.21	
Maximum	11.71	11.62	11.67	11.62	8.78	8.99	11.91	11.07	10.85

Appendix-E-6: Minimum round the year GWL at PAB 024 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	6.53	8.04	7.56	7.44	7.7	7.76			7.2
Feb	5.66	6.46	6.25	6.52	6.98	5.67	5.63		6.51
Mar	4.96	5.11	5.66	5.34	5.24	4.86	5.17	6.66	5.58
Apr	4.2	5.06	5.32	4.98	5.03	4.44	4.81		
May	4.85	5.32	5.21	3.96	4.24	4.56	3.91	5.11	
jun	6.01	6.13	5.46	4.56	4.02	5.37	4.66	5.33	5.04
July	7.25	9.03	10.5	8.7	4.01	7.76	7.36		6.06
Aug	10.26	10.66	11.34	10.24	6.74	8.61	10.65	9.56	8.31
Sep	10.41	10.02	11.03	10.04	6.72	8.73	9.96	9.96	10.57
Oct	9.94	9.71	9.12	9.3	5.77	8.19	10.36	9.4	
Nov	9.6	9.26	9.33	8.84	1.74	8.14		9.56	
Dec	9.06	9.87	8.93	8.23	1.5	8.32		10.12	
Minimum	4.85	5.32	5.21	3.96	4.01	4.56	3.91	5.11	5.04

Appendix-E-7: Maximum round the year GWL at PAB 025 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	7.03	6.12	6.32	6.58	6.51	7.41	7.3		
Feb	7.86	7.57	7.58	8.53		8.37			
Mar	8.46	8.19	8.61	8.95	9.2	8.67			8.76
Apr	9.1	8.13	9.02	8.89	9.55	8.47	9.01		9.16
May	7.93	7.71	8.76	8.63	8.52	8.45	8.61		8.73
jun	6.49	6.26	7.69	7.63	7.26	7.64	7.53		7.3
July	5.63	3.61	4.59	5.04	6.03	5.97			6.93
Aug	4.62	3.45	3.33	4.61	3.43	5.32			5.86
Sep	3.65	3.83	3.27	3.77	3.47	5.75			5.5
Oct	3.99	4.67	3.62	4.46	2.92	6.07			
Nov	4.62	5.07	4.72	3.36	3.91	4.23			
Dec	5.16	5.46	5.14	6.19					
Maximum	9.1	8.19	9.02	8.95	9.55	8.67	9.01		9.16

Appendix-E-8: Minimum round the year GWL at PAB 025 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	5.59	5.29	5.73	5.22	5.93	5.26	7.22		
Feb	7.55	6.64	6.61	6.77		7.38			
Mar	7.94	7.78	7.76	7.73	8.94	8.25			8.39
Apr	8.64	7.87	8.92	8.43	8.41	8	8.86		8.87
May	6.74	6.81	7.95	7.53	7.41	7.6	7.98		7.03
jun	5.74	4.99	6.77	4.7	6.11	5.57	6.49		6.76
July	4.56	2.9	2.93	0.33	2.63	4.85			6.1
Aug	4.52	2.94	3.19	1.18	2.52	4.71			2.62
Sep	3.21	3.49	3.12	3.03	2.32	5.2			4.23
Oct	3.6	3.35	2.99	1.68	2.32	3.74			
Nov	4.21	5	3.93	3.1	3.23	3.83			
Dec	4.7	5.19	4.89	5.8					
Minimum	3.21	2.9	2.93	0.33	2.32	3.74	6.49		2.62

Appendix-E-9: Maximum round the year GWL at PAB 026 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan		4.2	3.81	3.95	3.26	3.83	4.87		
Feb		5.01	4.58	4.01	4.08	4.62	5.56		
Mar		5.49	5.23	4.62	4.48	5.23			
Apr		5.71	5.56	5.09	4.41	5.69			5.55
May		5.72	5.58	5	4.41	5.81			5.41
jun		5.16	5.54	4.46	4.15	5.46			5.26
July		3.14	4.46	3.46	3.87	5.12			4.81
Aug		2.01	3.56	1.91	3.79				4.46
Sep		1.73	3.21	1.36	2.51	4.21			3.29
Oct		2.16	3.11	1.07	2.2				2.74
Nov		2.62	2.95	1.98	2.51				
Dec		3.01	3.41	2.16	2.73	4.29			
Maximum		5.72	5.58	5.09	4.48	5.81	5.56		5.55

