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Hydrological Characteristics of Barino Tract: A Case Study of Tanore Thana

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HYDROLOGICAL CHARACTERISTICS OF BARIND TRACT: A CASE STUDY OF TANORE THANA

M. PHIL THESIS

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF GEOGRAPHY & ENVIRONMENTAL STUDIES, FACULTY OF LIFE & EARTH SCIENCE IN THE UNIVERSITY OF RAJSHAHI FOR THE DEGREE OF MASTER OF PHILOSOPHY (M. Phil) IN GEOGRAPHY & ENVIRONMENTAL STUDIES.

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DEDICATED TO MY ESTEEMED GRANDMOTHER.

DECLARATION

I do hereby pledge that this dissertation entitled **"HYDROLOGICAL CHARACTERISTICS OF BARIND TRACT: A CASE STUDY OF TANORE THANA"**, submitted to the Department of Geography & Environmental Studies, University of Rajshahi, in fulfillment of the requirement for the Degree of Master of Philosophy is the result of my own research work under the supervision of Professor Abu Hanif Shaikh, Department of Geography & Environmental Studies, University of Rajshahi, Rajshahi, Bangladesh.

I further declare that this is an original research work of my own investigation and has not been submitted or published in part or full for any degree or diploma in this university or any other university.

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CERTIFICATE

I hereby certify that this M. Phil. Thesis entitled "HYDROLOGICAL CHARACTERISTICS OF BARIND TRACT: A CASE STUDY OF TANORE THANA" is an original research work carried out by **Md. Showkat Ali** for the degree of Master of Philosophy in Geography & Environmental Studies under my supervision in the Department of Geography & Environmental Studies, University of Rajshahi Bangladesh. The undersigned recommend the acceptance of the dissertation.

Md. Abu Hanif Shaikh

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Md. Showkat Ali

ABASTRACT

Water is one of the main elements of hydrological parameters and is vital to all living beings. In all sectors of development activities, water plays a key role and all the ecological and biological establishments are depend upon the hydrological components. The present study is an attempt to focus on the hydrological characteristics of the Barind Tract: A case study of Tanore Thana. Tanore Thana is an important thana of Rajshahi district, situated in the high Barind and northwest parts of Bangladesh. The Barind is a rich heartland of agricultural resources. To study the hydrological characteristics of the study area, some hydrological and climatic data were felt necessary. BWDB is a data collection Bank. Hydrologic and climatic data were collected from BWDB and BMD. Other necessary data were collected from different organizations. Quality of water was tested from the Phychology and Limnology lab of Botany department in Rajshahi University. To assessment, explain and analysis of the hydrological characteristics, data were first computed and plotted on the tables, then draw graphs and curves.

Hydrology of the study area is two categories: Surface and subsurface water system. In the surface water system, there are four types of water bodies like ponds/ tanks, beels/ swamps, khals and river. The area and number of the ponds /tanks were increased during the study periods in 1914-1998. The number of swamps/beels area was the same as from 1914-15 to 1965-67 but increased in 1998. This is perhaps happened due to the construction of embankment after 1967 in the eastern bank of the Sib -Baranai river. So the lower area of the western side of Sib -Baranai river was charge into a beel /swamp area. The lengths of Khals were same in 1914-15 and 1965-67 but decrease in 1998. Because, the construction of the embankment after 1967. The

river length is not charge during the study periods. Rainfall is the only source of surface and subsurface water. Rainfall characteristic i.e. monthly and yearly total, average, maximum, minimum, seasonal variation, trends of rainfall and rainy day from 1975-76 to 2001-02 are analyzed in this study. About 80% of total rainfall are available during the rainy season and the winter season is rainless or a scanty of rainfall occurs. The amount of annual average rainfall is 1446.31mm from 1975-76 to 2001-02, which is the lower value of the national average. So the study area is rainfall deficit area in the Barind Tract. Hydrographs of water level and discharge at Nawhata station in the Sib -Baranai river are analyzed in this study. The amount of annual average water level and discharge is 11.178m/PWD and 45.04 m^3/s at Nawhata station in the Sib -Baranai river in 1975-76 to 2001-02. During the study periods, August is the peak position of water level and discharge and April is the lowest position of the year at Nawhata station. Most of the Khals and river are dry-up during the dry season. So, the surface water bodies of the study area is not sufficient for large-scale water utilization.

In the subsurface water system, monthly and yearly ground water level, trend of water level from different wells, ground water contour map and water movement pattern, ground water fluctuation, recharge and discharge, relation between recharge and discharge etc. were investigated to visualize the response of ground water reservoir during the study periods. The study area includes both Recent flood plain and the Pleistocene upland (Barind Tract), which have different ground water potentiality. The Recent flood plain part in the eastern side of the study area is suitable for large-scale ground water development. The depth of the water table and the physiographic condition is desirable in the eastern part. But the Pleistocene upland part in the western, southwestern and northwestern part is not favorable for ground water development. The depth of water table, rate of fluctuation and physiographic condition are not suitable for large-scale ground water extraction. The highest water table (20.023m) is found in the western part of the study area and the fluctuation rate is very high. The aquïfer in this part of the investigated area has limited potentiality to produce water and low dischargeable well development to meet the requirements of group domestic supply and farm supply is suggested for this part of the study area. Total annual available recharge is 60.7 million cubic meters and annual withdrawal is 113.20 million cubic meters for the whole study area. Rainfall is the only major source of water of aquifer replenishment. The percolation of rainfall water to the aquifer is accelerated by the presence of mudcracks. Moreover, the aquifer adjacent to the river Sib -Baranai receives recharge from the river when the river stage is higher than the ground water table.

As regards quality, the subsurface water or groundwater as well as surface water is more or less of equal in importance to quantity. To establish quality criteria, measures of chemical, physical and bacterial constituents must be specified as well as standard methods for reporting results of water analysis is necessary. The physical properties of sample water of this study i.e. temperature, color and odor, conductivity, turbidity, taste etc. and chemical properties i.e. p^H, Do, Co_2, BOD_5, CL, Co_3, Eh, rH_2, Total hardness, Ca-hardness, Mg-hardness, Silicate, Phosphate etc. are tasted in this study. To compare the Lab test data and standard data given by different agencies, it is found that most of the sample water are suitable for drinking, agriculture, domestic and other purposes. There fore, it may be said that all the biological and ecological establishments depend on water. It may be concluded that pollution free water will save the people of this area and will improve environmental quality.

LIST OF CONTENTS

LIST OF TABLES

LIST OF MAPS

LIST OF FIGURES

LIST OF ABBREVIATIONS

GWC = Ground Water Circle.
BWDB = Bangladesh Water Development Board.
SSO = Senior Scientific Officer.
SPARSO = Space Research and Remote Sensing Organization.
BMD = Bangladesh Metriological Department.
PWD = Point Water Discharge.
TM = Thematic Mapper (Satellite Sensor).
FCC = Falls Color Composite.
P^{H} = Position of H^{+} ions.
O_2 = oxygen.
CO_2 = CarbondiOxiede.
CO_3 = Carbonate.
HCO_3 = Bicarbonate.
ALK = Alkalinity.
CL = Chloride.
BOD = Biological Oxygen Demand.
Ca^{++} = Calcium ions.
Mg^{++} = Megnacium ions.
Eh = Oxidation-Reduction Potential.
RH_2 = Oxidation-Reduction Index.
BBS = Bangladesh Bureau of Statistics.
JICA = Japanese International Co-operation Agencies.
MPO = Master Plan Organization.
mm = Millimeter.
UNDP = United Nation Development Program.
NWP = National Water Plan.
PHED = Public Health and Engineering Department.
BADC = Bangladesh Agriculture Development Corporation.
BARC = Bangladesh Agriculture Research council.
PPM = Parts per Million.
WHO = World Health Organization.
SIS = Indian Standards Institutions.
WSP = Water Supply Paper.
NNE = North and North East.
SSW = South and South West.
UNICEF = United Nation International children Emergency Fund.

CHAPTER-1:

INTRODUCTION

1.1:Introduction:

Water is vital to life and development in all parts of the world. In the third world countries including Bangladesh, the agricultural sector as well as economic growth plays a key role and management of water resources is given top priority in the all development activities of the country. One of the apparently more perplexing and essentially simple topics which has developed in recent years and which is continuing to grow even more rapidly is hydrology. Basically, hydrology deals with water as it occurs over precipitation, stream flow, soil moisture and ground water.

Bangladesh is a deltaic land. It is the eight populous nation and less developed country in South Asia. The country is in the northern hemisphere, tropic of cancer passing through the middle of it. Bangladesh is situated in the active monsoon region of the world with a variation of normal rainfall from 6496 mm in Lalkhan, Sylhet to 765.5 mm at Tanore thana (1994-95) in Rajshahi districts. The landform of Bangladesh is dominantly flood plain in nature with distinctive lithology, structure, geologic and tectonic history.

The total population of Bangladesh is about 123.15 million and the density of population per square kilometer is 834 persons in 2001 (Population Census-2001). One of the basic problems of the country today is generally known as large population overcrowded in a relatively small territory (Khan, 1994). Production of food grain has increased tremendously during the last four years and Bangladesh has attained self-sufficiency in food. The only viable alternative is to increase the internal production of grain. This has been possible by developing irrigation facilities during the dry season, improved crop varieties, more widespread use of fertilizers and modern technology of land cultivation.

The main purpose of this research is to examine the nature of hydrology of the Barind Tract. The Barind region that is lying in the northwestern part of the country includes parts of the districts of Rajshahi, Chapi-Nawabgonj Naogaon, Jaypurhat and Dinajpur. The Barind being a uniform alluvial plain land, its surface seems to be an old riverbed. It is a highly elevated tract and undulating too. The Barind, which is supposed to belongs to an older alluvium deposits formed during the Pleistocene epoch, probably known as pleistocene terraces. Geologically, this is one of the oldest land surfaces of the subcontinent. The Barind, however, with its gentle slopes resembles parts of Midnapur and Bakura of West Bengal on the fringe of the Chotonagpur plateau.

The Barind Tract consists of several terraces within the Bengal basin. Predominantly terraced in the west and level in the east. River-carved valleys have separated the tract into sections. Generally, the elevation of the western one regards up to 40 m and the mid-west ranges from 20-23 m. This tract is characterized by its comparatively high elevation, reddish and yellowish-gray clay soils, entrenched dendritic stream patterns and a relative paucity of vegetation (Hunt, 1984). About 70% of the total area of Barind Tract lie within the territory of Bangladesh and the remains 30% is in India. In Bangladesh, the Tract covers an area of 8466 square kilometers, spread over three sub-regions that are topographically distinct: (a) Dissected Barind Tract (b) Level Barind Tract (c) Northeast Terrain:

Three mighty river systems- the Ganges, the Bramaputra and the Meghna drain Bangladesh. These three rivers together with their numerous tributaries and distributaries have built up the largest delta complex of the world, occupying an area of about 60000 square kilometers. Hydrologically, the whole of Bangladesh can be categorized into 4 regions, such as Northwest, Northeast, Southwest and Southeast and actually the Tista flood plain and the Barind

Tract covers the whole of the Northwest region of the country (Huda and Choudhury, 1986).

In the broad sense, the Barind region goes under the Ganges river system. The Tista, the Atrai, the Mahananda, the Punarbhaba, the Sib-Baranai, the Little Jamuna, their tributaries and distributaries are within the Ganges river system and dewater the whole Barind region. In the study area, the Sib-Baranai river and her tributaries and distributaries are dewatered by rainwater. River, khals, ponds, beels are the main sources of surface water bodies. Underground water is the source of subsurface water. Master Plan Organization divided the whole country into 163 catchment areas and each catchmet area was divided into several planning areas. The present study area covers the planning area 9 in the catchment area 32 (MPO, 1980). The most conspicuous event leading to the initiation of arid condition in the Barind region has followed as the effect of the diversion of the major river courses flowing through the region. Most of the rivers now have become dead and dry, carrying some water during the rainy season and completely drying up during the winter months and dry season. With the changes in the river courses and the hydrological changes in their conditions, changes in soil characteristics and the microclimate are gradually occurring. While this is occurring in a slow and gradual process the northwestern region is getting dry. The probable causes of the increasing aridity in the region are due to population increase, increasing area of crop production, an increasing trend of double and triple cropping, cutting of trees, changing of river courses, ground water depletion, reclamation of water bodies, over- grazing and the unfavorable relief (Jabber et. al. 1982). Diversion of the Ganges water may have accelerated the dessertification process with tremendous effect (Ahmed, 1984). With the beginning of the winter season, the water level in the Ganges Farakka barrage section rapidly falls and consequently a new sharp gradient is formed. This largely contributes to the drying up of the river and the sharp fall in ground water level in the Barind region including the study area.

All the Biological and ecological establishments depend upon the natural resources like water. A large number of water bodies are available all over the country. Since the ancient time people of this country have used water for irrigation by local methods from surface water. The capricious nature does not always fulfill the necessity of water for agriculture. But the people of that time were able to use only the surface water for irrigation. Ground water was only used for drinking and other domestic purposes.

In the Barind region, surface water potential is seasonal and very limited. Practically it is impossible to irrigate this vast tract of land with the available limited surface water and thus ground water development is now an essential task particularly in the study area. So, water management and proper utilization of water is very essential for agricultural production in the dry season.

The Landsat image of the Barind region provided by SPARRSO (Includes study area, Plate-1) shows a definite change in vegetation cover, land use and soil moisture which indicates that a desert like condition prevails during the dry season (Summer, from March to May). The Barind Tract is a droughty zone of northwest Bangladesh that may be described as semi-arid in character through most of its stretches. Planning for drought-1 prone areas in the country should naturally pay attention to the Barind Tract. Therefore a very interesting and essential topic has been selected for this research entitled, **"Hydrological Characteristics of Barind Tract : A Case Study of Tanore Thana"**.

Plate-1 : Landsat TM FCC hard copy image 1998, SPARSO.
Location : 78/D, Scale-1: 200000.

Color Description : Red, Light Red and Redish gray=Agriculture Land
Gray, Dark Gray, Redish gray = Settlement.
Light Blue to Blue. and Dark Blue to Blue = Water Bodies
Gray, White to light blue, Yellowish blue = Uncovered Soil

1.2: Objective of the study:

The main purpose of this research is to examine the scope and nature of hydrology of the study area. This study provides factual basis for large-scale utilization of water resources of the study area. Perhaps no detailed work has so far been done on the hydrology of Barind Tract at the thana level and the present one is the pioneering stap. The main objectives of the study are:

To explain the surface water bodies of the study area;

To explain the rainfall characteristics;

To analyse the hydrograph of water level and discharge of Sib- Baranai river;

To discuss the hydrograph of water table, fluctuation of water table and the direction of subsurface water of the study area;

To estimate the actual recharge and annual discharge of ground water of the study area;

And lastly to explain the quality of water in the study area.

1.3: Definition of Hydrology:

Hydrology is one of the newest branches of natural science. In general, it may be defined as the study of water as it occurs over precipitation, stream flow, soil moisture and ground water. All over the world, many hydrologists try to define the term "Hydrology". Some of these definitions are:

"Hydrology is the science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth" (Wisler and Brater, 1949).

"Hydrology is that branch of physical geography dealing with waters of the earth with especial reference to properties, phenomena and distribution. It treats specifically of the occurrence of water on the earth, the description of the earth with respect to water, the physical effects of water on the earth, and the relation of water to life on the earth"(Linsley, Kohler and Paulhus, 1975).

"The science of Hydrology deals with the occurrence and movement of water on and over the surface of the earth. It deals with the various forms of moisture that occur and transformation between the liquid, solid and gaseous states of

***landmass. It is concerned also with the sea-the source and store of all the water that activates life on this planet*"**(Wilson, 1990).

So, from the above definitions it is said in brief, Hydrology simply involves the study of water resources on the earth surface and its proper management and scientific planning of the water resources to develop human affairs.

Hydrology is divided into two categories; surface water hydrology and subsurface hydrology or hydrogeology. Surface Water hydrology may be define as the study of precipitation, stream flow, discharge, water bodies (Permanent & seasonal) drainage pattern etc. And Subsurface Water Hydrology or Hydrogeology can be defined as the study of ground water with particular emphasis given to its chemistry, mode of migration, relation to the geologic environment, soil moisture, infiltration, recharge-discharge relation, fluctuation of water table etc.

1.4:Sourcs of data, Materials and Research Methodology:

The present study is principally based on data obtained from secondary sources, field observations and laboratory work. Detailed hydrologic investigations of the study area were performed by using all sorts of available hydrologic, climatic and hydrogeologic data collected from different organizations related to hydrological works.

Bangladesh Water Development Board possesses a good data collection network all over the country. The data which include water level monitoring, monitoring of river stage and discharge, recording of rainfall, evaporation, record of water analysis, analysis of water samples, drilling of exploratory borelogs and pump test data were collected from Gound Water Circle and Surface Water Hydrology Division of Bangladesh Water Development Board. Climatic data like temperature, duration of bright sunshine, relative humidity etc. were collected from the Department of Meteorology, Dhaka.

Both the satellite hard copy images (Landsat TM [FCC], Band 2,3,4, Location 78D/10, Scale 1: 50000) and topographical maps (Sheet No. 78D/5,6,.9,10;Scale 1: 50000) were used to identify the surface water bodies, past and present drainage pattern, origin of tributaries and distributaries of the study area. The satellite hard copy image and topographical maps were collected from SPARSO and Survey of Bangladesh. A base map was collected from thana engineering office at Tanore.

An attempt has been made to prepare a water bodies map by using both satellite hard copy images and topographical maps. Water bodies were verified during the fieldwork. And eventually the maps of the water bodies map were prepared by interpreting the satellite hard copy image, topographical maps and field checking.

Some other maps were prepared using suitable cartographic techniques and tables.

Analyses of the hydrological data, some statistical and diagrammatical techniques have been made in this study. The unclassified data are first plotted on the table by statistical methods. Line graphs, bar diagrams, contour maps, hydrographs etc. have been drawn to analyse the surface and subsurface hydrology diagrammatically.

To identify the water quality of the study area, laboratorical tests have been done and for this some chemical agents were used. The significance of water quality analysis mostly depends on the sampling. By purposive sampling, sampling stations have been selected on the basis of accessibility and uniformity of concentration. Tanore thana consists of six unions. One spot has been selected in every union for purposive sampling and this is shown in the table-1.1 and appendix-A.

Table-1.1: Sampling station selection of water quality test.

Spot ↓	Station ↓	Season ↓	Height (MSL)	Depth of the Sampling wells
A	Pranpur	Wet	73′	120′
B	Sadipur	Wet	100′	180′
C	Saranjay	Wet	68′	140′
D	Kalma	Dry	77′	175′
E	Parishow	Dry	47′	160′
F	Talando	Dry	59′	155′

In this study, the physical and chemical tests of sampling water have been done in the Phychology and Limnology Lab of Botany Department in Rajshahi University and the methodology of the study has been shown in the table-1.2

Table-1.2: Methodology of the sample water test.

	Parameters	Methods	References
PHYSICAL TEST	Air and Water temperature	Centigrade Thermometer	-
	Transparency	Sechi disk	Gautom-1990
	Conductivity	Conductivity Meter Model Cm-1k(0-10000)	-
CHEMICAL TEST	P^H of water	Digital P^H Meter, model HANNA instrument	-
	Dissolved O_2	Kit Box, model-2p cat no. 1469-00	HATCH CO.
	CO_2,CO_3, & HCO_3 ALK.	Tritration	Welch-1948
	Cl, BOD_5, Total hardness, Ca-hardness, Mg-hardness	Titration	APHA-1989
	Eh, rH_2	Calculation	Gautam-1990
	Phospate,Silicate	Titration	Gautam 1990

1.6:Review of Literature:

In the Barind area, the research work with detailed hydrological study and investigation at the thana level is the first carried out. No earlier attempts were made to deal with hydrology viz, surface and subsurface hydrological condition with detailed relevant informations. Through the lack of proper information and data, some sporadic research work was done in a district or regional basis based on insufficient data. There are some papers which have been reviewed in this chapter.

Bangladesh water development board (BWDB) published a series of regional hydrogeological survey reports for the year1977-2000 including basic data on groundwater table and lithological characteristics of the aquifer and the result of analysis of those data. BWDB (1985) also published the hydrologeological map of Rajshahi district showing different aspects of groundwater potentiality of Rajshahi and the surrounding region.

Joseph (1984), a consultant of Bangladesh Agricultural Research Council, in his paper "Area Development of the Barind Tract" discussed the physiography, environmental crisis, environmental policy, land use planning, water, vegetation and water resource management of the Barind region.

Ahamed (1984), scientific research officer of SPARASO, in his paper "Remote Sensing Study of Aridity in the Northwest Region (Barind Tract) of Bangladesh" deals with geomorphology, hydrology, soil, cropping, land use and remote sensing etc. of the region.

Assaduzzaman (1985), in his seminar paper,"Hydrology of Barind Tract", focuses on the general hydrological characteristics, nature of hydrology, condition of surface and subsurface water components and source of surface and subsurface water of the Barind Tract as a whole.

Islam (1991), in his article "physiography and river flow pattern of the Barind tract" (in Bengali) discussed the physiography, soil and river pattern.

Mazumder, Jahan and Ghose (1993) in their paper, "Hydrogeology of Tanore and Nachole thanas of the Barind projected Area" focussed mainly on the ground water hydrology and surface water hydrology.

Selim Reza (1995) in his M.Sc Thesis paper, "Evaluation the hydrogeological condition of Bholahat, Gomastapur, Nachole, Niamatpur, Porsa, Saphar and Patnitala thanas of the Barind Tract". investigated the ground water potentiality, moisture content, rate of vertical infiltration, fluctuation in ground water table, lithological variation,etc. of the region.

The present study is performed by the light of the above papers.

1.5: Limitation of the Study:

"Hydrological Characteristic of the Barind Tract: A Case Study of Tanore Thana" is a bonafide research work done by the researcher. It is very difficult to draw a perfect conclusion on this topic. The present research work is concerned with some of the components to the Hydrology within the Tanore Thana, Rajshahi, Bangladesh territory and it has been done on the basis of supplied data which are available in office of the BWDB, Dhaka. So, great care is taken during the handling data for this research work. Although BWDB is entrusted with the collection of all sorts of data and information, yet the accuracy of data seems to be doubtful but researcher has tried to present the work more correctly. Neverthemless this work may be regarded as a first attempt or may be a pioneering task in the field of hydrological aspect at thana level in Bangladesh. It is hoped that the present study will stimulate interest for a more comprehensive study in this discipline.

1.7:Research Organization:

The present thesis **"Hydrological characteristic of the Barind Tract: A case study of Tanore thana"** is organized into six chapters.

Chapter one is the introductory one, which discusses the scope and justification,objective of the study, definition of hydrology, source of data, materials and methodology, literature review, limitation of the research.

The location of the study area, physiography, surface configuration and land elevation, soil and soil structure, general geology, drainage system, climate, population etc. have been discussed in chapter two.

In chapter three, the hydrological variable like sources of surface water, rainfall characteristics, water level, discharge and hydrograph analysis of Sib-Baranai river have been outlined.