Appendix-E-10: Minimum round the year GWL at PAB 026 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan		4.14	3.19	3.11	2.83	3.03	4.51		
Feb		4.41	4.03	3.46	3.57	4.16	4.96		
Mar		5.16	4.7	3.79	3.81	4.79			
Apr		5.55	5.32	4.76	4.21	5.41			5.55
May		4.86	5.52	4.89	4.03	5.73			5.26
jun		3.41	4.11	3.95	3.96	4.62			4.8
July		2.05	4.2	2.16	3.28	4.9			4.46
Aug		1.39	3.18	1.31	2.56				3.4
Sep		1.26	1.29	0.61	2.25	3.79			3.25
Oct		1.74	2.43	0.56	1.51				2.26
Nov		2.41	2.57	1.56	2.02				
Dec		2.55	3.01	1.93	2.64	4.29			
Minimum		1.26	1.29	0.56	1.51	3.03	4.51		2.26

Appendix-E-11: Maximum round the year GWL at PAB 027 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	5.4	5.2	4.95	5.36	5.61	5.81		5.31	3.96
Feb	6.18	6.1	5.8	5.91	6.46	6.36			
Mar	6.6	6.7	6.15	6.96	6.91	7.01		6.81	7.51
Apr	6.9	6.5	6.2	7.16	7.01	7.51		6.91	7.61
May	6.7	5.95	6.1	7.31	6.86	8.01			7.46
jun	6.1	5.15	5.4	6.11	5.81	7.61		6.91	6.96
July	5.85	4	2.3	4.45	5.61	5.96	5.16	4.81	
Aug	5.4	2.9	2.3	3.21	3.26	5.31	3.41	3.05	
Sep	4.75	3.3	2.3	3.21	3.16	4.31		3.8	
Oct	3.95	3.7	2.95	3.16	3.51	4.61	3.71	4.21	
Nov	4.45	4.05	3.9	4.46	3.96	5.04	4.76	4.46	
Dec	4.8	4.5	4.54	4.81	4.81	5.21	4.91	4.91	
Maximum	6.9	6.7	6.2	7.31	7.01	8.01	5.16	6.91	7.61

Appendix-E-12: Minimum round the year GWL at PAB 027 station in Pabna sadar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	4.75	4.75	4.6	5.01	4.91	5.01		5.11	3.86
Feb	5.7	5.4	5.2	5.51	5.81	5.96			
Mar	6.3	6.25	5.9	6.21	6.61	6.61		6.61	7.31
Apr	6.65	6.1	6.1	7.01	6.76	7.21		6.91	7.46
May	6	5.3	5.65	6.51	6.86	7.66			7.21
jun	5.95	4.3	4.2	4.91	5.71	6.31		6.41	6.81
July	5.5	2.7	0.95	0.86	2.3	5.31	5.16	3.21	
Aug	4.85	2.6	2.03	1.46	1.76	4.46	3.41	2.11	
Sep	4.2	2.8	2.1	2.61	1.91	4.16		1.61	
Oct	3.3	3	2.4	2.21	2.66	4.01	2.21	3.8	
Nov	3.05	3.85	3.3	3.3	3.36	4.71	4.01	4.01	
Dec	4.4	4.15	4.2	4.56	4.58	5.11	4.51	3.71	
Minimum	3.05	2.6	0.95	0.86	1.76	4.01	2.21	1.61	3.86

Appendix-E-13: Maximum round the year GWL of all stations in Pabna sadar

Station ID\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB22	7.9	8.6	7.4	7.56	7.64	7.54	8.31	0	8.25
PAB23	10.41	10.99	11.27	11.85	10.56	9.52	11.65	11.35	10.38
PAB24	11.71	11.62	11.67	11.62	8.78	8.99	11.91	11.07	10.85
PAB25	9.1	8.19	9.02	8.95	9.55	8.67	9.01		9.16
PAB26		5.72	5.58	5.09	4.48	5.81	5.56		5.55
PAB27	6.9	6.7	6.2	7.31	7.01	8.01	5.16	6.91	7.61

Appendix-E-14: Minimum round the year GWL of all stations in Pabna sadar

Station ID\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB22	1.1	0.25	0.6	1.5	1.64	1.84	0.64	0	6.44
PAB23	3.24	3.78	4.09	3.15	3.43	3.15	2.89	2.88	2.93
PAB24	4.85	5.32	5.21	3.96	4.01	4.56	3.91	5.11	5.04
PAB25	3.21	2.9	2.93	0.33	2.32	3.74	6.49		2.62
PAB26		1.26	1.29	0.56	1.51	3.03	4.51		2.26
PAB27	3.05	2.6	0.95	0.86	1.76	4.01	2.21	1.61	3.86

Appendix-E-15: Average Maximum and Minimum GWL of all stations in Pabna sadar

Field	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average of Max GWL	9.20	8.64	8.52	8.73	8.00	8.09	8.60	7.33	8.63
Average of Min GWL	3.09	2.69	2.51	1.73	2.45	3.39	3.44	2.40	3.86

Appendix-F-1: Maximum round the year GWL at PAB 030 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan				6.82	7.72	7.36	8.32	6.93	7.18
Feb				8.07	8.23	8.39	8.41	7.73	8.22
Mar				8.47		8.79	8.65	8.63	8.88
Apr				9.27		9.09	9.17	8.81	9.36
May				9.1		9.03	9.19	8.64	8.92
jun					8.52	8.04		8.26	8.52
July				7.41	7.58	6.67	6.05	5.68	7.73
Aug				3.86	4.86	4.97	3.11	4.22	6.72
Sep				4	4.59	4.24	3.14	4.11	4.74
Oct				4.27	3.69	5.27	3.81	4.23	4.72
Nov				7.59	4.05	5.91	4.93	5.09	
Dec				6.47	6.06	4.67	6.18	6.26	
Maximum	0	0	0	9.27	8.52	9.09	9.19	8.81	9.36

Appendix-F-2: Minimum round the year GWL at PAB 030 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan				6.17	6.92	6.32	4.75	6.4	6.44
Feb				7.17	7.92	7.82	8.27	6.98	7.42
Mar				8.07		8.49	8.27	7.93	8.88
Apr				8.47		8.94	9.02	8.59	9
May				9.02		8.52	8.67	8.32	8.58
jun					8.42	6.77		6.15	8.22
July				4.57	4.52	4.99	3.86	4.47	7.39
Aug				3.86	3.77	4.51	2.88	3.67	4.82
Sep				3.64	3.92	3.81	2.44	3.23	4.21
Oct				3.86	3.44	3.52	3.02	3.48	4.11
Nov				4.27	4.05	4.36	4.11	4.33	
Dec				6.47	5.35	4.42	5.23	5.25	
Minimum	0	0	0	3.64	3.44	3.52	2.44	3.23	4.11

Appendix-F-3: Maximum round the year GWL at PAB 031 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	4.68	5.03	4.6	5.03	5.79	5.75	6.19	5.46	5.46
Feb	5.38	5.13	5.06	5.57	6.29	6.5	6.36	5.95	6.56
Mar	5.78	5.75	5.41	6.71	6.64	7.07	6.63	6.81	6.66
Apr	6.41	5.83	5.66	6.58	6.75	7.19	6.79	6.81	7.06
May	5.98	5.48	5.43	6.61	6.5	6.75	6.81	6.61	6.79
jun	4.76	4.63	4.54	6.45	6.45	5.13	6.13	6.21	6.31
July	2.01	2.93	1.31	3.41	2.53	1.91	4.19	1.81	4.96
Aug	0.63	0.13	0.2	1.66	1.66	1.81	0.08	0.81	3.46
Sep	-0.02	0.15	-0.52	1.36	1.25	1.05	0.5	1.81	2.5
Oct	1.03	1.6	0.88	1.91	1.74	3.21	1.81	2.32	2.53
Nov	2.6	2.76	2.08	4.32	3.49	4.16	3.36	3.56	
Dec	3.88	4	3.35	4.86	4.56	5.17	4.46	4.06	
Maximum	5.98	5.48	5.43	6.61	6.5	6.75	6.81	6.61	6.79