Chapter four discussed the availability and nature of hydrogeological data, ground water table analysis, groundwater contour maps and movement of water, ground water table fluctuation, natural recharge and artificial discharge and balance between the recharge-discharge in the study area.

The water chemistry i.e. physical and chemical quality of water of the study area have been discussed in chapter five. Findings, suggestions and conclusions are drawn in the summary and concluding chapter.

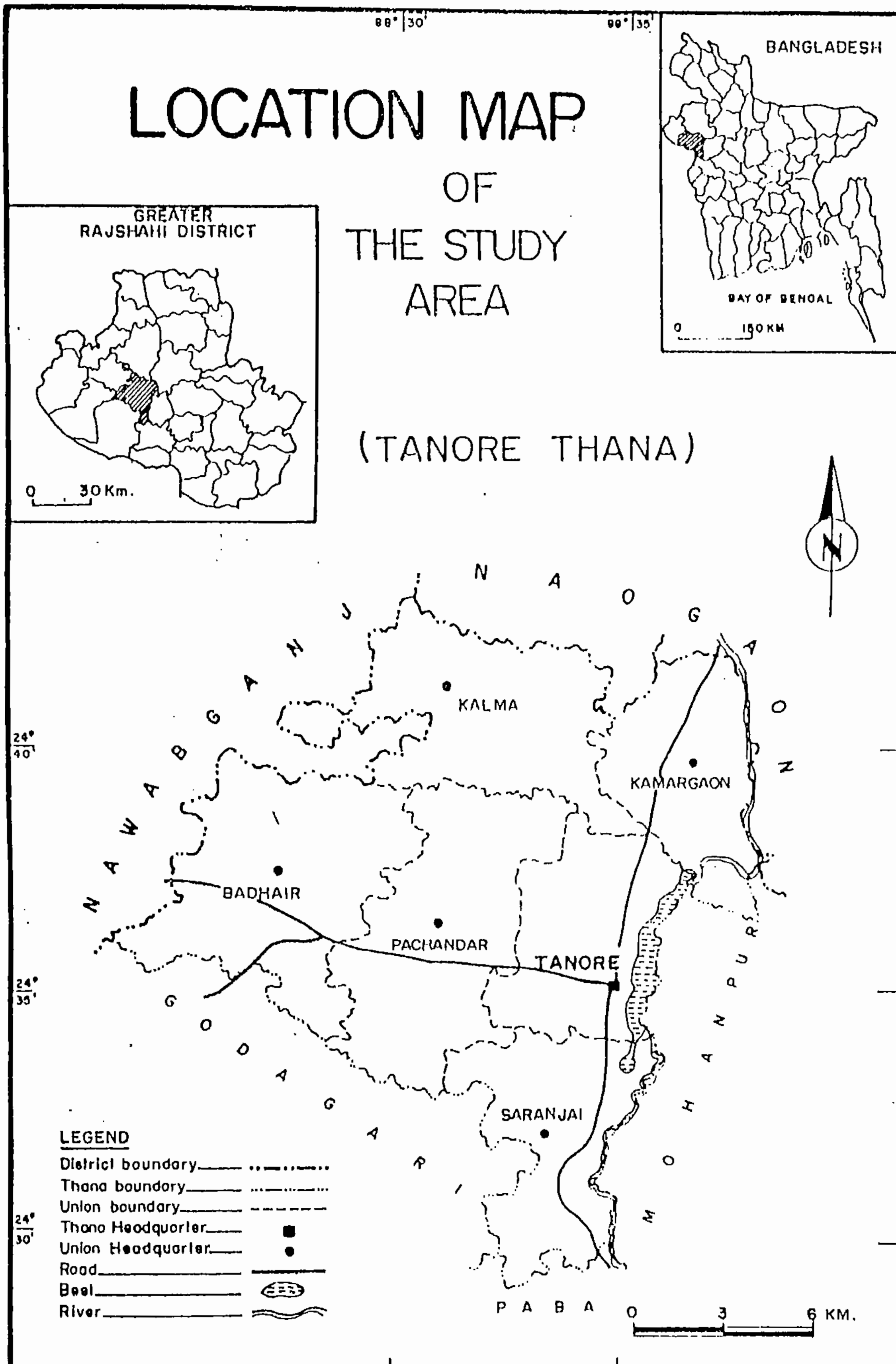
CHAPTER-2

GEOGRAPHIC SETTING OF THE STUDY AREA

In any geographical study, it is very important to know what is the geography of the area. This chapter deals with a brief outline of geography of the study area i.e. area and location, physiography, surface configuration and elevation, soil and soil structure, drainage, general geology, climate, population etc. of the study area.

2.1:Area and Location:

Tanore thana is the subdistrict of Rajshahi district, which occupies an area of 295.39 sq. km. It is located between 24°29′ to 24°43′ north latitude and 88°24′ to 88°38′ east longitude (BBS, Community Series, 1991). The thana is bounded on the north by Niamatpur and Manda thanas of Noagoan district, on the east by Mohonpur thana, on the south by Paba thana, both of Rajshahi district and on the west by Nachole and Nawabganj sadar thanas of Chapai-Nawabgonj district (Map-2.1). The thana consists of 6 unions, 211 Mauzas and 333 village.The study area is well connected with Rajshahi city by roads.



Source: BBS 1988

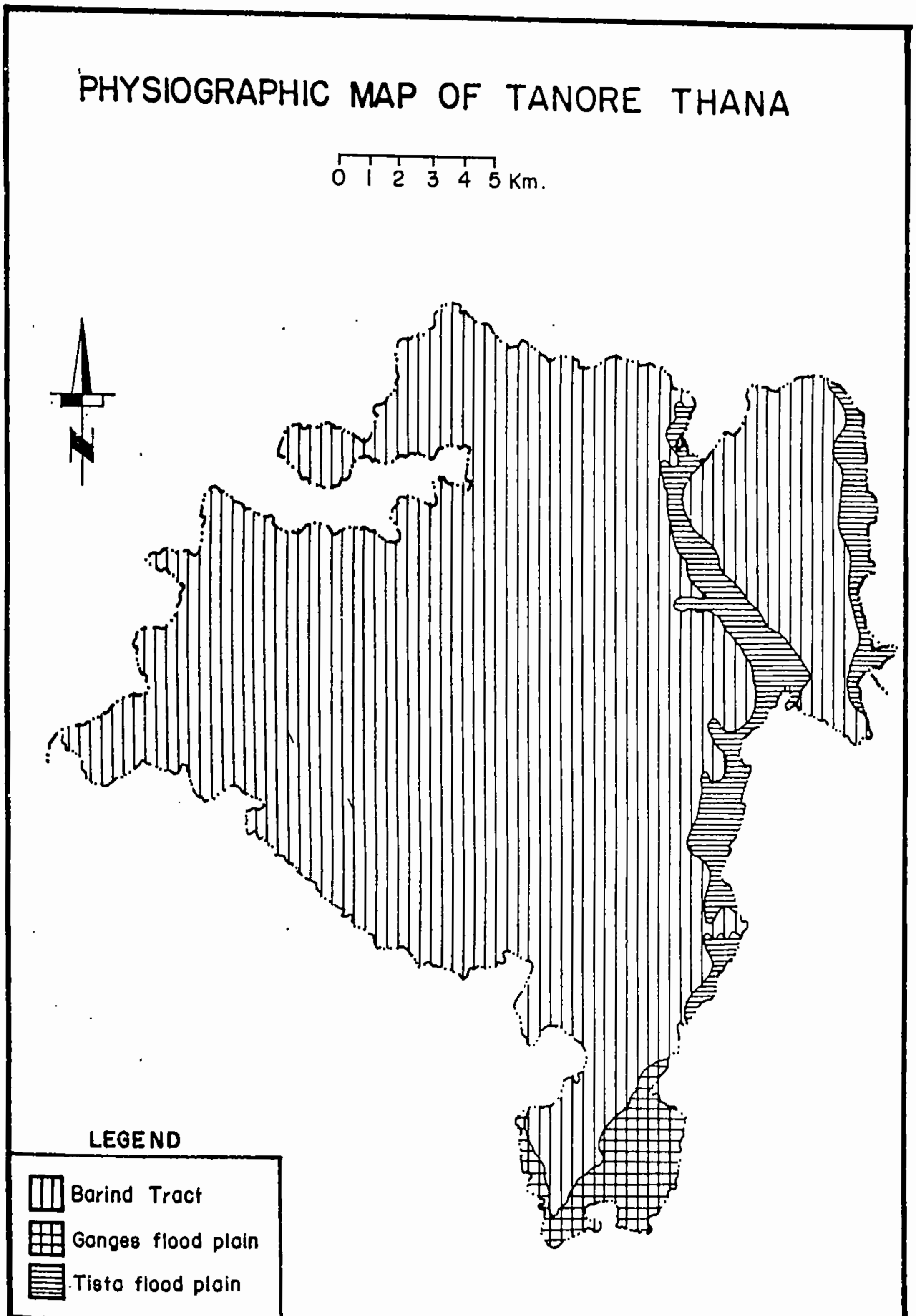
Map-2·1

2.2:Physiography:

The study area can be divided into three physiographic types. There are: (a) Braind Tract, (b) Ganges Flood Plain and (c) Tista Flood Plain. The physiography of the study area is shown in the table-2.1 and map-2.2

(a) Barind Tract: The Barind Tract is one of the several terraces of Pleistocene epoch within the Bengal basin (Rashid, 1991). The area is slightly raised and compressed to the surrounding area due to tectonic movement. Here the elevation of the land is comparatively higher than the adjacent flood plain. The Barind is a dome shaped slightly elevated land. The elevation is about 40 meters in the western side and the elevation is about 20 meters in the eastern side. The Barind Tract appears in the

landscape in the form of a series of tilted, uplift and fault blocks. The landform comprises mainly level in eastern and northern part where as dissected and undulating in the western part. The area is moderately undulation with large level land passing into relatively low laying area with gentle slope. The ridge tops are almost level. In the eastern side, the tract passes the adjoining flood plain sediments. In Tanore thana, Barind Tract has an area of about 24614 hectares of land or 83.21% of the total area of the thana (Table-2.1,).



SOURCE: Soil resource development institute, 1994, Rajshahi.

(b) Ganges Flood Plain: This portion of land of the Tanore thana is plain land and covers the southeastern side of the study area. In this area, a low land is the form of Hardo beel is found.In general, the topography is smooth and the land elevation is more less than 20 meters. In Tanore thana, Ganges flood plain has an area of about 519 hectares or 1.75% of the total area of the thana (Table- 2.1)

(c)Tista flood plain: It is covers the eastern and north- eastern part of the study area. Here the relief is medium level with ridges and shallow basins. Most of the land is shallow flooded (Rashid, 1991). Madaripur beel, Tanore beel etc. are situated in the Tista flood plain area. About 1660 hectares of land or 5.61% of the total area of the thana is in the Tista flood plain area (Table-2.1).

Table-2.1: Physiographic region of Tanore Thana

Physiographic unit ↓	Area (in hectare)	% of the total area
Barind	24614	83.21
Ganges flood plain	519	1.75
Tista flood plain	1660	5.61
Water bodies(including river)	2747	9.43
Total	29580	100

Source: Soil Research Development Institute-1994, Rajshahi.

2.3:Surface Configuration and Elevation:

Geologically, the Barind Tract is one of the oldest land surfaces of the Bengal basin. The area has a dome shaped topography. The south-western and western sides is slightly elevation and Pleistocene Terraces marges ultimately to recent flood plain. Pleistocene terrace has suffered vertical movement from Pleistocene onward. As a result, the sediment of the tract lies considerable above the surrounding flood plain. During the upliftment, the drainage with light increased meandering courses were formed. Differential relief, which now exhibited by the land surface, is the expression of differential upliftment of the individual fault blocks.

Again on the basis of the elevation of topography, which generally refers to as a land level, is also an important aspect, especially in the micro level study. In the south -western and western side, the elevation is about 40 m. The elevation decreases from 15 to 20 meters as the river valley is approached in the eastern side. The minimum elevation of the whole thana is about 12 meters and the maximum elevation is about 40 meters above the mean sea level. In the study area, land level has been identified as the relative elevated of land with respect to surrounding lands. According to the level, the Tanore thana can be divided into four units as:

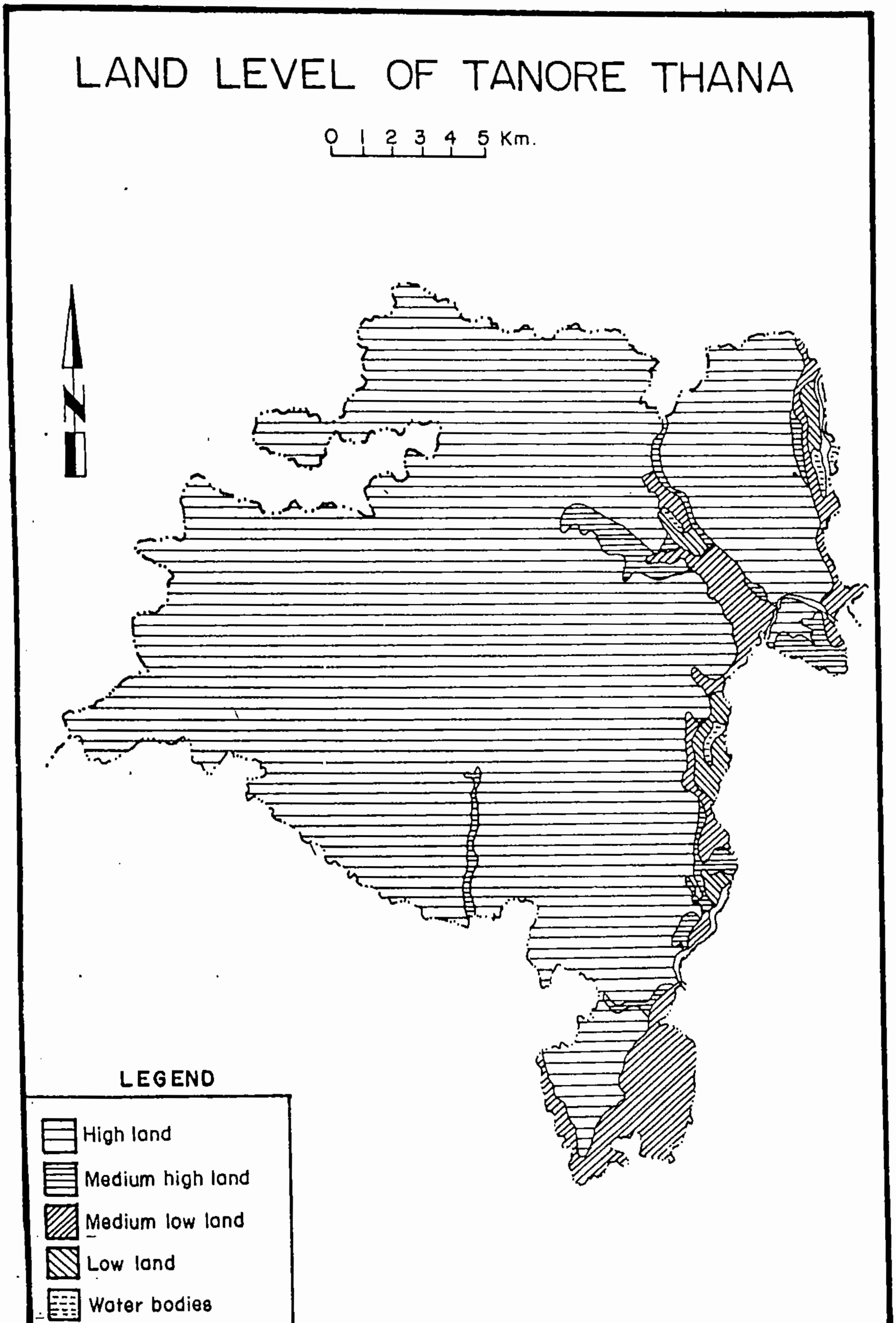
(1) Highland, (2) Medium highland (3) Medium low land and (4) Low land.

Land level, area and percentages of the total area are shown in Table-2.2 and Map-2.3.The area exhibits undulating land surface. The main characteristics of the region are irregular topography. The irregular depression formed in the land surface is expressed by marshy and swampy land. The top surfaces of the ridges are comparatively level. In the study area, most of the areas are high land occupying about 77.86% of the total and a very few part is low land, which scatterly distributed particularly in its eastern fringe.

Table-2.2: Area and percentage of land level of Tanore Thana.

Land Level ↓	Area (Hectare)	% of the total area
High land	23032	77.86
Medium high land	1368	4.62
Medium low land	1553	5.25
Low land	467	1.58
Water bodies	65	0.23
Others	3095	10.46
Total	29580	100

Source: soil Resource Development Institute - 1994, Rajshahi



SOURCE: Soil resource development Institute, 1994, Rajshahi.

Map – 2·3

2.6:Soil and Soil Structure:

The western and north-western part of the thana is characterized by oldest alluvium of Pleistocene epoch which has been considerable oxidized unlike the soil of the flood plains that are mainly composed of silt and clay loams. According to Morgan and Mc-Intire (1956), the soil of the tract is almost identical with that of the recent flood plain soil which is typically dark, loosely compacted, with a high water content and appreciable quantities of organic matter. The soil of the tracts has been severely oxidized to reddish brown or tan colour. Calcareous and ferruginous modules are found in many places, which shows mottling of red, brown and orange colours. The soil of the tracts is more compact than that of the flood plain soil because of the low water content. The content of organic matter is also very low. Oxidation of the soil took place perhaps due to deposition of these sediments in continental environment from Pleistocene age. In the study area, the soil may be identified as:

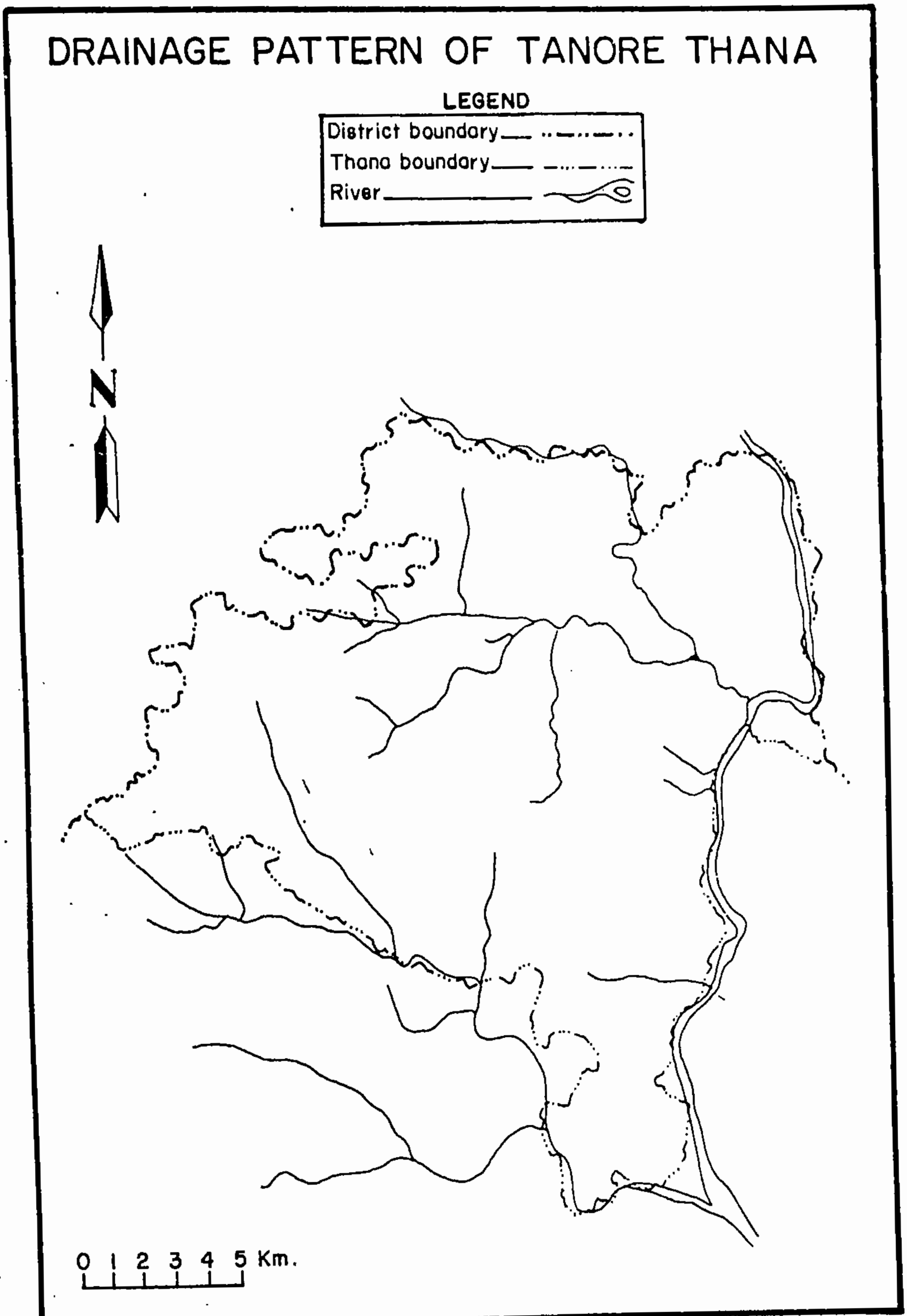
(a) Reddish Brown Terrace Soil: This type of soil occurs in the north-west and western part and it is mainly clayey, reddish to yellow in colour and contains high amount of iron and calcium carbonate with ferruginous concretions. The p^H value of the soil varies from 6 to 6.5 (Islam, 1967). The soil is generally deficient in nitrogen, phosphates and potassium that are needed to sustain higher crop yield. When dry, this soil becomes as hard as brick and when wet, it becomes stricky and slippery. They are generally above flood level and it is dry in the dry season.

(2) Flood Plain Soil: In the eastern and northeastern part of the thana, shows a pattern of friable silty loam or silty clay loam soils. The p^H value of the soil varies from 7 to 8.5 (Islam, 1967). The soil stratum is very below a depth of 0.2 to meters.

(3) Soil of the Marshes and Beels: This type of soils is found in some localized marshy and swamps lands. This soil is mainly black loam, friable and non-calcareous in character. This soil is highly fertile and contains qualities of organic matter.

2.5:Drainage:

In the study area, the Sib-Barani river (River No-98) drains in the eastern side. The drainage system in the thana is made up of the Sib-Barani river and its tributaries that show an intricate network of narrow meandering courses, exhibiting dendritic pattern (Map-2.4).