Appendix-F-4: Minimum round the year GWL at PAB 031 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	3.68	4.14	4.28	4.41	2.36	4.86	5.96	4.16	2.63
Feb	4.98	4.8	4.9	5.11	5.89	6.03	6	5.25	5.69
Mar	5.48	5.13	5.13	5.96	6.48	6.56	6.11	6.06	6.41
Apr	5.91	5.51	5.52	6.28	6.46	6.13	6.66	6.25	6.56
May	4.93	4.48	5.18	5.45	6.46	6.36	5.33	5.71	6.53
jun	2.58	3.32	3.01	4.37	5.08	4.71	4.13	3.62	5.39
July	0.12	0.09	0.16	1.00	1.06	1.91	0.85	0.83	4.31
Aug	-0.95	-0.52	-0.32	0.71	0.02	1.41	-0.33	0.16	1.72
Sep	-0.99	-0.32	-1.12	0.91	-1.29	0.82	-0.33	0	1.82
Oct	-0.32	0.53	-0.9	0.41	1.07	1.03	0.61	0.81	2.36
Nov	1.48	2.02	0.86	2.81	2.21	3.42	2.25	3.36	
Dec	2.83	3.08	2.38	4.03	3.78	-0.25	3.46	2.36	
Minimum	-0.99	-0.52	-1.12	0.41	-1.29	0.82	-0.33	0	1.72

Appendix-F-5: Maximum round the year GWL at PAB 032 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan		2.6	2.91	1.09	0.32	0.37	3.57	2.85	0.89
Feb		2.24	3.13	0.67	-0.37	-0.61	3.63	3.33	2.73
Mar		2.99	3.46	0.04	-0.77	-1.09	3.78	4.02	3.72
Apr		3.59	3.58	-0.52	-0.96	-1.76	4.8	4.65	3.97
May		3.31	3.04	0.39	-0.77	-1.06	4.64	4.17	3.9
jun		2.45	3.5	2.09	0.59	2.36	3.02	4.39	3.55
July		6.48	5.8	6.49	5.17	4.99	5.64	6.63	2.63
Aug		6.65	6.8	6.23	6.67	5.49		7.09	5.41
Sep		6.2	7.8	5.49	5.98	5.91	5.83	6.86	5.33
Oct		5.35	6.6	5.09	3.11	5.09	5.91	5.09	
Nov		3.24	4.7	3.49		2.14	4.14		
Dec		2.44	4	1.24	0.92	2.7			
Maximum		6.65	7.8	6.49	6.67	5.91	5.91	7.09	5.41

Appendix-F-6: Minimum round the year GWL at PAB 032 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan		2.05	2.61	0.71	-0.3	-0.47	3.04	2.77	0.69
Feb		1.42	3.08	0.21	-0.6	-0.98	3.63	2.89	0.67
Mar		2.49	3.1	-0.43	-0.91	-1.61	3.71	3.88	3.02
Apr		3.16	3.52	-1.01	-1.11	-2.08	3.84	3.99	3.78
May		2.14	2.94	-0.29	-0.98	-2.21	3.75	3.73	3.63
jun		1.05	1.26	0.49	-0.21	-0.37	2.22	1.26	3.25
July		3.23	4.48	3.04	1.54	3.09	3.29	5.39	1.3
Aug		6.26	6.38	5.87	5.54	5.23		6.64	4.15
Sep		5.68	6.9	5.16	5.07	5.54	5.83	5.15	4.32
Oct		3.6	4.9	3.94	1.83	2.49	4.47	3.68	
Nov		2.22	4.14	1.69		1.31	2.29		
Dec		1.54	1.24	0.51	0.67	1.07			
Minimum		1.05	1.24	-1.01	-1.11	-2.21	2.22	1.26	0.67

Appendix-F-7: Maximum round the year GWL at PAB 033 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan				5.71	5.42	5.86		6.21	
Feb				6.46	6.31	6.56	6.31	6.01	
Mar				7.29	6.87	6.94	7.24	7.31	
Apr				7.59	6.6	7.86	8.11	7.42	
May				7.39	6.26	7.01	6.8	7.61	3.35
jun				5.93		5.54	6.91	7.2	3.85
July				4.68	5.36	4.61	8.21	4.56	3.95
Aug				2.26	4.14	4.26	1.02		6.65
Sep				1.81	1.87	3.88	0.67	1.47	7.48
Oct				1.61	1.29	3.81	1.33	0.96	8.1
Nov				2.76	1.88	3.34	2.46		
Dec				3.73		4.71	4.41		
Maximum	0	0	0	7.59	6.87	7.86	8.21	7.61	8.1

Appendix-F-8: Minimum round the year GWL at PAB 033 station in Sujanagar

Month\Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Jan				4.41	4.11	2.09		5.56	
Feb				5.91	5.71	6.03	6.23	5.86	
Mar				6.61	6.53	6.52	6.17	6.41	
Apr				7.41	6.57	6.61	7.55	7.19	
May				6.26	6.06	5.88	6.76	7.31	0.55
jun				5.07		4.65	5.73	6.22	3.68
July				2.54	3.97	4.44	2.49	3.89	3.65
Aug				1.81	3.07	3.41	0.42		3.92
Sep				0.51	1.45	3.61	0.51	0.49	6.61
Oct				0.91	1.28	3.39	0.61	0.96	6.99
Nov				1.81	1.36	3.15	2.13		
Dec				2.81		3.61	2.46		
Minimum	0	0	0	0.51	1.28	2.09	0.42	0.49	0.55

Appendix-F-9: Maximum round the year GWL at PAB 034 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	8.56	7.48	8.08	4.57	4.02	4.97		5.52	6.57
Feb	7.81	6.68	7.68	5.02		5.77	7.17	7.07	7.47
Mar	7.1	5.98	6.63	7.87		6.62	7.87	7.52	8.07
Apr	7.65	5.93	6.2	8.87		7.62	8.12		8.37
May	5.98	6.33	6.29	8.72		6.88	8.47		8.57
jun	6.66	6.82	6.58	7.77		6.52	7.47		7.97
July	7.68	7.5	6.82	6.77	5.97	6.47	6.87	6.67	8.35
Aug	8.48	8.02	7.08	5.77	5.77	5.82	4.47	6.32	8.27
Sep	9.18	8.62	7.98	4.52		5.22	4.27	5.77	7.07
Oct	9.13	8.66	8.78	3.52	3.16	4.62	3.62	4.91	
Nov	8.73	8.48	9.13	3.07	3.16	4.66	3.82	4.22	
Dec	8.22	8.38	9.1	3.82	3.77	6.07	4.77	3.97	
Maximum	9.18	8.66	9.13	8.87	5.97	7.62	8.47	7.52	8.57

Appendix-F-10: Minimum round the year GWL at PAB 034 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	7.96	6.88	7.83	4.41	4.02	4.16		5.12	6.07
Feb	7.28	6.13	6.93	4.62		5.16	6.82	6.82	6.87
Mar	6.55	5.63	6.16	5.47		5.97	7.42	7.22	7.67
Apr	5.54	5.63	6.14	8.37		6.87	7.79		8.22
May	5.58	6.03	6.23	7.97		6.57	7.57		8.07
jun	6.14	6.43	6.34	7.02		6.27	7.02		7.87
July	6.84	6.95	6.64	6.02	5.97	5.97	6.77	6.27	7.91
Aug	7.88	7.74	6.88	4.77	5.37	5.07	3.77	6.12	7.32
Sep	8.68	8.14	7.18	3.77		4.77	3.57	5.63	7.07
Oct	8.83	8.56	8.18	2.87	3.16	4.16	3.47	4.53	
Nov	8.35	8.4	8.98	2.82	2.87	4.02	3.57	3.97	
Dec	7.63	8.18	8.98	3.22	3.27	4.97	3.91	3.97	
Minimum	5.54	5.63	6.14	2.82	2.87	4.02	3.47	3.97	6.07