Source: SPARRSO

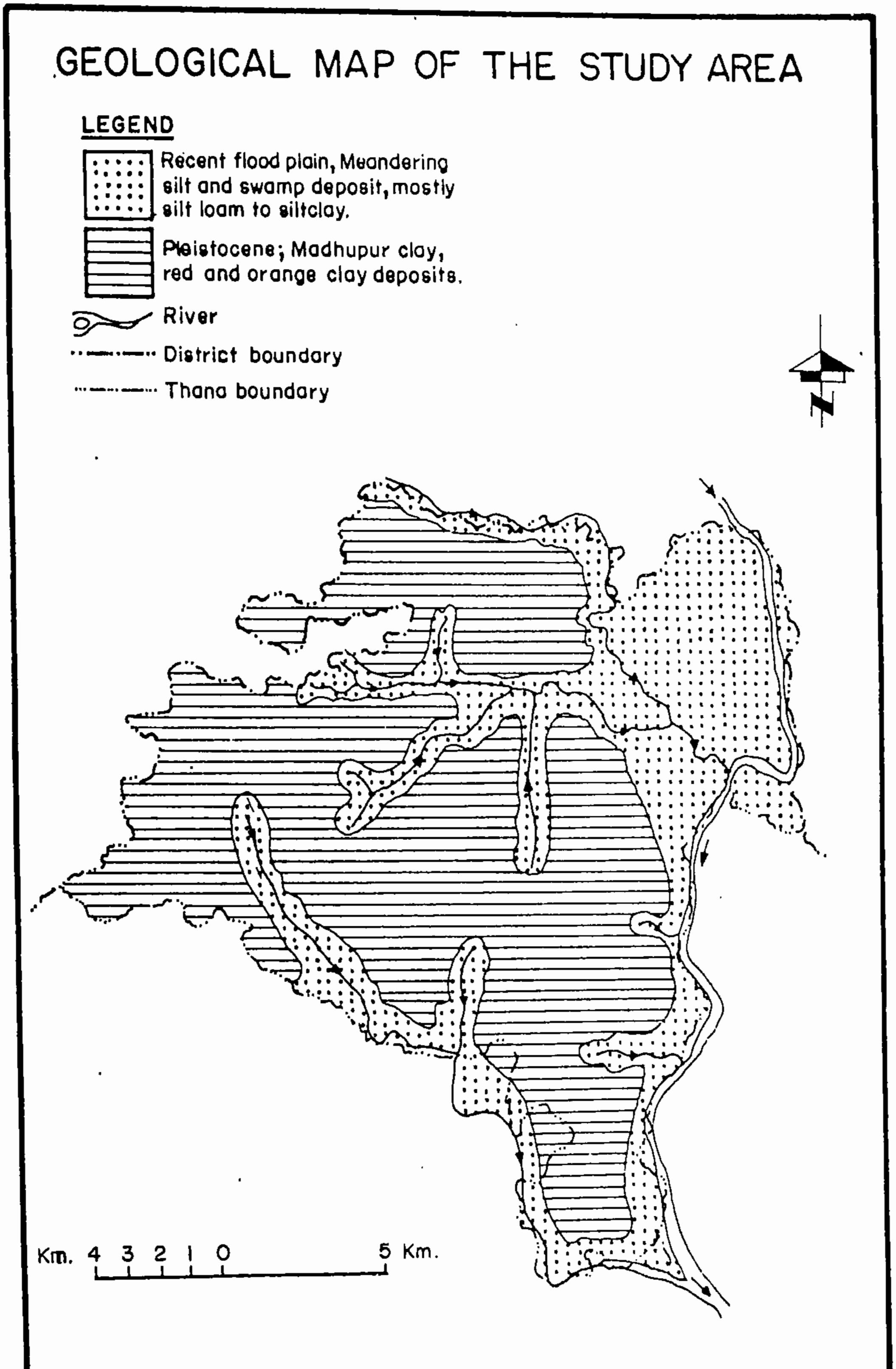
Map-2·4

The terraces of the area were severely dissected during the uplift, as a result of which shallow, narrow and deep broad valleys were formed. During the monsoon, intermittent flow takes place due to rainfall .All of the tributaries of Sib-Barani river have eastern flow of the study area (Map-2.4).

2.6:General Geology:

The surface geology of the study area consists entirely of sedimentary formations that include both recent flood plain deposits and Pleistocene sediments. The Pleistocene sediments are formation of the Barind tract of old alluvium and the recent flood plain deposits is the new alluvium. Barind tract is characterized by the undulating topographic features with high ridges and moderately leveled low area in between the ridges.

The Barind tract is predominantly composed of gray terraced clay soil, which weathered to form of gray silt topsoil; they are poorly drained, generally, except the dissected margin, which are composed of oxidized red brown terrace soil. (Joseph, 1984). The Pleistocene clay layer reaches maximum thickness (45m) at Nachole, which is situated near the western side of he study area. The Madhupur clay formation of pleistocene deposits is exposed in the central and western part of the study area (Map-2.5).



Source: After Bashar, 1990. Map-2·5

The organic matter content of the soils of Barind Tract is very low and it ranges from 0.8 to 1.2 percent in most of the soils. The natural fertility of the soils of Barind Tract ranges from moderate to moderately low.

The soil occurring on the summits and terraced slopes are imperfectly to poorly drained, mixed gray and brown or gray in color and silt loam to silt clay loam, occasionally silt clay or clay in texture. The sub-stratum is partially on unweathered Madhupur clay, occur at a depth of 0.6-0.9 meters from the surface.The p^H ranges from 5.5 to 6.5 of the study area;

The soils occurring in the valleys (flood plain deposits) are comprised of gray or mixed gray and brown, silt loam or silty clay loam over clay substratum at a greater depth. They are imperfectly too poorly drained and the value of p^H ranges from 6.0 to 7.0.

A unit of very fine sand, fine sand and medium sand occur below the clay layer covering the whole area. This unit is occasionally interrupted by clay layers and layers of coarse sand and gravel. Below the sandy unit, a unit of gray to earthy gray, silt, silty clay and clay with fine sand (Basher, 1990). The total thickness of this unit is not known.

2.7: Climate:

Climate is the general condition of weather for a place or region over extended periods of time. In Bangladesh, the Tropic of cancer passing through the middle from west to east and the study area is not far from the tropic of cancer. For this, climatically the study area falls under tropical-humid monsoon climate with high temperature, quite a good amount of humidity, moderate rainfall and fairly marked seasonal variation (Rashid, 1991) in summer (March to May) which is hot and periodic thunder showers; monsoon (June to October) which is warm, humid and during which 80% or more of total rain occurs.

In summer or pre-monsoon, Barind Tract (Grater Rajshahi District) experiences a very high temperature and it gradually becomes almost unbearable with extremely dry winds (Khan, 1989). The prevailing wind direction is southeasterly from April to September and northwesterly from October to March. The prevailing wind speed varies about 2.0 m/Sec to 4.5 m/sec. The wind speeds in this area of the country are generally much lower than that of its coastal belt (JICA-1986).

From the rainfall data of last 27 years (1975-76 to2001-02) of rainfall gauging station (R-219) at Tanore thana, it is found that the maximum rainfall was recorded in 1999-2000 with 2877.5 mm and the minimum rainfall was recorded in 1994-95 with 705.5mm (Table-3.8)

The mean monthly temperature is almost below 25°c from November to February and about 29°c to 44°c in March to October. The coldest month is January and warm month is April to May.

From table 2.3, it is found that the annual average highest evaporation was 1137.7 mm in 1989-90 and the lowest 767.9 mm was found in 1993-94 during the study periods. Again, monthly evaporation was 188.8 mm in the month of April in 1992 when both temperature and duration of sunshine are relatively high and relative humidity still low. The average relative humidity is about 75%. The lowest humidity was 53% in the month of April in 1992 and the highest was 90% in the month of July in 1995 in the study area.

Table-2.3:Annual Rainfall, Rainy day & evaporation in 1985-1995.

Parameters →	Rainfall in Tanore station (No-219)		Evaporation in Rajshahi station (No-292)
Year ↓	Rainfall (mm)	Rain day	Mm
1985-86	1319.2	66	938.3
1986-87	1593.7	72	961.7
1987-88	1802.8	57	1002.8
1988-89	1824.9	54	1084.2
1989-90	1842	57	1137.7
1990-91	1429.6	89	973.1
1991-92	1707.7	86	846.5
1992-93	124205	54	967.7
2993-94	1219.1	69	767.9
1994-95	765.5	60	877.7
1995-96	1792.7	79	-

Source: Bangladesh Water Development Board.

2.10:Population:

In the study area, the variation of the population distribution is caused perhaps indirectly by the Sib-Baranai river system. The Sib-Baranai fertilized the land and serve as a good communication facilities. In the western part of the study area is highly elevated (Barind Tract) where water is not available in dry season from any natural sources to mitigate the demand of the people. And there is no tube-well or dug well, the survival of the people in threatened in the dry season. As a result only in the rainy season, which is the time for harvesting crops, people from other places come to stay there temporarily. (Such temporary houses in the western part of the study area that is called "Bathan Baris").

Most of the peoples are Muslims (81.65%). There are 10.19% Hindus, 1.54% Christian, 0.21% Buddhist and 6.4% believers in other religions (population census-1991). In 1974, 1981, & 1991 census year the females population is higher than males population and this figure is 68949 person males and 69060 person females in 1991.

From the table-2.4 and figuire-2.1, it is found that the number of population in the study is increased almost triple fold during the last 50 years and this trend is also found in Rajshahi and Bangladesh.

Table-2.4: Total population of Tanore Thana, Rajshahi district and Bangladesh in 1951-1991.

Census years	Tanore thana		Rajshahi district		Bangladesh	
	Total population	Density (per/sq.km)	Total population	Density (per/sq.km)	Total population	Density (per/sq.km)
1951	46013	156	58214	242	4193329	293
1961	58864	199	728000	302	50840000	374
1974	91571	310	1190000	494	71497000	517
1981	112460	380	1540000	639	87052000	609
1991	138013	467	1880000	784	106314000	755
2001	158301	536	2262483	940	123150000	834

Source: (1) Population census of pakistan-1961, National Vol.-East Pakistan &District Vol.- Rajshahi.
(2) Bangladesh Population Census-1974, Bulletin-2.
(3) Bangladesh Population Census-1991, District Vol.-Rajshahi.
(4) Bangladesh Population Census-2001, Premilary Report.

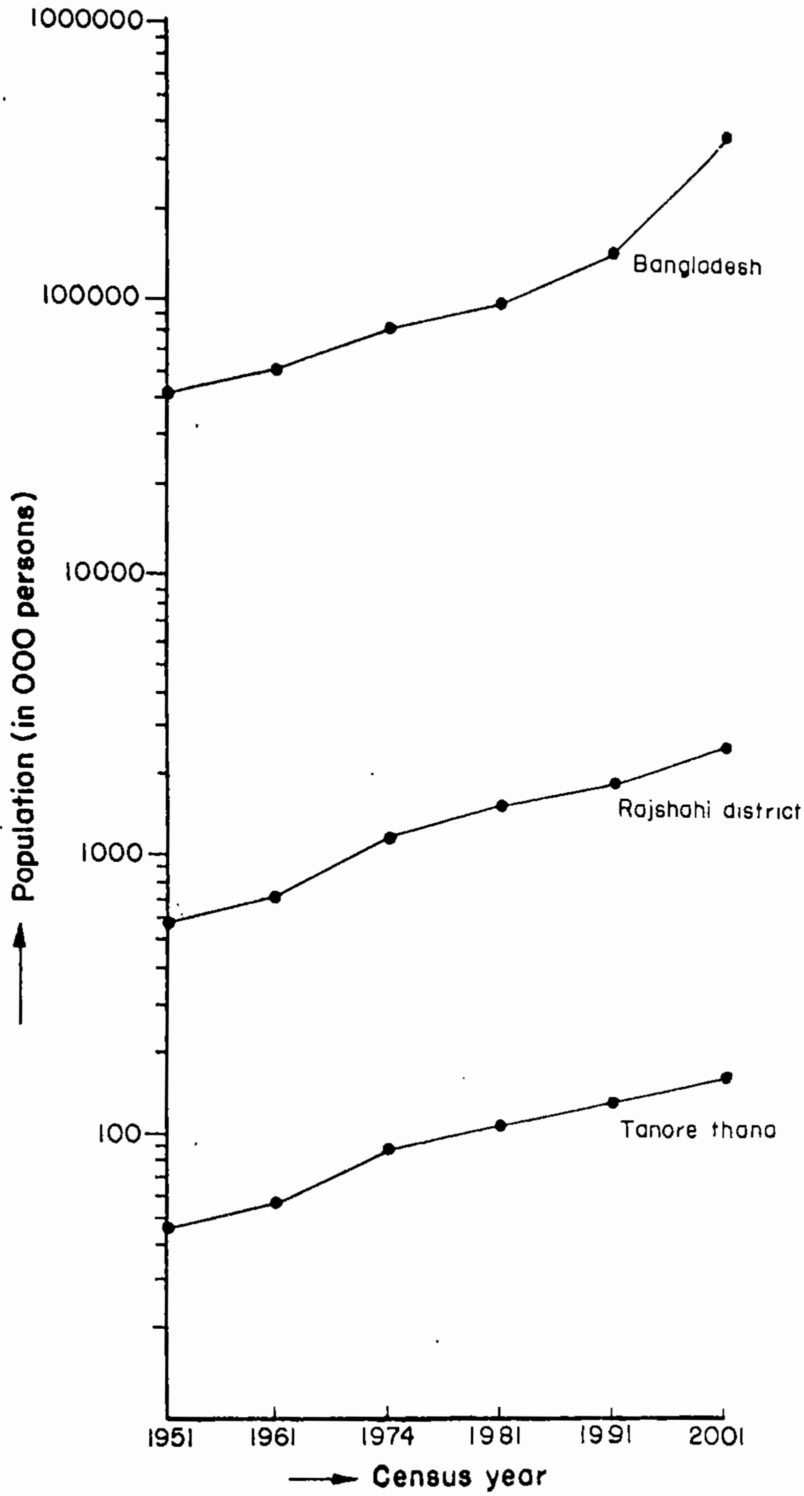


FIG. 2·1: Trend of population grouth.

CHAPTER-3

SURFACE WATER HYDROLOGY

The water, which is found and moves over the surface is regarded as the surface water. The surface water has an important role for the very existence as well as amended phenomena in the study area. The Surface water and subsurface water or ground water is closely related to each other. Its occurrences, movements, storage and fluctuation of an area depend upon the physiography, drainage, soil type, climatic condition and other factors. Surface water is generally easy and economical to hardness but its availability varies with the season and its natural used for irrigation frequently causes problems like water logging. In the study area, surface water bodies are ponds beels, canals and river that drains the area and in the alluvial deposits and bedrock underlying the surface. A brief study in the surface water hydrology, deals with surface water system as ponds, beels, cannals and river, sources of water, rainfall characteristics, seasonal variation of rainfall, hydrograph analysis of Sib-Baranai river in the study area.

3.1: Surface water system:

Surface water system in the study area are in the forms of river, ponds, beels and canals etc. Moreover, water may temporarily retain on land surface immediately after precipitation until its secondary movement as over land runoff or vertical infiltration takes place.

The study area is a part of elevated Barind Tract due to comparatively steeper slope of the area. Here water moves readily down the surface slope towards the river Sib-Barani or canals and beels. A part of surface water moves to the saturated zone through infiltration. The length of canals/khals and river and the number and area of ponds, beels, are shown in the table 3.1,3.2,3.3 respectively and these parameters are widely discussed in below:

3.1.1: Ponds:

Pond is the dominant forms of surface water in the study and these ponds are contains large amount of water. Some of the ponds are dry up in summer due to lose of water in their body. Maximum ponds in the study area contain water in all time through the years. At Tanore thana the number of ponds are 99 that of area is 400.24 acres in 1914-15, the number of ponds are 2105 and area is 1158.81 acres in 1965-67. According to thana fisheries office at Tanore, the number of ponds are 22437 and the area is 1375.08 acres but 442 ponds are traced from the map of SPARSO in 1998,which is shown in the map-3.3. The pond of Kashardighi of Sanranjay Union, Naranpur dighi and Taluapara dighi of Badhair Union are the largest pond in terms area and that is, the number and area of ponds have increased during the study periods from 1914 to 1998. The thana have six unions and the number and area of ponds are plote union wise in the table and maps. (Table-3.1and Map-3.1, 3.2, 3.3, respectively). From the map and table it is observed that the Proportion of ponds are much larger in the western and southwestern part than that of the eastern and northeastern part in the study area. It is also evident that perhaps due to item of another of all upon ponds beels canals and river. In the study area, the highest number of ponds (511) are found in 1998 at pachandor union and the lowest number of ponds (236) are found in 1998 at Kamargong union. In the study area, average maximum depth of water of the rises 10 feet to 12 feet and minimum depth of the water falls up to 9 feet but some times level in the month of March to May surpresingly fall in between 4 feet to 4.5 feet.It is perhaps due to longer dry season in some of areas. It is truly noticed that in the dry season, most of the forms of water bodies were dry up accepting the pond. That is why, pond water is regards the most important form of surface water body in the study area. Maximum use of ponds water are for irrigation in the driest month and for pisciculture it is all the year round. The main characteristics of some larger ponds are discussed bellow: -

Kashordige: It is one of the largest pond of saranjay union, with total area about 39.32 acres. This pond does not dry in any time through out the year. Its water is used for piscicutture throughout the year and in the driest month for irrigation.

Talupara dighi: It is another largest ponds under Badhair union in the study area. The area of this pond is 18.31 acres. It is perennial and used only for piscicuture and domestic purposes.

Narayanpur dighi: Narayanpur dighi is the 2nd largest forms of ponds of Badhair union. It is occupies an area of 15.30 acres. This pond is not dry-up in any time throughout the year. It is used for irrigation in the driest month and pisciculture throughout the year.

Table-3.1: Surface water body (Pond) of Tanore Thana from 1914-15 to 1998.

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Years →	1914-15		1965-67		1998	
Name of Unions ↓	Number	Area (acres)	Number	Area (acres)	Number	Area (acres)
Saranjay	12	63.50	334	201.08	408	251.75
Pachandor	12	42.62	511	291.96	589	328
Badhair	25	94.94	445	202.82	530	260
Kanargong	08	31.68	245	158.82	236	156.6
Kalma	25	102.48	303	177.88	407	251.89
Talando	17	65.02	267	126.09	267	126.09
Thana total	99	400.24	2105	1158.81	2437	1375.08

Source: (1) Survey of India, 1914-15(Topographical map, Rajshahi college).
(2) Survey of Bangladesh, 1965-67(Topographical map, Sheet No. 78D/6, 78D/10).
(3) SPARSO-1998 (Landsat TM(FCC), Band 2,3,4 and Scale 1:50000).
(4) Thana Fisheries office, Tanore thana.

3.1.2: Beels :

Union wise area of beels are shown in the table-3.2. In the study area, three unions have no swamps or beels. At saranjoy union 93.86 acres, kamargong union 32.11 acres and talando union 675.25 acres beels are found in 1914-15 and 1965-67. But the beel area of talondo union is increased in 1998 and the area is 864.05 and other two union is same during the study periods. This is shown in the maps and table (Map-3.1, 3.2, 3.3 and Table-3.2). An embankment is built-up through the eastern bank of Sib-Baranai river after 1965-67. For this,ultimately the lower area of talando union in the western side of the river is changed into a Beel area. This is why, the Beel area is increased at talando union.

In the rainy season, the beel area is flooded and damages the crop in the surrounding area. This time, different types of are found in the beel area. But it is dry up or a little water in their body in the driest month of the year. In

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In the rainy season, the beel area is flooded and damages the crop in the surrounding area. This time, different types of are found in the beel area. But it is dry up or a little water in their body in the driest month of the year. In the dry season, the farmers put up their paddy in the beel area and shallow pump or deep tubwell performs irrigation.

Table-3.2: Surface water body (Swamp/Beel) of Tanore Thana in 1914-15 to 1998.

Years → Name of Unions ↓	1914-15 Area (hectors)	1965-67 Area (hectors)	1998 Area (hectors)
Saranjay	93.86	93.86	93.86
Pachandor	-	-	-
Badhair	-	-	-
Kanargong	32.11	32.11	32.11
Kalma	-	-	-
Talando	789.25	789.25	864.50
Thana total	915.22	915.22	990.47

Source: (1) Survey of India, 1914-15 (Topographical map, Rajshahi college).
(2) Survey of Bangladesh, 1965-67 (Topographical map, Sheet No. 78D/6, 78D/10).
(3) SPARSO-1998 (Landsat TM(FCC), Band 2,3,4 and Scale 1:50000).

3.1.3: khals :

There are several khals are present in the study area and most of the khals are linked with one another and lastly fall into the river. Among this khals, Musakha khals, Islampur-Koail khal, Charkhar-Billi-Khal are the bighest khal in the study area. The length of the khals is 92.3 kilometers in 1914-15 and 1965-67 and 90.50 kilometers in 1998.There is no remarkable change in khals length in 1914-15and 1965-67. But a steep change in 1998. Because 2.80 kilometers Khal was change into a beel area. After 1967, an embank was built-up through the eastern bank of Sibu-Baranai river and the khal area was change into beel area. The lengths of khals are calculated according to union wise and this is shown in the table (Table-3.3).

little change occurs in the case of tributaries and distributaries . The Sib-Barani river enters into the study area from Niamaltpur Thana of Nawgong district in the north east side. Union wise length of Sib-Baranai river is shown in the table -3.3 and map-3.1, 3.2 and 3.3 respectively. The catchment area of the river about 2175 squire kilometer in Bangladesh including 273.39 squire kilometers in the study area.

During the rainy season, the Sib-Baranai river gets a large volume of water from rainfall and the river turns into a new artery of communication network. Some times the river flooded the surrounding area and this time different types of fishes are found in this river. The fishermen are catch fish through the rainy season. In the dry season, the river became about dry but contain a very little water. The farmers cannot get so much water for irrigation purposes during the dry season and a little portion of water is used for domestic consumption.

3.2: Source of Water:

Precipitation is source of all classes of water in the surface and subsurface bodies and it maintain a cycle. The forms of precipitation are rainfall, hail, ice, snow, dew, fog etc. In a broad sence, the source of almost all our water is the sea. In the study area, rainfall, hail, dew, fog are occur but only the record of rainfall is available and a station have been set-up since 1975. And for this, only rainfall characteristics have been discussed in the present study.

3.2.1: Rainfall characteristics:

Rainfall is the most significant source of water in the study area. Rainfall in Bangladesh originate from three sources: the western depressions of winter which account for 5% of the total, the early summer thunder storms (north westerlis) which account for about 15% of the total and the summer monsoon which account for about 80%. The monsoon accompanied by strong winds and heavy squall moves from the southwest in May-June generally associated with tropical depression in the Bay of Bengal and Indian 0cean. July is the wettest month. From August to May it experiences a dry season particularly in the west but a secondary ,monsoon rainfall peak may occur in September. From November to Aprial,it experiences a rainfall of less than 100 mm and some times it contain up to may.

3.2.2: Monthly Rainfall

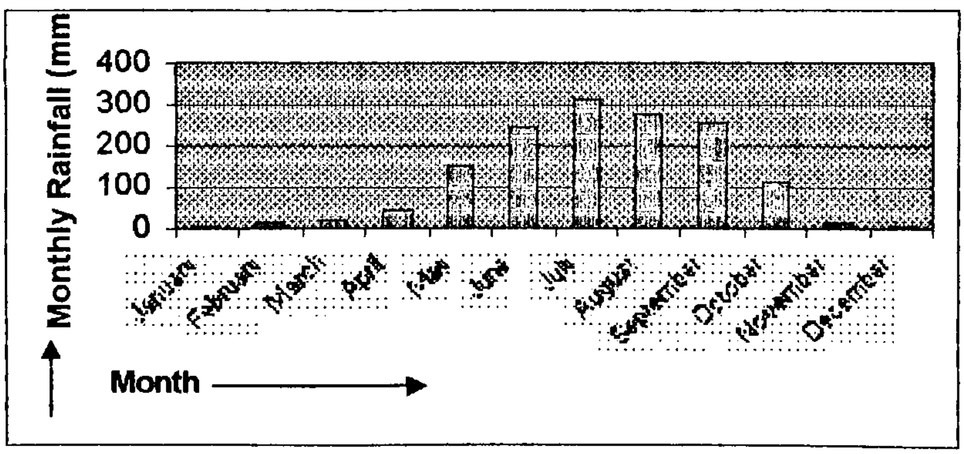
The monthly average, maximum minimum rainfall are shown in the appendix-F and appendix-G. The study area is characterized by moderate rainfall with a marked regional and seasonal variation. The average annual rainfall in the study area of the last 27 years (1975-76 to 2001-02) is 1446.31 mm. The highest and lowest rainfall was 1842mm in 1989-90 and 765.5 mm in1994-95 respectively at Tanore station within the last 27 years .The annual maximum and minimum one day rainfall was 203.2mm in 1986-87 and 0.1mm in 1990-91 at Tanore station within the last 27 years .From the appendix-F and appendix-G it is found that the rainfall is occurs only rainy season and the maximum and average rainfall are found in the rainy season. The minimum rainfall is occurs in the dry season.

Table -3.4 mean monthly rainfall over the study area (Averaging 27 years data).

Month	Monthly mean rainfall (mm)
January	08.06
February	10.33
March	16.64
April	43.86
May	151.95
June	243.20
July	310.19
August	272.71
September	259.15
October	110.14
November	12.01
December	07.94
Annual total	1446.31

Source: BWDB.

Fig- 3.1 : Mean monthly rainfall over the study area (Averaging 21 years data).



3.2.3 :Seasonal variation of Rainfall:

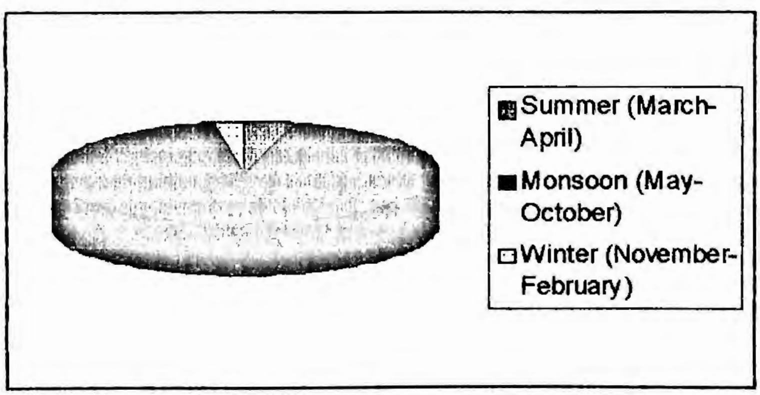
Rainfall is not evenly distributed throughout the year in the study area. Abrupt seasonal variation in the intensity of rainfall takes place. The skewed distribution of rainfall in the area shows almost the same pattern like all other parts of Bangladesh. The figure of the study area shows the fact. Generally rainfall is caused by monsoon in rainy season from the month May to October. About 93% of the total rainfall take place in this period. From November to April (Winter and Summer), the whole area remains dry due to scarcity of rainfall over the study area can be seen from the following table and figuire-.

Table-3.5: Seasonal distribution of rainfall over the study area for the last 27 years.

Season	Rainfall (mm)	Percentage of yearly total
Annual	1446.31	100
Summer (March-April)	60.50	04.18
Monsoon (May-October)	1346.47	93.16
Winter (November-February)	38.34	02.66

Source: BWDB carried out

Fig-3.2: Seasonal distribution of rainfall over the study area for the last 21 years.



3.4.4: Trend of rainfall and Rainy day

Trend of rainfall and rainy days have an important role in any hydrological analysis of an area. In the present study, the annaul total rainfall and is given in the table 3.6 and figure-3.3, 3.4, 3.5 and 3.6 .To observe the change in the amount of annual rainfall with time, a graph (Figuire-3.3) has been constructed from the annual rainfall data of last 27 years at Tanore station. Another graph (Figuure-3.4) has been constructed from annual rainy day versus time. The average rainfall of the station was also shown in the figure points about the dotted line indicate more rainfall than average and those bellow average line shown rainfall less than the average. To observe from the table-3.6, it is found that 12 years annual rainfall is less than that of the station average and 9 years annual rainfall is higher than that of the station average. The station average of rainfall from the last 27 years is 1446.31 mm and the national average is 2030mm. Annual rainy day versus time (year) graph has been constructed in this study. The graph shows, 14 years rainy day is less than the average and 7 year rainy is higher than the average and the average rainy day was about 61. The highest rainy day was 89 in 1990-93 and the lowest rainy day was 44 in 1982-83 (Table-3.6).

3.6-Table: Rainfall data in 1975-76 to 2001-02 (Station: 219, Tanore).

Year	Annual Rainy day	Rain fall data		
		Annual Total (mm)	Annual Max.(mm)	Annual Min.(mm)
1975-76	59	1135.5	73.7	2.5
1986-77	47	1318.3	113.0	2.5
1977-78	61	1510.3	130.8	3.8
1978-79	54	1400.7	158.8	3.0
1979-80	60	1430.6	112.0	2.5
1980-81	58	1601.9	194.3	2.5
1981-82	48	1760.3	152.4	1.3
1982-83	44	1059.4	107.9	2.5
1983-84	56	1265.6	99.6	1.3
1984-85	59	1350.1	69.3	3.0
1985-86	66	1319.2	61.0	2.5
1986-87	72	1593.7	203.2	1.8
1987-88	57	1802.8	171.5	2.5
1988-89	54	1824.9	129.2	0.5
1989-90	57	1842.0	75.3	0.3
1990-91	89	1429.6	60.0	0.1
1991-92	86	1707.8	71.0	0.4
1992-93	54	1242.5	80.0	0.5
1993-94	69	1219.1	70.0	0.4
1994-95	60	765.5	40.0	0.4
1995-96	79	1792.7	95.0	0.5
1996-97	43	1201.5	85.0	0.5
1997-98	78	1684.0	85.0	0.5
1998-99	70	1875.0	95.0	0.5
1999-00	83	2877.5	95.0	0.5
2000-01	65	1412.5	95.0	0.5
2001-02	75	1750.3	110.0	0.5

Source: BWDB

Fig-3.3: Trend of Rainfall at Tanore station From 1975-76 to 2001-2002

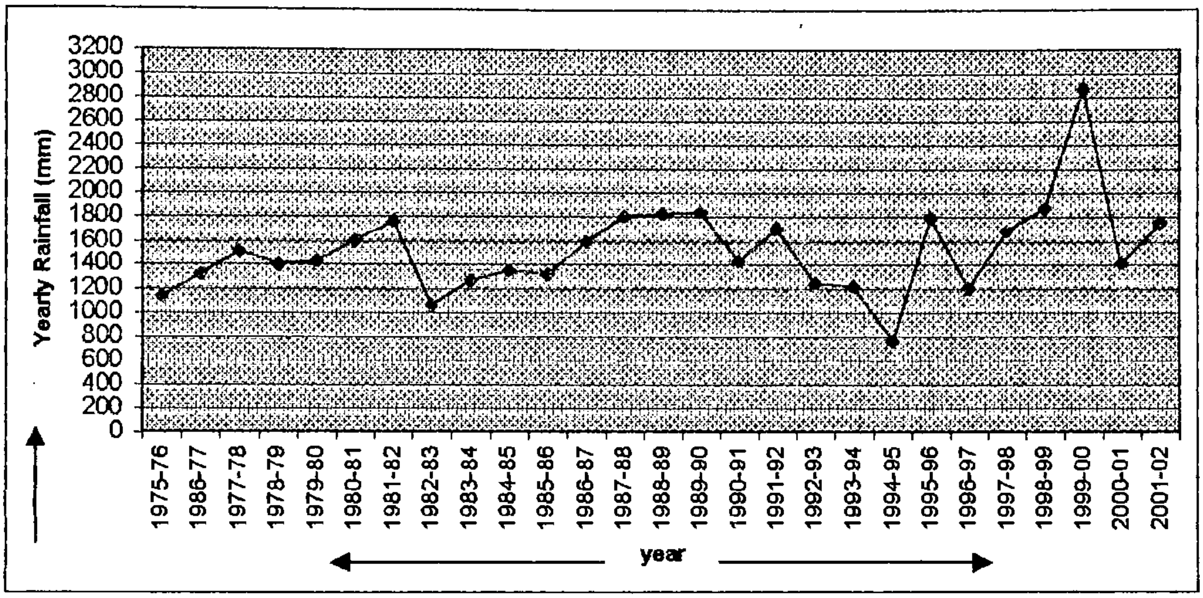


Fig-3.4 : Trend of Rainy day at Tanore station From 1975-76 to 2001-2002

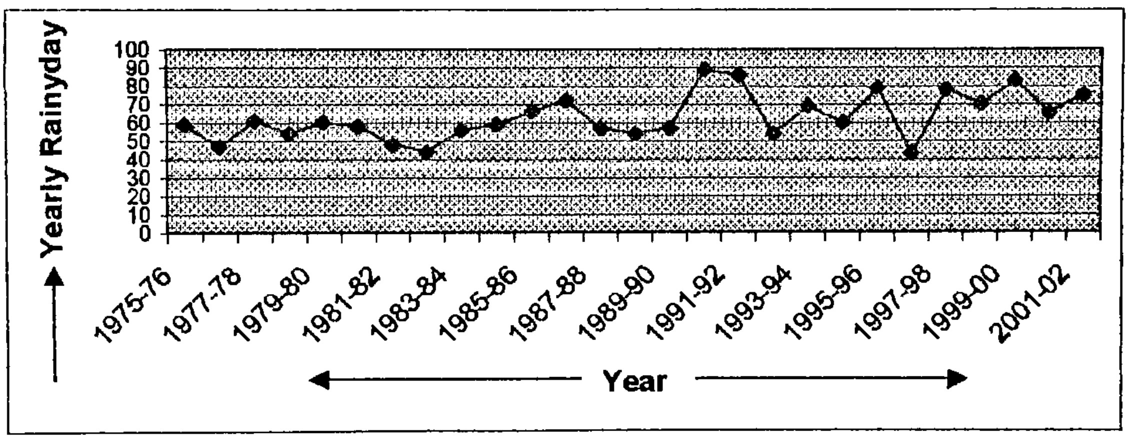


Fig-3.5 : Annul Max Rainfall at Tanore station From 1975-76 to 2001-2002

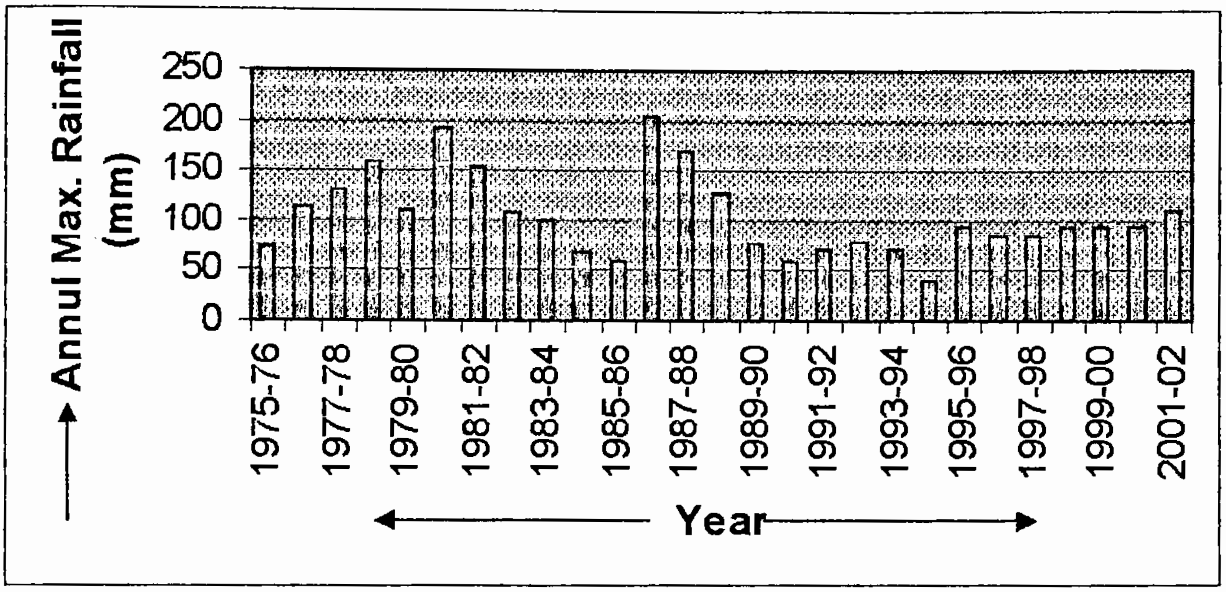
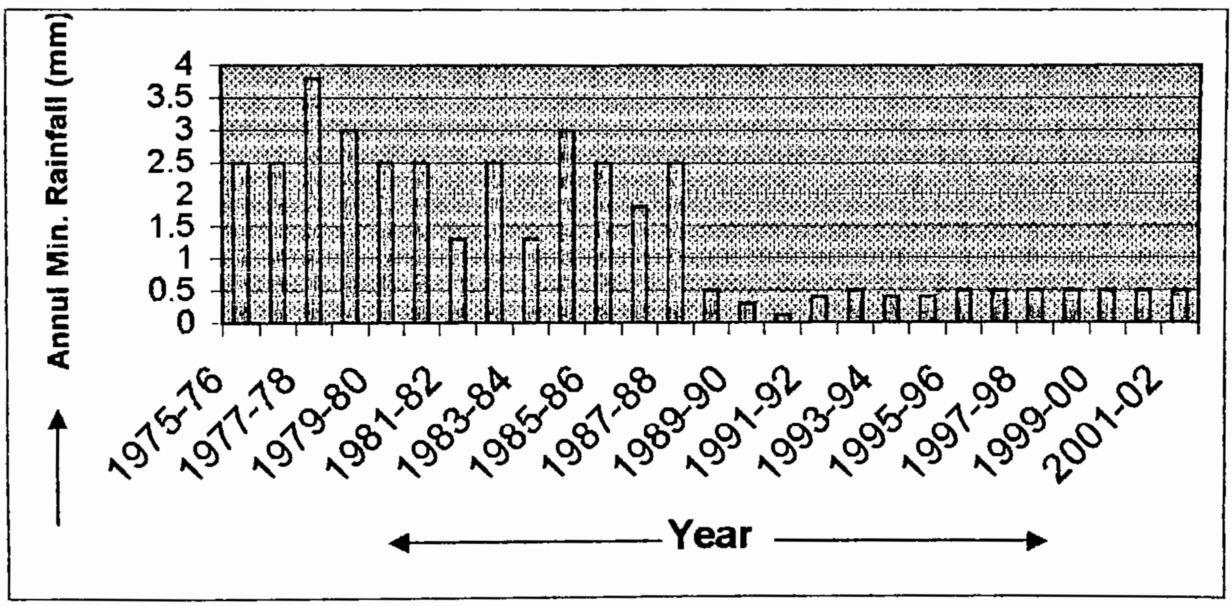


Fig-3.6 : Annual Minimum Rainfall at Tanore station in 1975-76 to 2001-2002



3.3: Hydrograph Analysis:

Hydrograph is an important study of hydrology. By analysis the hydrograph, it is easy to know the condition of water resources of a particular area. Hydrograph analysis refers to those studies, which deals with the detail descriptions of discharge with its associate components. The main components of the hydrograph analysis are time, rainfall, water level, discharge and ground water condition to the river. There is no measuring station in the study area. The nearest station is situated at Nawhata in the Sibu-Baranai river (River No.-98) and the station No. is 261. The water level and discharge of last 21 years have been computed here to analysis the hydrograph. In spite of limitation of available data, an attempt has been made to analysis the hydrograph of water level and discharge of Sibu-Baranai river in the following paragraph.

3.3.1:Hydrograph analysis of monthly water level:

The table and figure (Table-3.9 and figure -3.6) shows the monthly average water level of the last 21 years (1975-76 to 2001-02) of the Sibu-Baranai river with the elevation of ground water table of well No.- 38 and rainfall occurrence. It is mentioned that the well No.-38 is the nearest ground water table measuring station of the Sibu-Baranai river. It is evident from the figure and table that the river water level maintained between 9.7o m/PWD to9.17 m/PWD during the months of January to late April. From January to March, the groundwater table lies down from the river water level and then it is increased. On the other hand, the groundwater table is increased from the river water level at the end of October. So it is concluded that the water level of Sibu-Baranai river is available from late September to early March. Because, during the months from late September to late March, the river water level lies down the ground water table and the Sibu-Baranai river becomes influent river during the some period. It is mention that there is no or a little rainfall occurred during the same period.

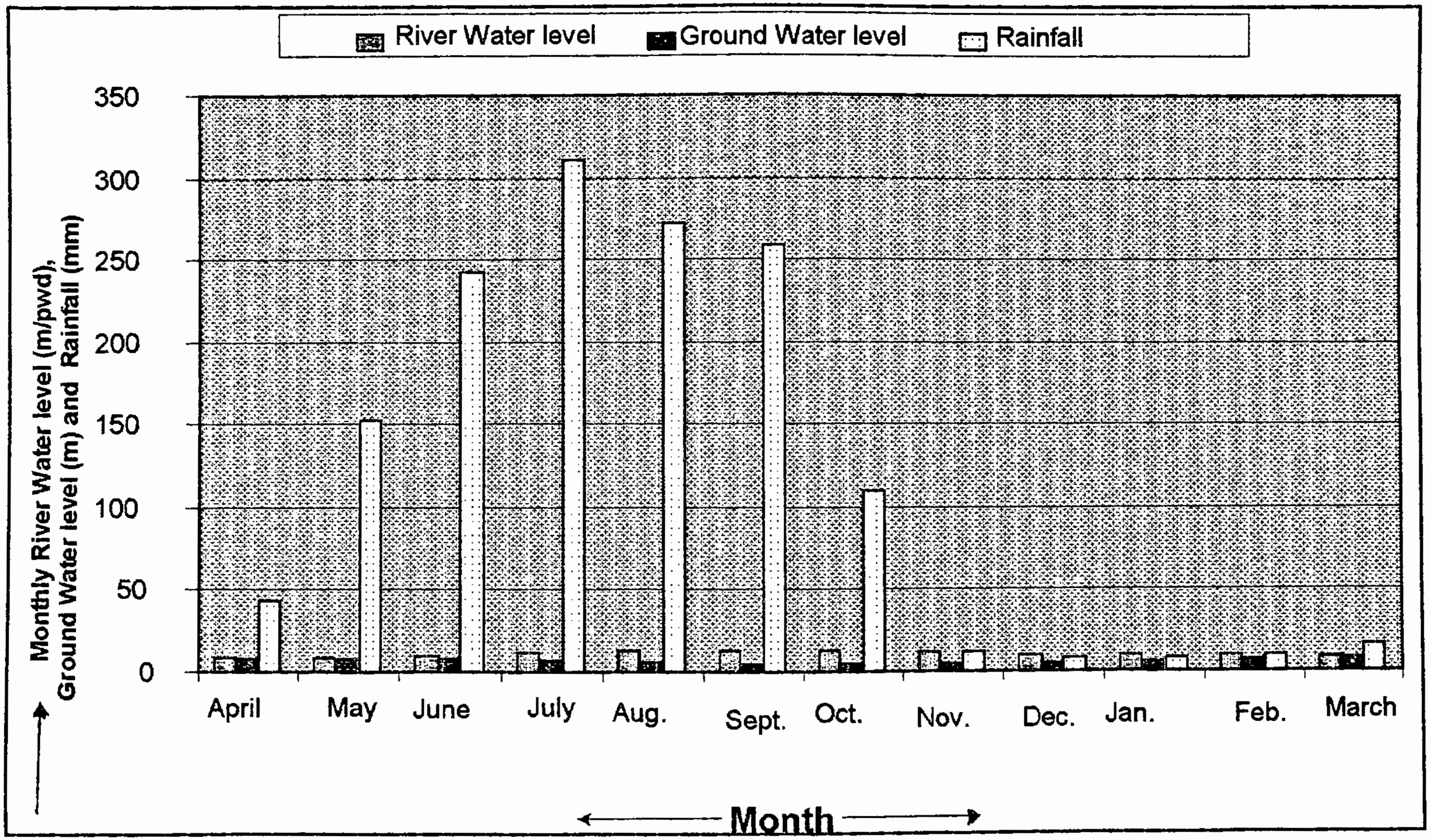
On the other hand, the river water level begins to rise from late March above ground water table. In this time, the study area is experienced heavy rainfall. River water level reaches at the topmost point during the months of July to September. Both this times, the river water level remains 12.57 m/PWD and 13.54 m/PWD. Thse maximum rainfall experienced in the study area during the month of July and the amount is 310.19 mm. From the month of June, the ground water table rises rapidly and it's continuing still at the river water level up to the month of October. The river water level lies above from the groundwater table from late March to late September. In this time, groundwater recharges from river body and the river becomes as an influent river during the same months. Monthly water level of the Sibu-Barana river, elevation of ground water table at well No.-38 and monthly rainfall at Tanore station of the last 27 years (1975-76 to 2001-02) of the study area is given bellow in the table -3.9.

Table-3.7: Monthly water level of Sibu-Baranai river, elevation of ground water table at well No.-38 and rainfall at Tanore station of the last 27 years.

Month	Water level of the Sibu-Baranai (m/PWD)	Elevation of groundwater table (m)	Rainfall (mm)
April	9.17	8.34	43.86
May	9.53	8.36	151.95
June	10.48	7.71	243.20
July	12.57	6.72	310.19
August	13.43	5.74	272.71
September	13.54	5.25	259.15
October	13.46	4.81	110.14
November	12.18	5.03	12.01
December	10.43	5.47	07.94
January	9.70	6.05	08.06
February	9.65	6.86	10.33
March	9.14	7.78	16.64

Source: BWDB

Fig:-3.7:Monthly water level of Sibu-Baranai river, elevation of ground water table at well No.-38 and rainfall at Tanore station of the last 21 years.