Appendix-F-11: Maximum round the year GWL at PAB 035 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	2.28	2.28	2.53	3.09	2.69	2.98	2.79	3.39	6.19
Feb	2.58	2.88	2.88	3.59	3.74	3.59	3.89	4.79	3.48
Mar	3.28	3.08	3.28	4.24	4.64	4.74		4.94	4.19
Apr	3.68	3.48	3.38	4.41	4.89	4.64	4.49	4.59	4.29
May	3.78	3.68	3.48	4.74	4.74	4.54		4.69	
jun	2.98	3.73	3.48	4.64	4.89		4.39		4.74
July	1.38	3.18	2.88	3.89	3.39		2.39	3.19	4.49
Aug	0.68	1.48	2.18	2.14	2.09	1.98	0.48		4.14
Sep	0.18	-0.02	1.78	2.09	1.44	1.69		4.61	3.19
Oct	-0.22	0.48	1.38	1.19	1.19	1.84	1.39	5.21	
Nov	0.38	1.38	0.68	1.89	1.44	2.19	1.98	5.71	
Dec	1.98	2.18	0.98	2.48	1.73	2.73		2.79	
Maximum	3.78	3.73	3.48	4.74	4.89	4.74	4.49	5.71	6.19

Appendix-F-12: Minimum round the year GWL at PAB 035 station in Sujanagar

Month\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	1.68	2.13	2.28	2.39	2.69	1.98	2.79	2.94	2.39
Feb	2.38	2.38	2.64	3.29	3.64	3.09	3.79	4.74	2.59
Mar	2.68	2.93	2.98	3.69	4.59	3.89		4.49	3.64
Apr	3.33	3.18	3.33	4.29	4.59	4.59	4.29	4.59	4.29
May	3.18	3.53	3.41	4.44	4.64	4.3		4.59	
jun	1.88	3.28	2.98	4.19	3.59		4.29		4.69
July	0.93	1.68	2.38	2.09	2.98		1.59	2.37	4.19
Aug	0.28	0.38	1.88	1.94	1.39	1.73	0.39		2.39
Sep	-0.02	-0.42	1.53	1.39	1.09	1.54		0.69	1.79
Oct	-0.42	-0.22	0.88	0.98	0.89	1.59	0.48	4.51	
Nov	-0.12	0.88	0.48	1.19	1.29	1.89	1.69	5.71	
Dec	0.68	1.58	0.38	1.98	1.48	2.23		2.69	
Minimum	-0.42	-0.42	0.38	0.98	0.89	1.54	0.39	0.69	1.79

Appendix-F-13: Maximum round the year GWL of all stations in Sujanagar

Station ID	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB30				9.27	8.52	9.09	9.19	8.81	9.36
PAB31	5.98	5.48	5.43	6.61	6.5	6.75	6.81	6.61	6.79
PAB32		6.65	7.8	6.49	6.67	5.91	5.91	7.09	5.41
PAB33				7.59	6.87	7.86	8.21	7.61	8.1
PAB34	9.18	8.66	9.13	8.87	5.97	7.62	8.47	7.52	8.57
PAB35	3.78	3.73	3.48	4.74	4.89	4.74	4.49	5.71	6.19

Appendix-F-14: Minimum round the year GWL of all stations in Sujanagar

Station ID	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAB30				3.64	3.44	3.52	2.44	3.23	4.11
PAB31	-0.99	-0.52	-1.12	0.41	-1.29	0.82	-0.33	0	1.72
PAB32		1.05	1.24	-1.01	-1.11	-2.21	2.22	1.26	0.67
PAB33				0.51	1.28	2.09	0.42	0.49	0.55
PAB34	5.54	5.63	6.14	2.82	2.87	4.02	3.47	3.97	6.07
PAB35	**-0.42**	**-0.42**	**0.38**	**0.98**	**0.89**	**1.54**	**0.39**	**0.69**	1.79

Appendix-F-15: Average Maximum and Minimum GWL of all stations in Sujanagar

Field	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average of Max GWL	6.31	6.13	6.46	7.26	6.57	7.00	7.18	7.23	7.40
Average of Min GWL	1.38	1.44	1.66	1.23	1.01	1.63	1.44	1.61	2.49