3.3.2: Trend Analysis of Maximum, Minimum and Average Water Level:

The trend of maximum, minimum and average water levels at Sib-Baranai river from 1975-76 to 2001-02 is shown in the table 4.10 and figure 4.8. It is evident from the table and figure that the maximum water level varies from12.78 m/PWD to 16.02 m/ PWD during the study periods. The highest one was found 16.02 m/ PWD in 1995-96 and lowest one was found12.78 m/ PWD in 1975-76. Heavy rainfall (1792.7 mm) occurred in 1995-96 and the river becomes overflow condition and the water level was highest in this year. In 1975-76, the amount of rainfall was 1135.5 mm and the lowest water level was found 12.78 m/ PWD and the river water was lowest in this year. Maximum water level is increased during the period 1982-83. There are some ups and downs of maximum one-day water levels are found fluctuation trend during the study periods.

The annual minimum water level varies from 8.58 m/ PWD to 9.12 m/ PWD in the study periods. The highest one was found 9.12 m/ PWD in 1993-94 and lowest one was found 8.58 m/ PWD in 1979-80. There is a little change was found from the minimum water level at Nawhata station in the Sib-Baranai river during 1975-76 to 2001-02.

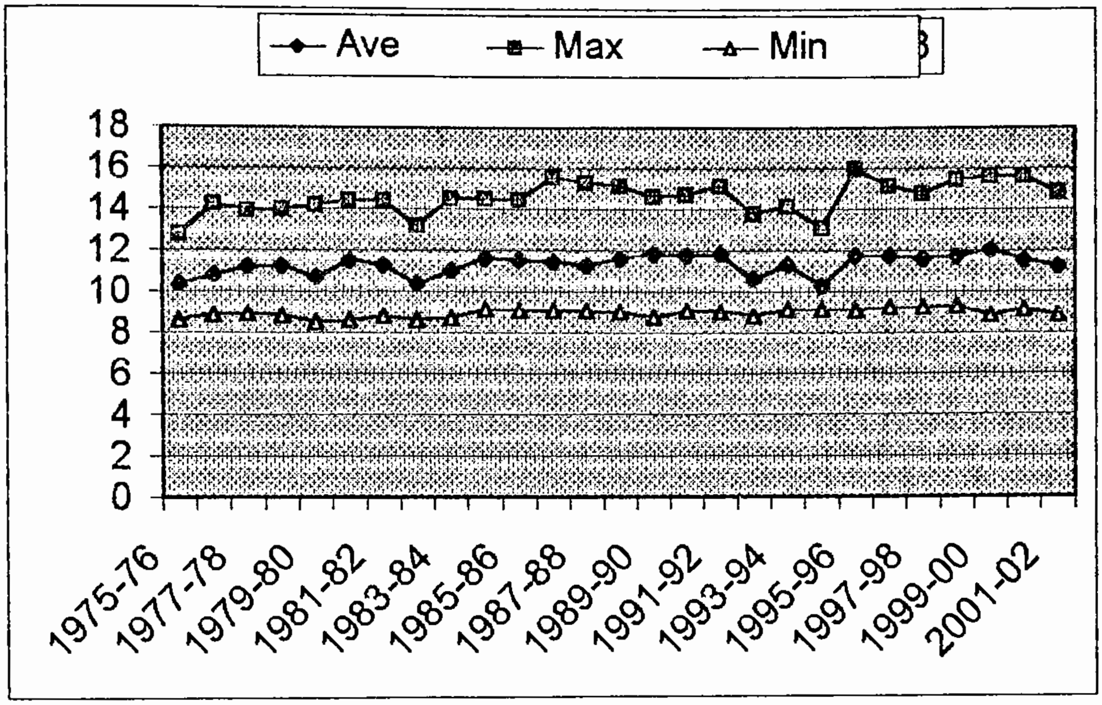
The annual average water level of Sib- Baranai river varies from 10.307 m/ PWD to 11.776 m/ PWD The highest average water level was found 11.776 m/ PWD in 1995-96 and lowest average was 10.307 m/ PWD in 1994-95. From 1975-76 to 1995-96, the average water level of Sib-Baranai river is increased gradually. In 1994-95, the amount of rainfall was 765.5 mm which was the lowest rainfall of last 21 years and the lowest annual average water level was occurred in this year. On the other hand, 1792.7 mm rainfall was occurred in 1995-96 and highest annual average water level was found in that year

Table-3.8: Annual water level and discharge at Nawhata station in 1975-76 to 2001-02 (station No.-261).

Year ↓	Annual water level ↓			Annual discharge ↓		
	Average (m/PWD)	HWL (m/PWD)	LWL (m/PWD)	Average (m^3/s)	Max. (m^3/s)	Min. (m^3/s)
1975-76	10.389	12.780	8.625	11.70	42.20	0.324
1976-77	10.805	14.265	8.870	53.90	153.00	3.620
1977-78	11.222	13.960	8.946	49.50	170.00	7.240
1978-79	11.246	13.981	8.839	52.60	75.10	29.400
1979-80	10.706	14.195	8.505	48.60	102.00	20.100
1980-81	11.505	14.432	8.580	50.80	90.00	27.900
1981-82	11.304	14.448	8.800	39.60	85.20	1.520
1982-83	10.390	13.220	8.620	52.00	88.10	2.521
1983-84	11.007	14.530	8.730	49.20	114.00	3.720
1984-85	11.633	14.510	9.116	44.60	102.00	0.358
1985-86	11.544	14.490	9.088	43.20	80.20	1.920
1986-87	11.471	15.580	9.070	36.70	177.00	2.120
1987-88	11.279	15.350	9.060	41.90	175.00	0.286
1988-89	11.621	15.150	9.020	59.80	145.00	2.430
1989-90	11.826	14.640	8.750	40.20	130.00	3.360
1990-91	11.775	14.720	9.070	47.50	137.00	0.446
1991-92	11.867	15.160	9.050	52.80	106.00	1.710
1992-93	10.647	13.780	8.840	29.10	103.00	0.079
1993-94	11.322	14.140	9.120	52.20	24.00	0.801
1994-95	10.307	13.130	9.110	46.20	39.50	1.021
1995-96	11.776	16.020	9.080	44.80	92.10	1.021
1996-97	11.758	15.15	9.22	69.453	176.530	16.196
1997-98	11.611	14.79	9.23	151.900	197.933	102.032
1998-99	11.730	15.47	9.30	81.458	112.130	14.397
1999-00	12.046	15.62	8.85	55.790	72.923	28.032
2000-01	11.562	15.63	9.13	27.525	45.697	0.429
2001-02	11.263	14.87	8.85	22.273	43.596	0.458

Source: BWDB

Figure-3.8: Annual water level at Nawhata station from 1975-76 to 2001-2002 (station No.-261



4.3.3: Hydrograph Analysis of Monthly Discharge:

Monthly average discharge of Sib-Baranai river at Nawhata station in 1975-76 to 2001-02 was shown in the table-3.11 and figure-3.8. It is noticed from the table and figure that the hydrograph shows three runoff condition; rising limb, peak flow and recession limb. The discharge rate is depending upon water flow and water level. The monthly average discharge rate was varied from 0.587 m^3/s to 66.294 m^3/s. The highest one was 66.294 m^3/s in the month of August (rainy season) and the lowest one was 0.587 m^3/s in the month of April, which was the driest month of the year. After the month of April, the discharge rate began to rise gradually up to the month of September and reaches to the peak position, then gradually recession up to the month of March. When the rainfall occurred, then the discharge rate is increased. The discharge rate of four-month (July to October) is found in a peak position because heavy rainfall was occurred in those months.. And the rest of the months, the discharge rate was very low because no or a scanty rainfall was occurred in those months.

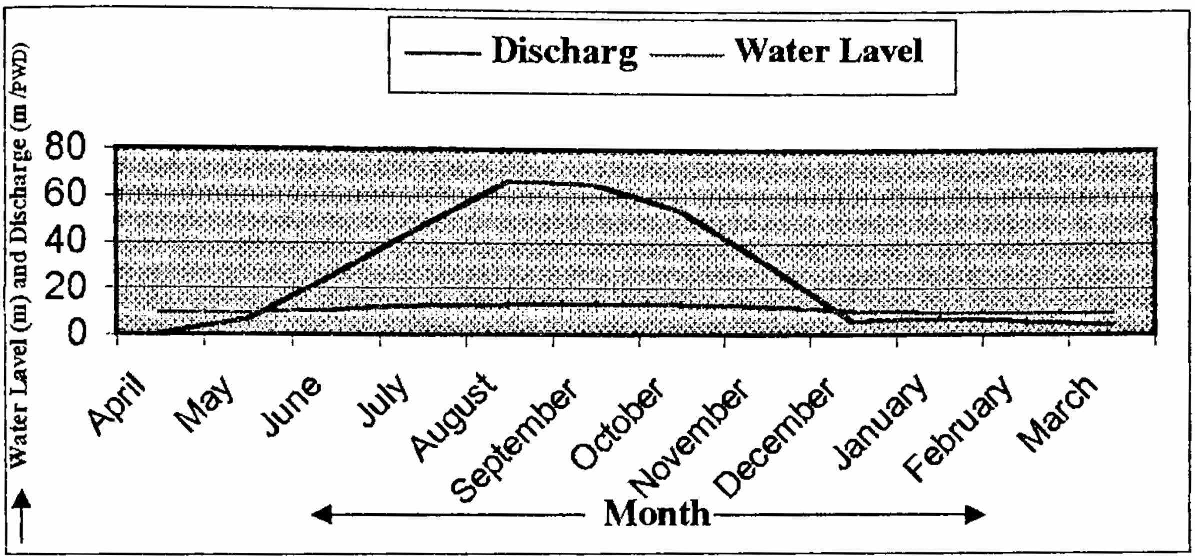
In comparison with the tables-3.7 and 3.9, it was found that when rainfall begin then the discharge rate and water level of Sib-Baranai river is gradually increased. The peak position of water level and discharge was found in the month of September but the peak position of rainfall was found in the month of July. Because, after the rain, water of runs to the canals, swamps or beels and then fall into the river and the water level and discharge rate Began to rise gradually.

Table-3.9: Monthly average discharge and water level of Sibu-Baranai river at Nawhata station (station No.-261) in 1975-76 to 2001-02.

Month	Water Level (m/PWD)	Discharge (m^3/s)
April	9.17	0.587
May	9.53	6.665
June	10.68	26.191
July	12.57	46.973
August	13.43	66.294
September	13.54	65.064
October	13.46	54.111
November	12.18	30.631
December	10.43	5.801
January	9.70	6.923
February	9.65	5.440
March	9.41	4.430

Source: BWDB

Figure-3.9: Monthly average discharge and water level of Sib-Baranai river at Nawhata station (station No.-261) in 1975-76 to 1995-96.

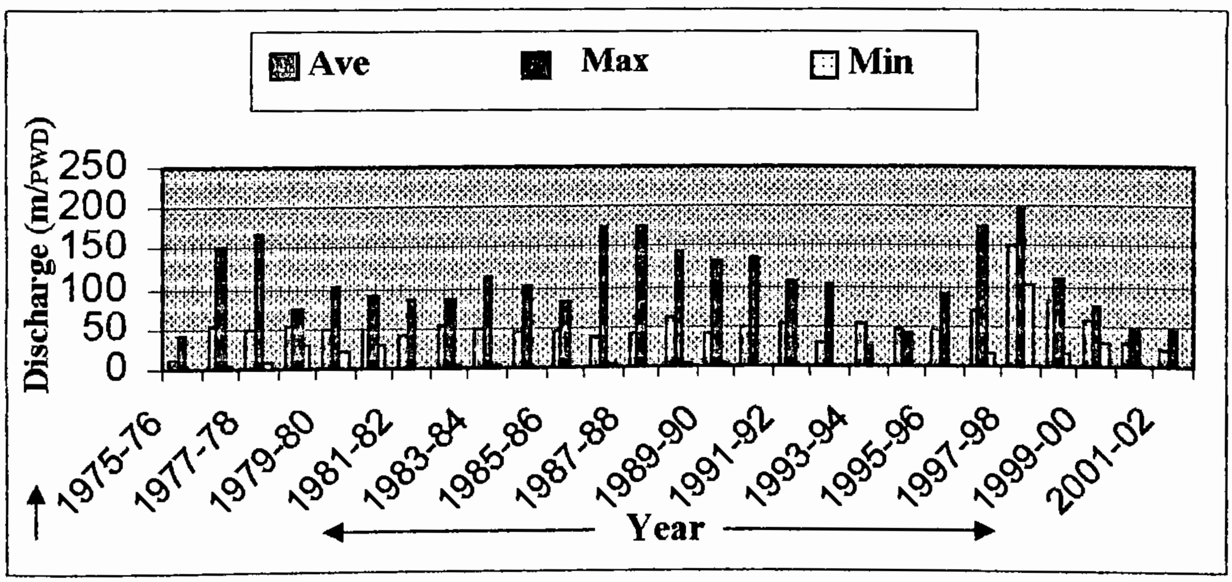


3.3.4: Trend Analysis of Average, Maximum and Minimum Discharge Rate:

In the study area, generally the maximum discharge rate and minimum discharge rate of Sib-Baranai river occurs in the month of August and April.The average, maximum and minimum discharge rate of Sib-Baranai river during 1975-76 to 2001-02 is given in table-3.10 and figure-3.10. The average discharge rate was varying from 11.7 m^3/s to 59.8 m^3/s of the last 27 years. From the table and figure it is evident that the highest average discharge rate was 59.8 m^3/s in 1988-89 and the amount of rainfall was 1824.9 mm of the last 27 years. The lowest average discharge rate was 11.7 m^3/s and the amount of rainfall was 1135.5 mm which was the 2nd the lowest rainfall in 1975-76 and the discharge rate was the lowest in that year. There are some ups and downs are found in the hydrograph of average discharge rate. The discharge rate is related on the rainwater in the study area.

It is evident from the table and figure that the maximum one-day discharge ranges from 177 m^3/s to 39.5 m^3/s during the study periods. The highest one-day discharge was 177 m^3/s in 1987-88 because the highest one-day rainfall (203.2 mm) was occurred in that year. The lowest one-day discharge was 39.5 m^3/s in 1994-95 because one-day rainfall (40 mm) was found in that year in the study area. It is conclude that there is no chronological up and down in the maximum discharge rate. Again, the minimum one-day discharge rate varied from 0.072 m^3/s to 29.4 m^3/s during the study periods. The highest minimum one-day discharge was 29.4 m^3/s in 1078-79 and the lowest minimum one-day discharge rate was 0.072 m^3/s in 1994-95. But in 1978-79 and 1994-95, the amount of minimum rainfall was not lowest. So it is concluded that there is no relation between one-day minimum highest and minimum lowest rainfall and discharge rate but there is a close relationship between one-day minimum highest and minimum lowest water level and discharge rate.

Figure-3.10: Annual discharge at Nawhata station from 1975-76 to 2001-02 (station No.-261).



CHAPTER –4

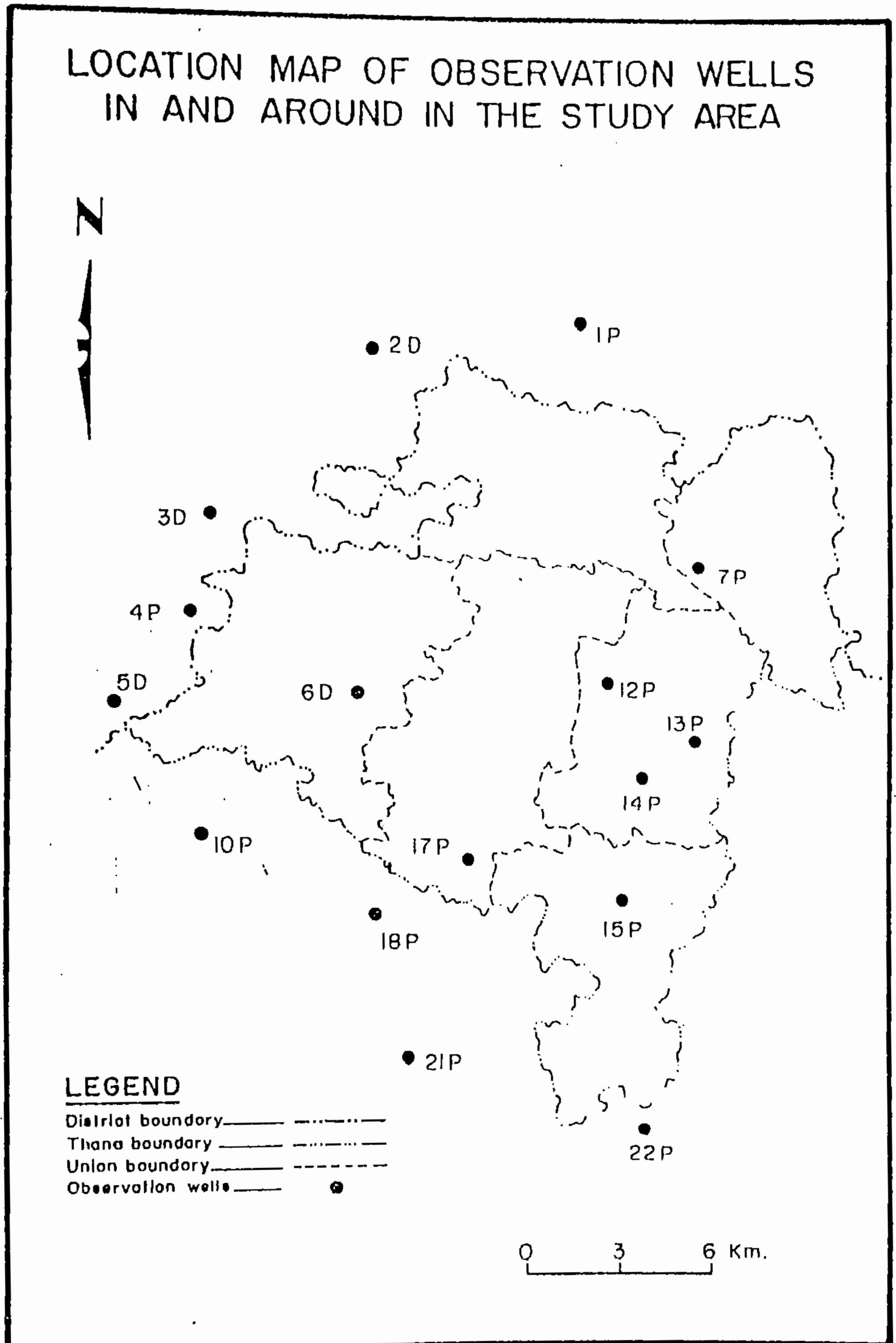
SUBSURFACE WATER HYDROLOGY

The study of groundwater is a science, which deals with the investigation, development and management of groundwater for mitigating human requirements. Groundwater is an important source of fresh water supply throughout the world. It is obtainable all the year round and it can be starved and used influence equals. The present study in this chapter deals with the availability of groundwater, its nature and extent and hydraulic properties in the study area.

4.1:Availability and Nature of Hydrogeological Data:

In any hydrogeological study, it is necessary to collect bore-log data, which are the most reliable source of information regarding subsurface conditions. The groundwater data on which this study is based were collected primarily from the Groundwater Circle (GWC) of Bangladesh Water Development Board (BWDB). The GWC is responsible for collection of groundwater data and investigations since 1968. The GWC is working with Bangladesh Agricultural Development (BADC) and Public Health Engineering Department (PHED). Recently a reasonable number of Test Wells were drilled by GWC of BWDB for detail hydrogeological study of Barind Tract. Majorities of the drill hole within the study area have been drilled to a depth round 92 to 155 meters.

There are 16 observation wells in and around the study area of which 11 are piezometric wells and 5 are dug wells. The location map of observation wells in the investigated area is shown in map-4.1. The table (Table-4.1) shows the list of observation wells used in this study.



Source: BWDB

Map-4·1

Table-4.1: observation wells within the study area.
(Designation of Observation Wells)

In the report	According to GWC or BWDB Register	In the report	According to GWC or BWDB Register
1P	RS-127	12p	RS-27
2D	RS-45	13P	RS-136
3D	RS-41	14P	RS-86
4P	RS122	15D	RS-42
5D	RS43	17P	RSS-32
6D	RS-40	18P	RS-38
7P	RS-39	21P	RS-100
10P	RS-120	22P	RS-37

Source: BWDB,

4.2: Groundwater Level:

Groundwater level is an important hydrogeologic parameter. It provides valuable information for evaluation and determination to day water supplies, recharge condition and availability, trends of groundwater level etc. The upper surface of the zone of saturation is generally called the water table. The depth and the gradient of groundwater table very much significant for any hydrogeological study.

The depth of the groundwater table from the surface, minimum and maximum elevation of the water table respect to mean sea level, fluctuation of water table during dry and wet season etc. are determined by analyzing the collected data of the observation wells. The analyzed data are used to draw water level hydrograph and contour maps. Hydrographs show early seasonal fluctuation in the level in and around the study area, which is directly related to recharge and discharge condition of the investigated area. The attitude and the direction of the water table vary directly with the permeability of the saturated beds and with the amount and rate of recharge and discharge. Abrupt change in either of these parameters may cause local high or low water table on the main water table. Three contour maps (Map - 4.2, 4.3 and 4.4) of the groundwater level which give a vivid picture of different aspects of the aquifer as well as the position of water table in different seasons, its fluctuation etc. From hydrographs (Figure -4.1,4.2a, 4.2b, 4.2c, 4.2d, 4.2e, 4.2f and 4.2g) of representative observation wells are showing the trend of ground water level. Available groundwater level data of last 24 years (Table- 4.2, 4.3, 4.3a, 4.3b, 4.3c and 4.3d) are studied for most of the observation wells to observe the condition of ground water level of the study area.

4.2.1: Monthly Ground water level:

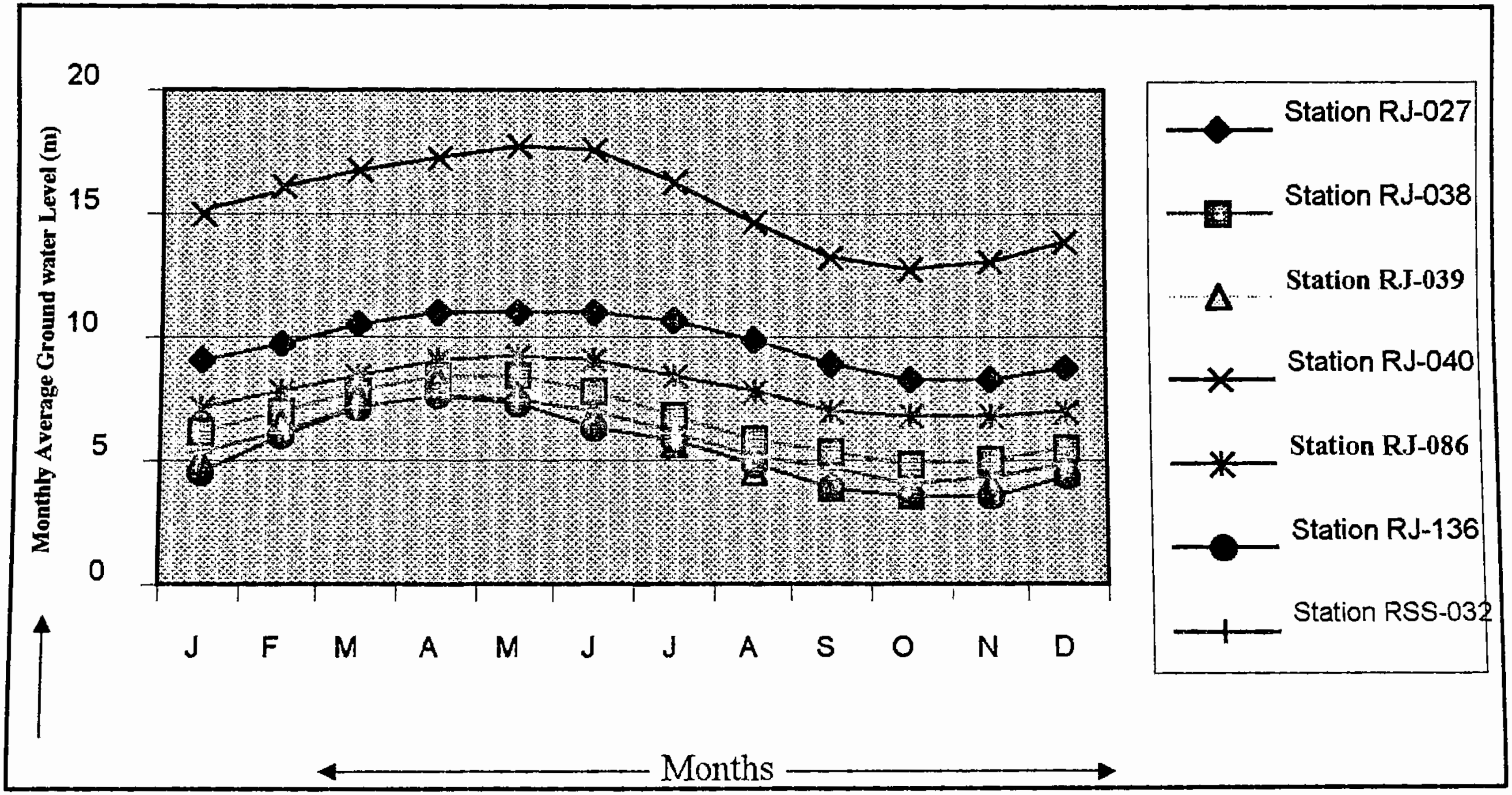
From table -4.2 and figure - 4.1, it is found that the trend of monthly average ground water level of the study are varied from 17.67 m to 3.50 m. The highest value is found 17.67 m at Mundumalahat observation wells (RJ040) in the month of May because May is the most driest month of the year and this time, the withdrawal of water reach at the top most point. The lowest value is found 3.50 m at Tanore observation wells (RJ136) in the month of October, which month is the end of the rainy season and that time the ground absorve recharge from rainwater. The ground water levels are increased in the month of November and reach the top most point in the month of May. With the beginning of rainy season, the ground water level is decreased.

Table-4.2: Monthly average ground water level at Tanore thana of the last 24 years (1977-2000).

Station Month	Station RJ-027	Station RJ-038	Station RJ-039	Station RJ-040	Station RJ-086	Station RJ-136	Station RSS-32
J	9.01	6.05	5.04	15.07	7.02	4.56	5.28
F	9.75	6.86	6.5	16.05	7.71	6.04	6.19
M	10.53	7.78	7.58	16.78	8.41	7.10	7.05
A	11.02	8.34	8.27	17.29	8.99	7.64	7.54
M	11.04	8.36	7.66	17.67	9.12	7.18	7.43
J	10.97	7.71	6.77	17.55	8.96	6.32	6.94
J	10.58	6.72	5.60	16.30	8.45	5.86	6.08
A	9.78	5.74	4.55	14.63	7.74	4.78	5.22
S	8.91	5.25	3.89	13.16	6.98	3.86	4.62
O	8.20	4.81	3.52	12.67	6.83	3.50	4.08
N	8.21	5.03	4.02	13.12	6.73	3.62	4.32
D	8.70	5.47	4.46	13.93	7.01	4.32	4.84
M+A+M	10.86	8.16	7.83	17.24	8.84	7.30	7.34
S+O+N	8.44	5.03	3.81	12.98	6.84	3.66	4.34

Source: BWDB

Fig-4.1: Monthly average ground water level at Tanore thana of the last 21 years (1977-1997)



4.2.2: Annual Ground Water Level:

From the table-4.3a, 4.3b, 4.3c, 4.3d and figure- 4.2a, 4.2b, 4.2c, 4.2d, 4.2e, 4.2f, 4.2g are showing the annual average, maximum, minimum ground water level and fluctuation of ground water in the study area. It is evident from the tables and figures that the average ground water level ranges from 3.19 m to 17.74 m. The highest value (17.74 m) of annual average groundwater table elevations are observed in the western part of Tanore thana at Mundumalahat observation well (RJ-040) and the lowest value (3.19 m) of annual average water table elevations are observed in middle-eastern part of Tanore thana at Tanore observation well (RJ-136). The annual maximum elevation to ground water table from mean sea level varies from 4.90 m to 20.73 m. The highest value (20.73 m) of maximum ground water table elevations is found in the western part of the study area at Mundumalahat observation well (RJ-040). The lowest value (4.90 m) of maximum groundwater table elevations is observed in the northeastern part of Tanore thana at Shamaspur observation well (RJ-039). In the investigated area, the annual minimum elevations of groundwater table from mean sea level are vary from 0.91m to 15.52 m. The highest value (15.2 m) of minimum groundwater table elevations is observed in the western part of Tanore thana at Mundumalahat observation well (RJ-040). The lowest value (0.91 m) of minimum groundwater table elevations is observed in the northeastern part of the study area at shamaspur observation well (RJ-039). The following tables and figures showing the trend of increasing pattern of ground water in the study area from 1977 to 2000. Because, discharge of water is increasing with the increasing demand of ground water for agriculture purposes and domestic uses. It is found that the trend of average, maximum, minimum ground water levels and fluctuations are increased from 1977 to 1992 but it is decreased from 1993 to 2000 at Mundumalahat observation well (RJ-040). It is perhaps happened due to built-up two dam near the well of the khari.

Table-4.3a: Annual Average, Minimum, and Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ027 and Station No.-RJ038).

Ground water level bellow measuring point in meter.								
Year ↓	Station No.-RJ027				Station No.-RJ038			
	Ave.	Min.	Max.	Fluct.	Ave.	Min.	Max.	Fluct.
1977	6.96	09.93	4.52	5.41	4.07	5.94	2.51	3.43
1978	5.60	8.00	4.03	3.97	4.81	6.80	2.38	4.42
1979	8.69	9.44	D.U.	-	4.86	7.59	1.00	6.59
1980	N.D.	N.D.	N.D.	-	4.44	7.36	2.18	5.14
1981	N.D.	N.D.	N.D.	-	4.47	6.78	2.46	4.32
1982	N.D.	N.D.	N.D.	-	5.61	7.96	3.30	4.66
1983	N.D.	N.D.	N.D.	-	5.53	8.03	3.37	4.66
1984	8.10	10.54	5.41	5.13	4.73	6.81	3.90	2.85
1985	8.33	10.49	5.46	5.03	N.D.	N.D.	N.D.	-
1986	8.30	10.92	5.31	5.61	8.46	9.30	4.80	4.50
1987	8.61	10.53	5.87	4.66	7.23	8.76	5.49	5.27
1988	8.98	10.95	6.38	4.57	7.52	9.64	4.57	5.07
1989	10.49	11.76	8.03	3.73	8.71	10.59	6.50	4.09
1990	9.33	11.15	6.57	4.58	9.18	9.50	4.71	3.79
1991	8.51	10.70	6.13	4.57	N.D.	N.D.	N.D.	-
1992	10.48	11.47	7.78	3.69	7.18	8.97	5.23	3.74
1993	10.24	11.90	8.21	3.69	6.91	8.55	4.65	3.90
1994	10.19	11.30	6.66	4.64	7.72	N.D.	N.D.	-
1995	11.00	11.72	9.96	1.76	8.11	12.15	6.20	5.95
1996	11.29	11.97	10.67	1.30	8.13	10.55	6.65	3.90
1997	11.64	12.15	10.91	2.24	8.30	10.25	7.00	3.25
1998	11.30	11.94	10.51	1.43	8.18	10.98	6.61	4.37
1999	11.41	12.02	10.69	1.33	8.20	10.59	6.75	3.84
2000	11.45	12.03	10.70	1.33	4.23	10.60	6.78	3.82

Source: BWDB

Fig-4.2 a: Annual Average, Minimum, and Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ027).

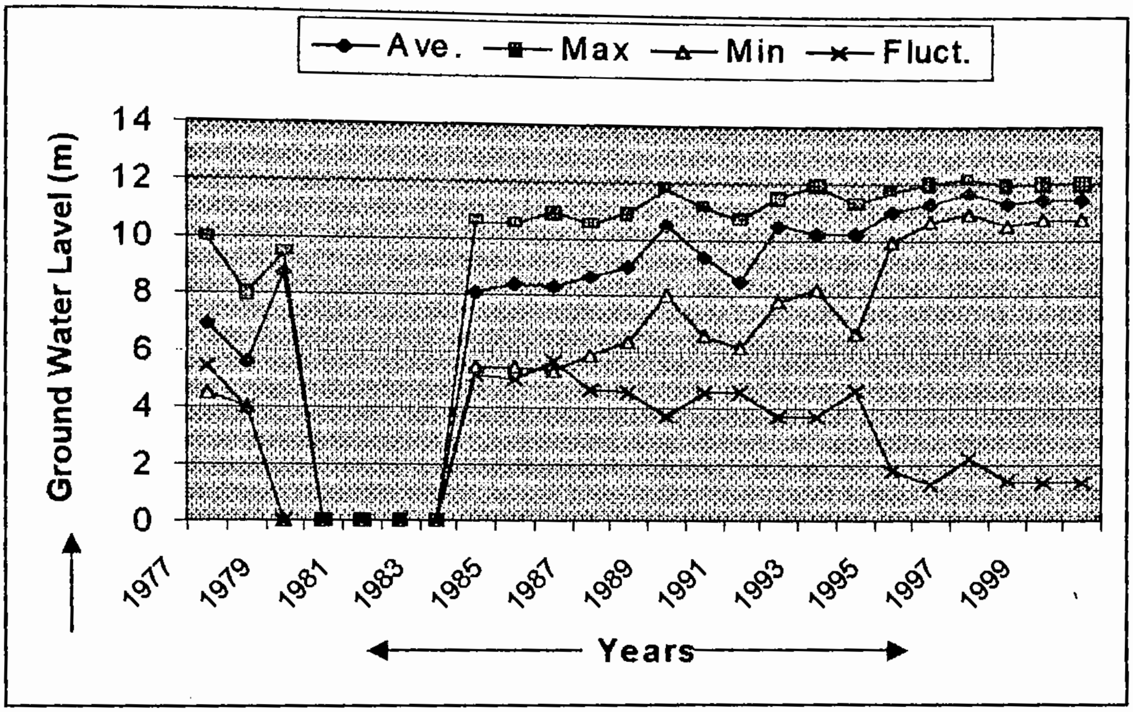


Fig -4.2 b: Annual Average, Minimum, and Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ038).

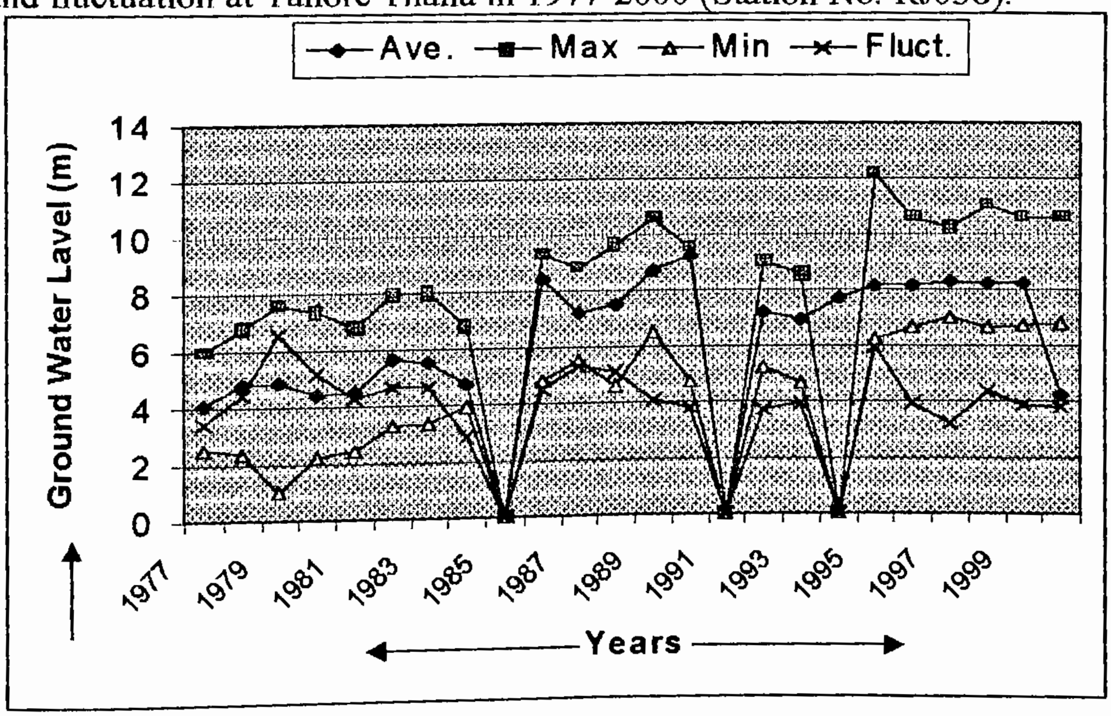


Table-4.3b: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ039 and Station No.-RJ039).

Ground water level bellow measuring point in meter.								
Year	Station No.-RJ039				Station No.-RJ040			
↓	Ave.	Min.	Max.	Fluct.	Ave.	Min.	Max.	Fluct.
1977	3.33	4.90	1.57	3.43	15.44	18.13	12.97	5.16
1978	3.47	6.24	1.37	4.87	15.40	17.73	13.25	4.48
1979	4.43	7.36	1.65	5.71	16.21	18.94	13.38	5.56
1980	4.14	7.63	1.57	6.06	15.79	18.51	13.46	05.65
1981	3.50	6.55	1.11	5.44	15.25	17.60	12.94	4.66
1982	4.87	8.13	1.39	6.74	16.72	18.30	14.61	3.69
1983	4.16	6.71	0.91	5.80	17.61	19.97	14.40	5.57
1984	4.43	6.86	1.95	4.91	16.5	19.16	13.39	5.77
1985	5.07	6.91	2.89	4.02	16.05	18.65	13.36	5.29
1986	5.46	9.10	2.03	7.07	16.08	18.87	13.26	5.61
1987	5.65	9.47	2.80	6.67	16.56	19.10	13.72	5.38
1988	5.84	9.5	2.95	6.35	16.81	19.89	13.31	6.58
1989	7.29	10.60	4.70	5.90	17.74	20.73	14.41	6.32
1990	5.94	9.70	3.15	6.55	16.24	18.98	13.71	5.27
1991	5.54	9.45	2.65	6.80	15.98	19.05	13.18	5.87
1992	7.26	10.60	4.32	6.28	17.68	20.45	15.52	4.93
1993	6.77	9.36	4.25	5.11	12.15	19.07	7.33	11.74
1994	7.28	9.35	5.25	4.10	11.18	14.08	8.46	5.52
1995	8.01	10.61	5.50	5.11	12.06	14.95	8.50	6.45
1996	8.28	10.92	6.20	4.72	12.12	15.12	8.60	6.52
1997	8.58	10.73	6.35	4.38	12.79	15.13	8.65	6.48
1998	8.29	10.75	6.01	4.74	12.32	15.06	8.58	6.48
1999	8.38	10.80	6.18	4.62	12.41	15.10	8.61	6.49
2000	8.41	10.76	6.24	4.52	15.50	12.50	8.62	6.47

Source: BWDB

Fig-4.2 c: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ039).

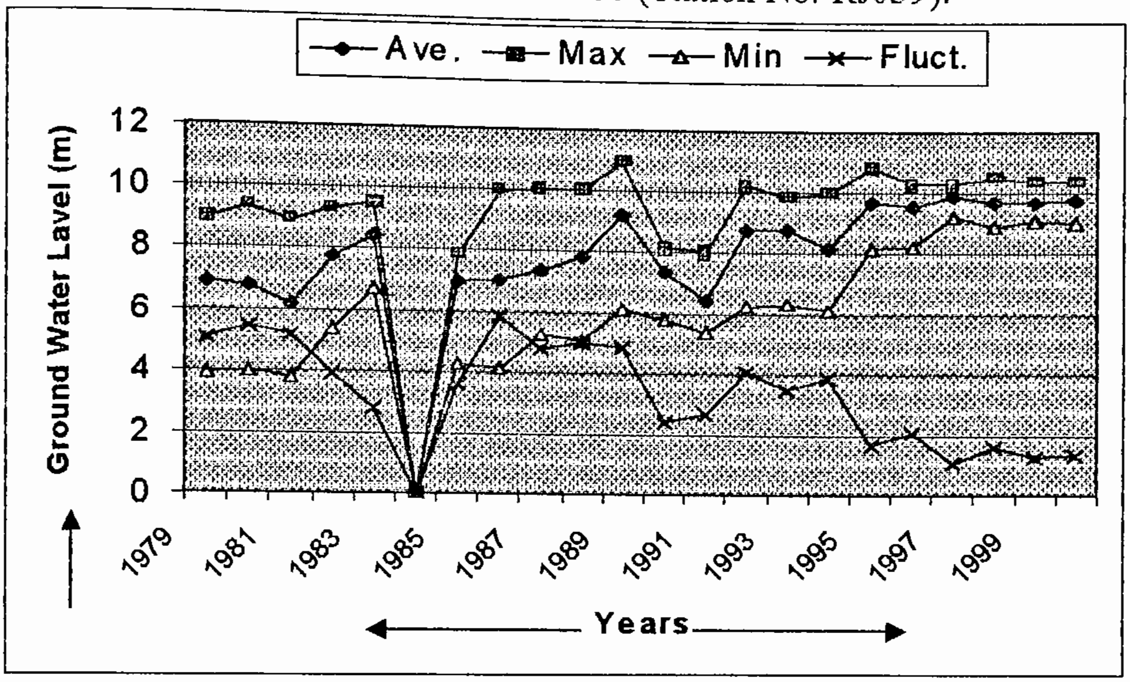


Fig-4.2 d: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ040).

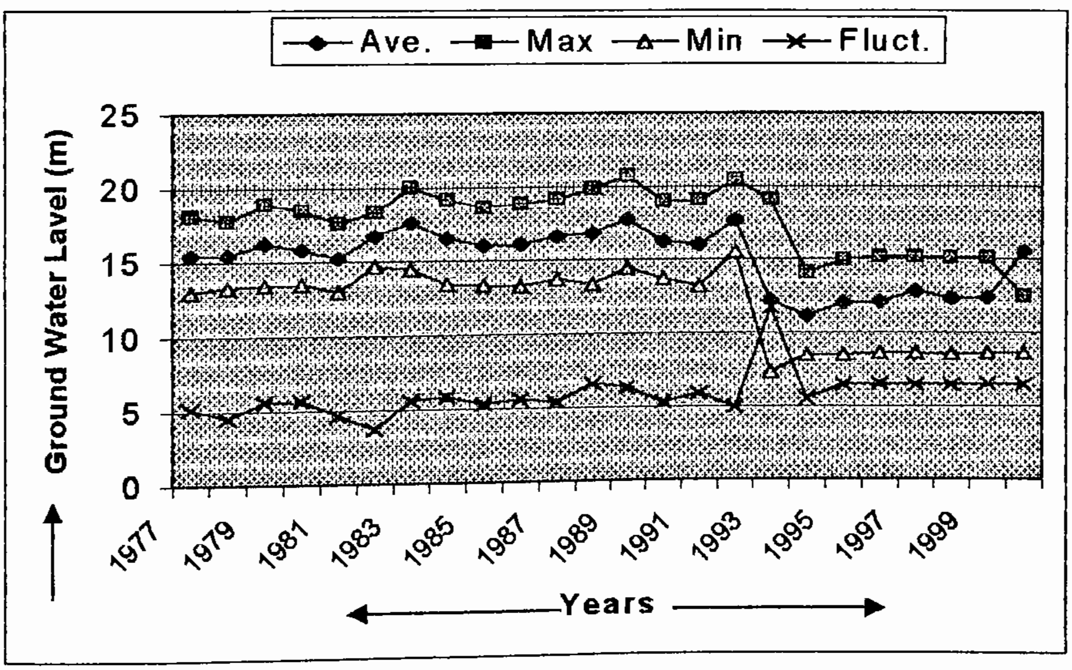


Table- 4.3c: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1979-2000 (Station No.-RJ086 and Station No.-RJ136).

Ground water level bellow measuring point in meter.								
Year ↓	Station No.-RJ086				Station No.-RJ136			
	Ave.	Min.	Max.	Fluct.	Ave.	Min.	Max.	Fluct.
1979	6.90	8.96	3.93	5.03	-	-	-	-
1980	6.79	9.37	3.96	5.41	3.60	7.16	1.09	6.07
1981	6.18	8.91	3.75	5.16	3.19	5.79	0.96	4.83
1982	7.76	9.29	5.35	3.94	4.90	7.16	2.32	4.84
1983	8.44	9.50	6.71	2.79	5.62	8.03	2.74	5.29
1984	-	-	-	-	4.71	7.69	1.90	5.79
1985	6.93	7.82	4.21	3.61	4.76	9.91	1.35	8.56
1986	7.01	9.92	4.10	5.82	4.72	7.34	1.08	6.26
1987	7.37	10.00	5.25	4.75	4.82	7.67	2.59	5.08
1988	7.85	10.00	5.05	4.95	5.31	7.82	2.39	4.92
1989	9.22	10.91	6.10	4.81	6.30	8.95	3.99	4.96
1990	7.38	8.15	5.77	2.38	5.29	8.05	2.56	5.49
1991	6.46	8.00	5.37	2.63	4.92	8.00	2.60	5.40
1992	8.76	10.23	6.21	4.02	6.38	8.63	3.60	5.03
1993	8.72	9.79	6.33	3.46	5.98	7.90	3.80	4.10
1994	8.14	9.96	6.10	3.86	6.01	8.20	3.60	4.60
1995	9.67	10.82	8.18	1.64	6.44	8.72	4.26	4.46
1996	9.58	10.28	8.20	2.08	6.45	7.90	5.15	2.75
1997	9.86	10.27	9.20	1.07	7.25	9.10	5.75	3.35
1998	9.70	10.45	8.86	1.57	6.71	8.57	5.05	3.52
1999	9.71	10.33	9.08	1.25	6.80	8.52	5.31	3.21
2000	9.75	10.35	9.04	1.31	6.92	8.73	5.37	3.36

Source: BWDB

Fig- 4.2 e: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ086).

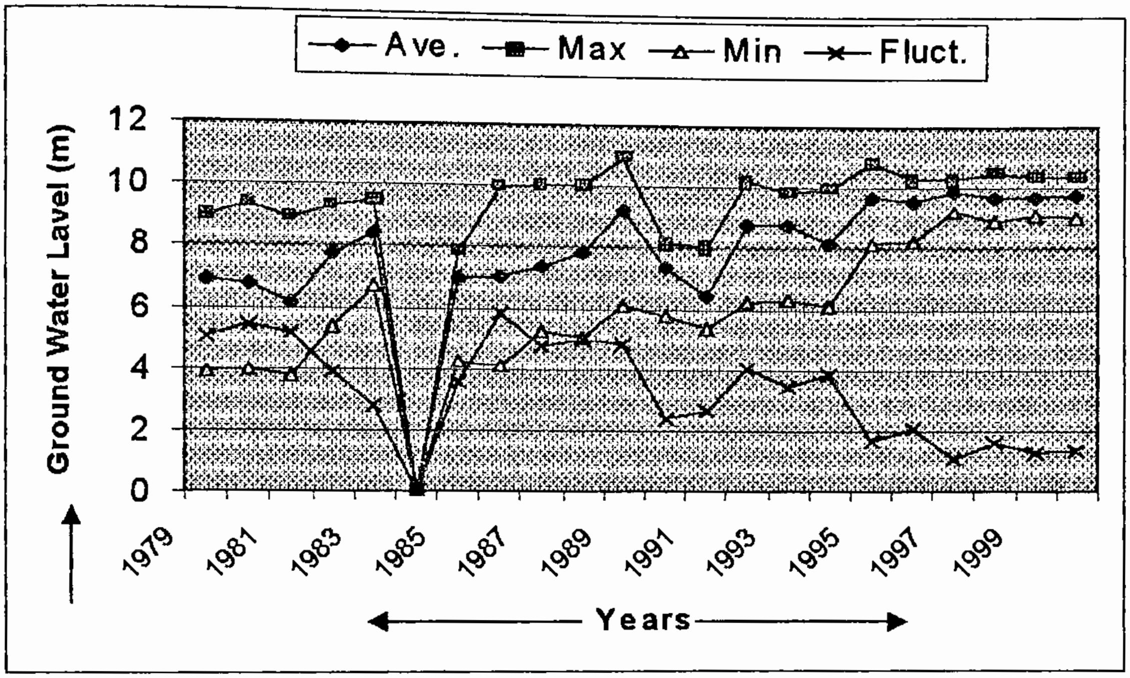


Fig-4.2 f: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1977-2000 (Station No.-RJ136).

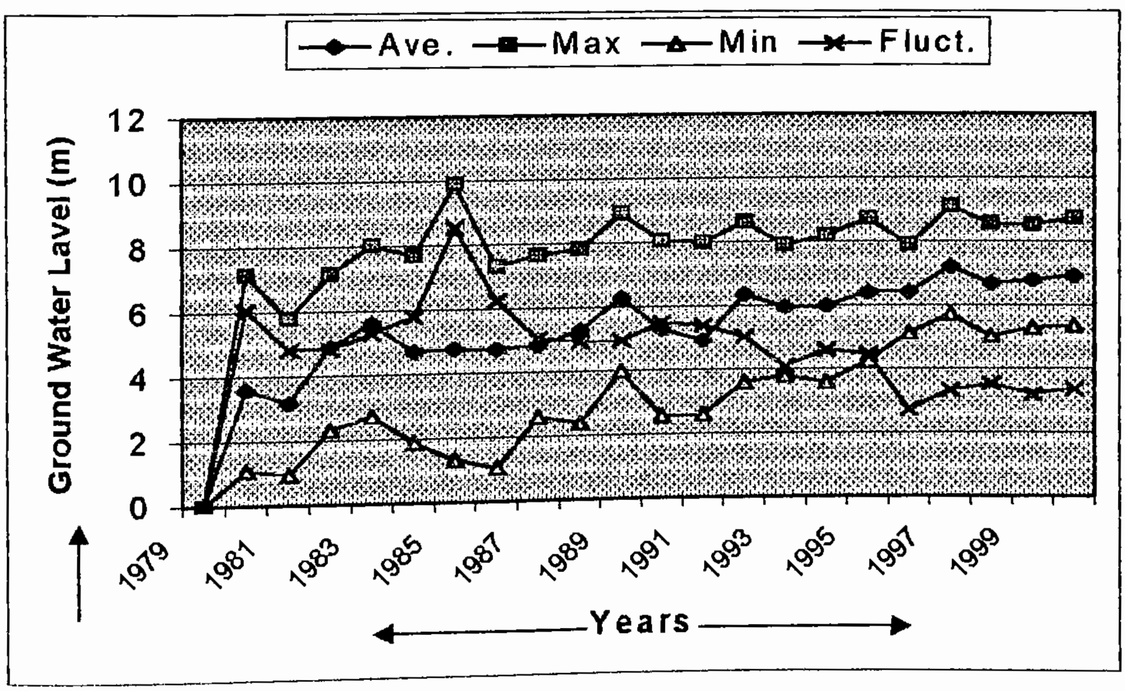
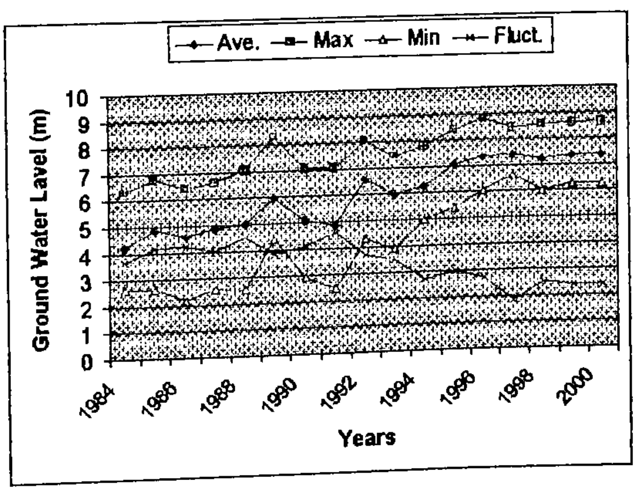


Table- 4.3d: Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1984-2000 (Station No.-RJS32).

Groundwater level bellow-measuring point in meter.				
Year ▼	Station No.-RJS32			
	Ave.	Min.	Max.	Fluct.
1984	4.26	6.32	2.67	3.65
1985	4.90	6.81	2.64	4.17
1986	4.59	6.45	2.20	4.25
1987	4.88	6.63	2.59	4.04
1988	5.02	7.08	2.55	4.53
1989	5.95	8.33	4.46	3.87
1990	5.12	7.10	2.95	4.15
1991	4.91	7.10	2.51	4.59
1992	6.58	8.07	4.33	3.74
1993	5.99	7.43	3.91	3.52
1994	6.27	7.79	5.02	2.77
1995	7.07	8.43	5.43	3.00
1996	7.35	8.84	6.09	2.75
1997	7.38	8.48	6.62	1.86
1998	7.26	8.58	6.04	2.54
1999	7.33	8.63	6.25	2.38
2000	7.35	8.68	6.30	2.38

Source: BWDB

Fig: 4.2 g : Annual Average, Minimum, Maximum groundwater level and fluctuation at Tanore Thana in 1984-2000 (Station No.-RJS32).

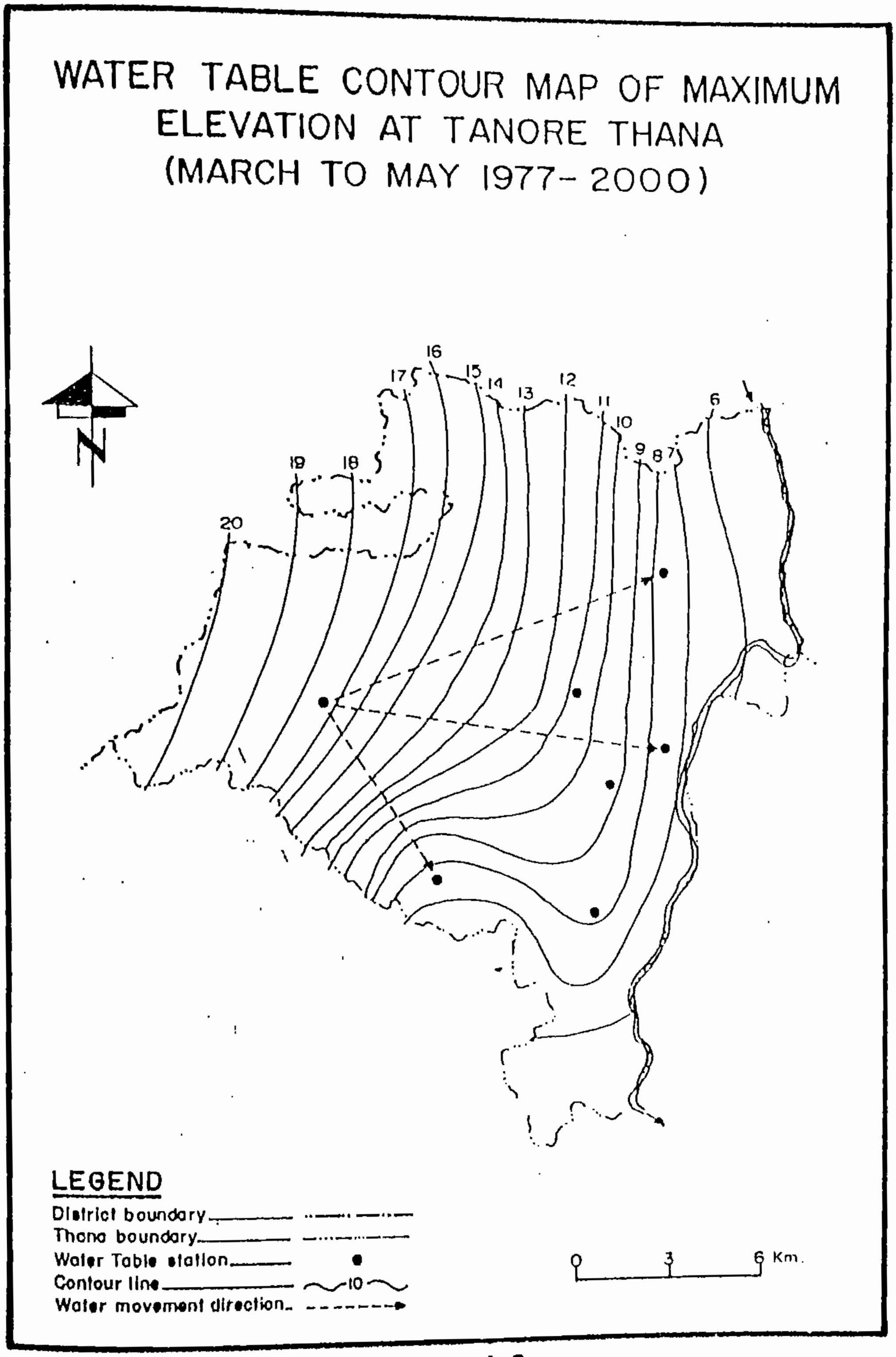


4.2.3 Groundwater Table Contour Maps and Movement of Water:

From the Map-4.2 and 4.3, it is found that the ground water table elevation represents an energy head, flow line or stream line which is perpendicular to the direction of movement of groundwater. Ground water contour maps are very much significant for identifying the area of recharge and discharge and the direction in which the groundwater moves. By comparing contour maps of different times any changes of ground water storage or in the direction of movement that may have taken place can be determined. Some information of regional Transmitting capacity of the aquifer and regional horizontal pattern of groundwater movement can be inferred from water table contour maps. The descriptions of the contour maps are given in the following paragraphs.

Groundwater Table Contour Map of Miximum elevation

In the present study, low water table elevation takes place generally in the driest period of the year while groundwater reservoir does not receive any recharge from surface sources and much water is exploited through the tubwells. By Subtracting the values of water table depth from the values of surface elevation of the place where records have been taken, the values of low water elevation are found. As the rise and fall of water levels are related to the recharge and discharge condition. The minimum elevation of the water table takes place when recharge was minimum and the maximum elevation of water table takes place when the recharge was maximum. With few exceptions, due to early and late rainfall, the maximum elevation of water table generally prevails in the months of March to May.


WATER TABLE CONTOUR MAP OF MAXIMUM ELEVATION AT TANORE THANA (MARCH TO MAY 1977-2000)
N
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
LEGEND
District boundary
Thana boundary
Water Table station
Contour line
10
Water movement direction
0
3
6 Km.

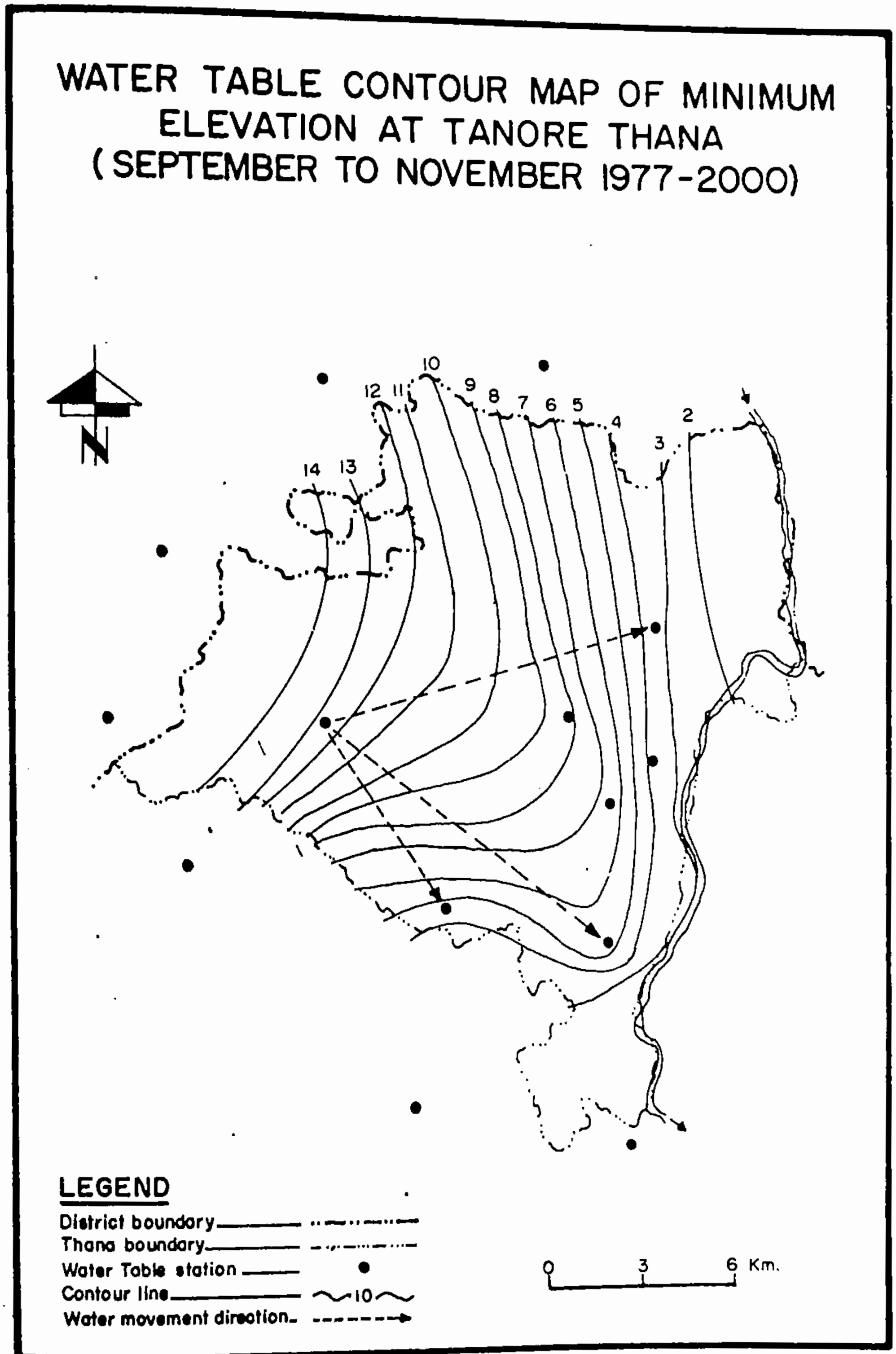
Map-4.2

From the map-4.2, it is found that the marked variation in the gradient of the contours indicates in homogeneity of nature of subsurface materials. The gradient is most gentle near the eastern margin where it is 4m/ km and indicates very high permeability. The gradient in the southeastern portion is very steep where it is about 2 m/km. The steep gradient in these places indicates low permeability. The gradient is 1m/ km in the middle and northwestern part of the study area. The minimum elevation is 6 meters above main sea level at the southeastern most part of the area. From this part, the level gradually rises towards the western side where it reaches a maximum elevation of 20 meters.

The flow direction of the ground water is varying from place to place. The highest elevation of the water table occurs in the northwestern part, from where the ground water flow takes place towards east, southeast, and northeast direction. The ground water out flow is directed towards the river Sib-Baranai in the east.

Groundwater Contour of Manimum Elevation

Generally the highest elevation of water table occurs in August to October, which vary from 2 meters in the east to 14 meters in the northwest (Map-4.3). The values of the minimum depth of water table below the ground is subtracted from the elevation of the ground surface to get the values of maximum elevation of water table with respect to mean sea level. Average values of such records for the months of August-October from 1977 to 2000 were computed for all the 16 observation wells situated in and around the study area. These values are used to draw the water table contour map of minimum elevation taking the sea level as datum.


WATER TABLE CONTOUR MAP OF MINIMUM ELEVATION AT TANORE THANA (SEPTEMBER TO NOVEMBER 1977-2000)
N
14
13
12
11
10
9
8
7
6
5
4
3
2
LEGEND
District boundary
Thana boundary
Water Table station
Contour line
10
Water movement direction
0
3
6 Km.

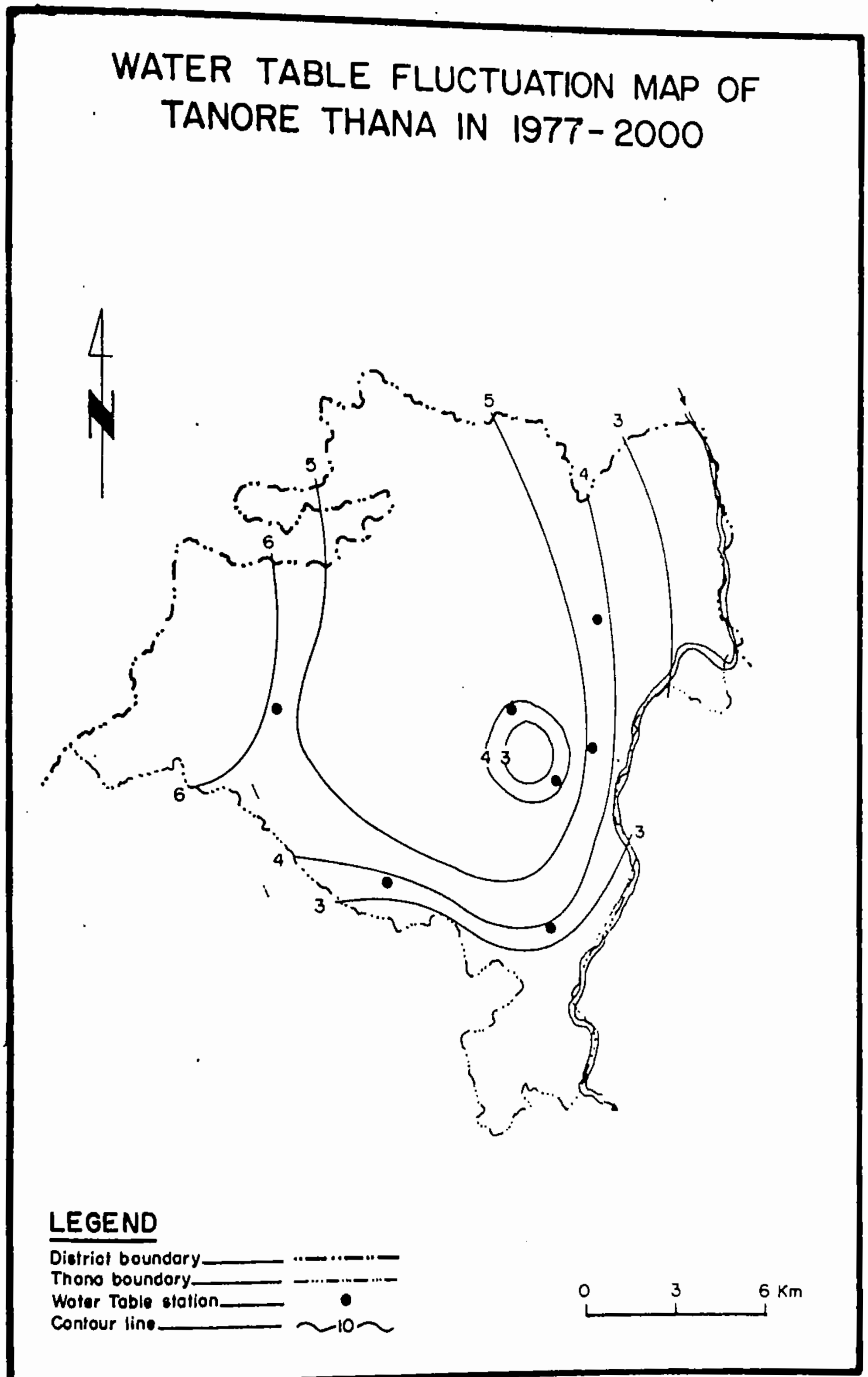
Map-4.3

The elevation gradually declines towards southeast and east. The gradient of water table is steep in the northwestern part where the value reaches up to 2m/km indicating inferior hydraulic properties of the aquifer. In the eastern part of the study area, the gradient of 4m/km is found which indicates high permeability of the aquifer. From the northwest where highest elevation of groundwater level takes place, the elevation decrease towards the east, northeast, and southeast, in which the flow of ground water is directed. The outflow of ground water towards the river Sib-Barani in the east.

4.3 Groundwater Table Fluctuation:

The fluctuation of groundwater water table takes place with the change of season, when ground water storage is reduced or increased due discharge and recharge respectively. The magnitude of the fluctuations of course depends upon the quantities of water recharged and discharged and usually a fully developed aquifer will have greater range than one partially developed. The highest water table generally occurs in August to October whereas lowest water table occurs in March to May. Water table fluctuation maps are important in determining annual change in storage and hence annual variation in water level with respect to recharge and discharge.

From the map -4.4, it is found that the maximum fluctuation takes in the western part of the study area, which amounts at 6 meters. The minimum fluctuation of the water table takes place in the southern and eastern part of Tanore thana which amount at 2 meters. In the middle portion of the study area, fluctuation of water table was about 3 meters.


WATER TABLE FLUCTUATION MAP OF TANORE THANA IN 1977-2000
N
5
3
5
4
6
4
3
6
3
4
3
LEGEND
District boundary
Thana boundary
Water Table station
Contour line
10
0
3
6 Km

Map-4.4

4.4: Depth of Water Table:

The contour map of maximum depth to water table (4.8 m) is very much significant in designing tube-wells. It is used for determining pumping level, soil moisture, deficiency etc. It is also indicates probable areas of ground water recharge and discharge and hence probable areas for groundwater development.

The contour map of maximum depth to water table can be prepared wither by superimposing the surface contour map with the low water table contour map or by directly plotting the records of maximum depth for different wells. The depth of water level at the end of dry season from 1977 to 2000 have been taken for all the 16 observation wells, situated in and around the study area. The contour map of maximum depth to ground level was drawn at 1-meter interval by joining the points of equal value.

The maximum depth of occurrence of ground water level range from 4 meters to 17 meters. In the northwestern part of the study area, where the thickness of upper clay and silt layer is higher, the occurrence of ground water table was observed at the deepest level. From this place, the depth of water table becomes shallower in the east and southeast directions. The shallowest occurrence of the maximum depth to ground water table was observed in the eastern part of the study area, at a depth of 6 meters. In most of the study area, the maximum depth of water table below ground surface was more than 6 meters.

The recession of the water level in the study area starts from November and reaches to the maximum depth generally in the months of April and May due to reduction of groundwater storage by natural and artificial discharge. The reduced flow of reservoirs and scanty rainfall also contribute to the lowering of water level.

Ground water can be easily extracted by centrifugal pumps, where water table lies within 6 meters. So during dry season, in almost the whole study area ground water can not be pumped with centrifugal pump, except the eastern part and southeastern part of the study area. Deep tubewell is suitable for a larger part of study area for irrigation. Due to lowering of the water table below 12 meters during dry season, deep tubewell irrigation is not applicable for the western part of the study area throughout whole dry season.

4.5: Groundwater Recharge and its sources:

Groundwater management practice generally is based on the safe-yield concept. The safe-yield of groundwater system is the amount of water, which can be withdrawn without causing problems. Examples of such problems are excessive water level declines, reduction of base flow of streams, deterioration of water quality, land subsidence and sea water intrusion in coastal aquifers. The safe-yield concept can be also thought of annual withdrawals, which will keep the groundwater basin essentially in equilibrium with the long-term natural recharge.

The term recharge means the replenishment of groundwater storage, which has been reduced by groundwater discharge. The principal source of groundwater includes: -

Rain waters that infiltrate and percolate through the unsaturated zone;

Flood waters which overflow river and stream banks that infiltrate and percolate;

Rivers and canals where the surface water level is higher than the groundwater level;

Percolation from ponds, beels and others static water bodies above the water table;

Seepage from the irrigation ditches and water from irrigated fields that is not evaporated or transpired by crops;

Lateral flow of groundwater from adjacent areas with higher water levels and

A fraction of used and lost industrial and domestic withdrawals (MPO/Harza, 1986).

Regarding the principal sources of groundwater recharge in the study area, the following points are considered: -

The study area includes mostly the highly elevated part of the Barind Tract. The groundwater table referred to the mean sea level, in the study area is on higher level than the surrounding areas except in the northwest. This means that the recharge to groundwater in the study area direct from ground surface during the rainy season and the lateral inflow of groundwater from adjacent areas with higher water level is negligible.

Most of the study area is included in the non-flooded zone. Only minor part of the study area (in the eastern side) is effected by shallow flood of the short duration. That is why the recharge from the vertical percolation of floodwater is ignorable

At present level there is no major natural canal system and artificial recharge scheme in the study area.

The recharge of groundwater by the percolation from ponds, beels, and swamps above the water table may take place but its extent is not very high.

The Sibu-Baranai river contain more water two or three months during the rainy season and the rest of the months are dry-up or contain a little water in her body. So it is clear that the aquifer adjacent to the river Sibu-Baranai receives a minor quantity of recharge for about two or three months in a year from the river.

Most of the study area is covered by Pleistocene Madhupur clay, which is reddish brown in colour, sticky and plastic when wet.

The rate of percolation of water derived from rainfall, to the aquifer is dominated due to high thickness of the upper clay and silt layer covering the aquifer and low infiltration rate of water through the Pleistocene Madhupur clay formation. The infiltration rate of the sediments covering the Barind Tracts is 13 percent (Deppermann and Thiele, 1973) to 16 percent (Khan, A. A. et. al, 1986).

In the study area, mud-cracks are formed in dry season due to desiccation of clay. From November to April the whole area is dried up due to absence or scanty rainfall, high temperature and low humidity. As a result, the depth of the mudcracks is supposed to be several meters and mudcracks of 10 to 15 centimeter wide are formed in the surface. But it s accurate extent is not known.

The researcher seems that the mudcracks are highly significant for their contribution to recharge. With the beginning of the monsoonal rainfall, in the month of May and June, aquifer starts to receive recharge. Water passes directly through the mudcracks to the aquifer. Mudcracks augments the transmission of water from the surface to the aquifer.

So it is evident from the above discussion that the principal source of groundwater in the study area is rainfall. Groundwater level responses to recharge from land surface from May to early November. In the early June, the rainfall fills the soil moisture deficit and creates standing water with in bounded paddy fields. Once soil moisture exceeds the field capacity deep percolation of excess water begins at the rate upper clay and silt layer on the surface. The water table rises in response to deep percolation generally up to late October. The total volume of water gained by the infiltration of water from May to October constitute almost entirely the actual recharge. After October, groundwater level starts to fall in response to surface drainage, evapo-transpiration etc.

4.6: Recharge Calculation:

In Bangladesh, the elevation of available groundwater resources in generally based on the calculation of recharge. The mean annual actual recharge has been calculated for the whole study area to determine the safe yield of water for the whole region. The study area has been divided into 12 polygons (Map-4.5) following Theissen method. Then the recharge over each of the polygons has been measured by the Theissen polygons method


POLYGON DISTRIBUTION WITH RECHARGE OF TANORE THANA
Polygon-1 Recharge 683hact.m.
Polygon-2 Recharge 332 hact. m.
Poygon-3 Recharge 2162hact.m.
Polygon-4 Recharge 594·57 hact. m.
Polygon-5 Recharge 921hact.m.
Polygon-6 Recharge 544hac.m.
Polygon-7 Recharge 427·39 hact. m.
Polygon-8 Recharge 1228·91 hact. m.
Polygon-9 Recharge 1254 hact. m.
Polygon-10 Recharge 423·26 hact. m.
Polygon-11 Recharge 533hact. m.
Polygon-12 Recharge 313·73 hact.m.
LEGEND
District boundary
Thana boundary
0 1 2 3 4 5 Km.

Map-4·5

formula which is $R = A \times T \times Sy$; Where, R = recharge, A = area of the polygon,

T = Thickness of the fluctuation zones,

Sy = Specific yield of the rock unit within fluctuation zone of water table.

If the fluctuation zone is composed of a single type of rock unit than its specific yield value is employed. But if it is composed of more than one type of rock units then an average specific yield is calculated by using the following formula

$$Sy = \frac{T_1Y_1 + T_2Y_2 + T_3Y_3 + \cdots + T_nY_n}{T}$$

Where,

Sy = Average specific yield of the fluctuation zone within the polygon in percent,

T_1, T_2, T_3 etc. = Thickness of individual layer within the fluctuation zone in feet,

Y_1, Y_2, Y_3 etc. = Assigned specific yield of the respective layer in percent,

T = Fluctuation of water table during the year in feet.

The specific yield used for different rock types is as follows:

Table-4.4: Specific yield for different rock types.

Rock Type	Specific Yield (Sy)
Clay, Silty clay	3-5%
Very fine sand	7%
Fine sand	10%
Fine sand with clay	8%
Medium sand	12-15%
Coarse sand	15-20%
Coarse sand with gravel	20-25%

Calculated recharge over individual polygon is given table-4.5

Table-4.5: Calculated recharge over individual polygon in 2001.

Polygon No.	Area (in hectares)	Average Thickness of Fluctuation zone (Meters)	Specific Yield (Sy)	Recharge R =A×T×Sy (in hectares/meters
1	1378.1	11.85	4.18%	682.614
2	1379.8	6.04	3.98%	331.691
3	5387.6	7.35	5.46%	2162.097
4	3178.3	8.46	3%	806.653
5	2486.6	6.5	5.7%	621.285
6	2716.3	6.67	3%	543.532
7	2165.1	6.5	3.4%	478.487
8	2900.1	6.5	6.6%	1244.143
9	3035.7	5.82	7.1%	1254.412
10	1828.5	4.53	5.11%	423.264
11	1611.1	5.07	6.52	532.572
12	1361.7	7.68	3%	313.735

Total area = 29428.9 hectare Total Recharge = 9394.485 hectare/ meter

So it is found that total 9394.485 hectare/meters or approximately 93.94 million cubic meters of water is added annually to the groundwater storage. This volume of water can cover the entire area of 295.05 km^2 to a depth of about 359mm.

Karim (1984) have been made recharge calculation for all the Upazilas in Bangladesh. According to him the actual recharge of Tanore Upazila is 238 mm. By applying theoretical method (water balance method) Matin, (1987) determined that the actual recharge of Tanore Upazila is 248 mm. So it is observed that the present study shows lower value of recharge in the study area than those calculated by Karim (1984) and Matin (1987).

4.7: Groundwater Discharge:

Discharge means the depletion of groundwater storage that is generally replenished by groundwater recharge. It is the measure of outflow from groundwater reservoirs i.e. from aquifers. Generally groundwater discharge occurs by:

Withdrawal of water by lifting from dug wells and by pumping from tub-wells.

Outflow to rivers, canals, and ditches that have water levels lower than the water table.

#Capillary rise from the water table and evaporation when near land surface and

Transpiration by plants whose roots are near the capillary zone or the water table (MPO, 1986). The estimation of discharge that takes place annually is an essential task to determine the development potentiality of an area. Pumpage from wells constitutes the principal artificial discharge of groundwater. For proper groundwater management discharge, discharge and recharge should be balanced properly.

The artificial discharge that takes place in the study area by different types of wells has been discussed in the following paragraphs. Most of the tub-wells were set-up recently by BIADP and PHE. The number of deep tub-wells installed in the study area is 432. These tubwells have an average discharge of 202.18m^3/h (2cusec) and they run from late December to early May that is for about days per annuam with an average 8 hours a day. Hence, the total annual withdrawal during this period is 4325202.18585135 = 94329101 cubic meters.

Again 339 shallow tubewells which have an average 50.95 m^3/h (0.5 cusec) discharge capacity running from late December to early May average 8 hours a day. Hence total annual withdrawal during this time is 339550.95585135 = 18653814 cubic meters.

The total number of hand tubwells in the study area is calculated about 2036. The actual discharge of tubwells and dug wells is not known accurately. Here it is assumed that a person uses about 3.79510^{-3} m^3 (6 gallon) of water per day. There are 158301 persons in the study area, according to the population census of 2001. Then the volume of water withdrawal by a hand tubwells in a year is 158301 53.79510^{-3} 5365 = 218985.69 cubic meters. So the total abstraction of water per annum from the aquifer in the study area is 94329101+18653514+218985.69 = 113201900.69 cubic meters = 113.20 million cubic meters.

4.8: Determination of Available Recharge:

Potential recharge is the mean annual volume of surface water that could reach an infinite ground reservoir and be stored there, limited only by the rate at which the soil or subsurface clay allows the water to infiltrate and percolate. Useable recharge is net equal to 75% of potential recharge leaning 25% to account for such uncertain factor as future land use and flood control development. Available recharge is then determined by reducing useable recharge for geographic and physical limitations on groundwater use, eliminating areas where water needs are already met by surface water development and deducting out flow to rivers from the start of the monsoon season to the beginning of the irrigation season (MPO, National water plan -

II; 1986). Recharge that occurs under natural condition is referred to as actual recharge. However, if the groundwater table is artificially lowered by the abstraction, the opportunity is created for increasing recharge to get some maximum value. This value is the function of the condition, (which determine the infiltration rate) and availability of water at the surface, the maximum value is referred to as potential recharge. That is, Potential Recharge = Actual Recharge + Rejected Recharge. Rejected recharge is the fraction of water available at the surface, which cannot infiltrate and percolate because the water is at the surface. Rejected recharge becomes surface runoff. Al most of the area under consideration lies above flood level, so, the value of rejected recharge is negligible. As a result, the actual recharge calculated for the study area is roughly equal to the potential recharge. Now, it can be said that the potential recharge of the study area is 93.94 million cubic meters.

According to the definition stated above, the useable recharge is the 75% of the potential recharge; i.e. the useable recharge is about 70.5 million cubic meters. 25% of potential recharge is placed in reserve to account for unplanned groundwater development, uncertainities in the estimate of potential recharge, cropping pattern change etc. Now, available recharge can be calculated by deducting loss of recharge area due to (a) the exibiting geographical and Physical envirorns on groundwater use for agricultural practice, (b) existing surface water scheme (c) loss of recharge as outflow to rives and as capillary evapotranspiration.

For the present study only the outflow to rivers, which takes place before the beginning of the irrigation season has been considered. Water table reaches to the maximum elevation generally in the month of October. From that position water table declines due to outflow of water to the rivers in an average 1-meter before the beginning of the irrigation season in January. The total discharge of water to the rivers (also due to evapotranspiration) is calculated by multiplying the total area, with the average specific yield of upper clay and silt layer (about 3.5%) times the fluctuation. So, the outflow to the river from the annual recharge before the beginning of the irrigation season is 29428.9 5150.035 hectare-meter that is about 10.3 million cubic meters.

In the other ways of the loss of recharge is neglected then the available recharge can be calculated by deducting 10.3 million cubic meters of water from the useable recharge. So, the available recharge is 60.2 million cubic meters.

4.9: Recharge -Discharge Balance:

The natural conditions of the under groundwater system has an annual equilibrium in which the recharge during the monsoon is balanced by the losses of evapotranspiration and drainage during the dry season. The fundamental relationship for the groundwater is Recharge = Groundwater losses + Change in Storage.

Where the water table recovers annually to the land surface, there is no annual change in storage and recharge is equal to losses. For the present study the annual recharge is 93.95million cubic meters. Considering rejected recharge as negligible this actual recharge is equal to the potential recharge. That is the potential recharge is 93.95 million cubic meters.

The useable recharge is about 70.5 million cubic meters and the available recharge is about 60.2 million cubic meters. For the development of the Barind area, Barind Integrated Area Development Project (BIADP) was established in July-1986. This project covers 5132 squire kilometers of land of 15 Thanas of Rajshahi, Chapai Nawabganj and Naogoan districts. The study area is included in BIADP groundwater development is a part of the development program of this project. Recently large number of deep tubwells and shallow tubewells were sunk as a part of the development program in the study area, without proper investigation regarding the potential of the aquifer to produce water.

Now if all the tub-wells work properly, then total 113.20 million cubic meters of water will be abstracted annually as artificial discharge and the calculated available recharge is 60.2 million cubic meters. This value is 53 million cubic meters higher then the available recharge. Thus, if the estimated amount of annual discharge is made artificially by the tube-wells then there will be a possibility of break down of the natural equilibrium between groundwater discharge and recharge in future. This result is indicating an alarming situation in the Tanore thana as well as in the Barind Tract. As a result permanent lowering of ground water table might take place due to over-development of the area.

CHAPTER-5

QUALITY OF GROUND WATER.

All over the world, water is the most valuable asset to human development. All the biological, environmental and the ecological phenomena depend on fresh water. But now days, it is very difficult to get fresh and pure water from the river and this is due to mishandling and reckless use of water by man everywhere. The volume of fresh ground water of the world is 8250,000 km^3 and considering all the classes of water the percentage becomes 0.605 (Wilson-1990). An agriculturist needs water to grow crops, uses soil moisture, rainfall and natural water for his needs and to the general people recreational aspects are important apart from drinking water (Gautom-1990). The ignorance of the people about water pollution concerning the use of different chemical fertilizers and insecticides is one of the major factors. Farmers use the fertilizers and insecticides in their fields that pollute water and lastly the polluted water is infiltrated to the ground level. In this way, the physio-chemical properties of fresh water are changing gradually.

The Barind area of Rajshahi is a rich heartland of agricultural production. A large volume of ground water is used to irrigate the vast land for agricultural production, as well as domestic consumption's. The deep tubewells and shallow tubewells are used here for supplying water. In this chapter, mainly discusses the quality of groundwater i.e. physical and chemical quality of groundwater in the investigated area.

5.1: Groundwater Quality:

A study on quality of groundwater at Tanore thana is mainly on based personal observation; instrumental reading and laboratory test of selected sample water of the study area. Personal observation, instrumental reading and laboratory testing methodology, which has been done in this study, are shown in the table-1.2. The results of sample water are given bellow in the table-5.1 and table-5.2 respectively.

5.?.1: Physical Quality:

The results of the physical quality of sample water were mainly based on personal observation and instrumental reading. The physical properties of sample groundwater were including temperature, transparency, conductivity, colour, taste & odour and turbidity. According to the table-5.1, the temperature of sample water varied between 27^{0}c to 33.5^{0}c and the air temperature varied from 29^{0}c to 25^{0}c in all season. In the morning the temperature was low in all season, peak point in midday and gradually decrease in the evening. The sample water available in the shallow and deep tube-wells was colourless and free from objectionable odour and normal taste. The transparency of all sample water was normal, the conductivity varies from 1 to 8 µ-mohs/cm and the turbidity value was 1 to 7 NTU units. According to the report of the department of public health engineering zonal laboratory, Rajshahi, the physical characteristics of the different sample water of Tanore thana was suitable for drinking domestic uses and irrigation purposes and the study show this fact.

Table-5.1: Physical properties of sample water in 1998-99.

Season and place →	Wet Season			Dry Season		
Physical Properties ↓	Pranpur (11.10 AM)	Sadipur (12.50 PM)	Saranjay (3.10 PM)	Kalma (8.30 AM)	Talando (10.00 AM)	Parishow (1.10 PM)
Air Temperature(^{0}c)	33	30.5	33.5	29	32	35
Water Temperature(^{0}c)	31.3	30	28	27	29.5	31
Transparency	Normal	Normal	Normal	Normal	Normal	Normal
Conductivity(µ-mohs/cm)	4.52	7.76	1.26	4.64	1.32	5.18
Colour	Water	Water	Water	Water	Water	Water
Taste & Odour	Normal	Normal	Normal	Normal	Normal	Normal
Turbidity (NTU)	3.21	6.72	1.25	4.89	2.72	5.01

Source: Personal observation and instrumental reading

5.[illegible].2: Chemical Quality

The result of the laboratorical tests of sample water was shown in the table-5.2, which indicates the chemical qualities of water in the study area. Various chemical tests of sample water were carried out to determine the strength and concentration of different constituents present in it. The mineral content of sample water is most compounds expressed either in parts per million (ppm) or milligram per liter (mg/l). These two units are numerically same. The chemical properties of sample water may include P^H value, CO_2, DO, CO, HCO_3, Cl, Total hardness, Ca-hardness, Mg-hardness, BOD5, Eh, rH_2, Silicate, Phosphate etc. The limited concentration of various constituents in water is called standard criteria. The standard value given by USPH, ISI, WHO and ICMR are presented in the table-5.3. The table shows the standard criteria given by ISI and ICMR are higher far few constituents than that of WHO and USPH standard. Discussion of chemical properties of sample water which was tested in this study are given below and comparing this value by the standard value given by various agencies.

Table-5.2: Chemical Properties of sample water in 1998-99.

Chemical Properties ↓	Wet Season			Dry Season		
	Pranpur	Sadipur	Saranjay	Kalma	Talando	Parishow
P^H value	6.8	7.0	8.2	7.3	5.8	7.2
CO_2 (mg/l)	120	120	160	60	55	48
DO (mg/l)	3.55	5.79	4.04	1.60	1.20	2.40
CO_3 (mg/l)	Nil	Nil	Nil	Nil	Nil	Nil
HCO_3(mg/l)	133	282	34	152	170	158
CL(mg/l)	38.34	58.22	45.44	69.64	110.76	134.90
Total	68	184	70	128	334	126
Ca-Hardness(mg/l)	63	66	37.8	54.6	79.8	63
Mg-Hardness(mg/l)	1.22	28.79	7.85	17.90	33.22	15.37
BOD_5(mg/l)	0.76	0.90	1.60	5.23	5.79	2.37
Silicate(mg/l)	0.002	0.0016	0.0001	Nil	Nil	Nil
Phosphate(mg/l)	Nil	Nil	Nil	Nil	Nil	Nil
Eh value	0.47	0.45	0.30	0.40	.058	0.42
RH_2 value	29.72	29.41	26.85	28.52	31.55	28.81
TDS (mg/l)	239.34	524.22	149.44	349.64	414.76	560.90

Source: Phycology and Limnology Lab, Department of Botany, University of Rajshahi.

Table-5.3: Standard value of water given by various agencies.

Chemical Properties ↓	Name of the Agencies			
	WHO (1971)	USPH (1962)	ISI (1974)	ICMR (1975)
Turbidity (NTU)	5-25	5	-	-
Test & Odour	not lesirable	Test & odourless	-	-
Colour (pt. Scale)	5-50	15	-	5-25
Conductivity(μ-mohs/cm)	-	300	-	-
P^H value	6.5-9.2	-	6.4-9.0	6.5-9.2
DO value (mg/l)	-	40-60	3.0	-
Chloride (Cl) (mg/l)	200-400	400-500	600	250-1000
Total hadrness(mg/l)	100-500	-	-	300-600
Mg-hardness(mg/l)	30-150	-	-	50-150
Ca-hardness(mg/l)	75-200	-	-	75-200
BOD_5 value(mg/l)	-	-	3.00	-
Phosphate(mg/l)	-	0.1	-	-
TDS value(mg/l)	5-1500	500	-	-
* Arsenic(mg/l)	0.05	0.05	0.20	0.20

P^H Value:

P^H value was always observed neutral to alkaline, which is a general characteristic of water as also observed by Robert et. al (1940), Zafar (1964), Back and Ranking (1962). It has been observed by some agencies from various instrumental tests that the P^H value of water ranges from a minimum 6.5 to a maximum 9.5 (Table-5.3). The P^H value of sample water of the study area was seen from a minimum 5.8 to a maximum 8.2 (Table-5.2) in 1998-99. An important side effect of high P^H value in water cause the depression of the solubility of some plant nutrients and consequent plant injury. Only one spot (Spot-F) show a lower value (5.8) and the average P^H value was 7.05. So the P^H value of ground water of the study area is suitable for any purpose of human consumption.

Carbon-Di-Oxide (CO_2):

Carbon-di-oxide enters an aquatic system through respiration or from the atmosphere. It is conducted by living organisms and also resulted due to decomposition of organic mater. The reaction of producing CO_2 in organic mater is organic mater $+O_2 \xrightarrow{Bacteria} CO_2+H_2O$. It has been observed that the presence of CO_2 in water varied from 48 mg/l to 160 mg/l in 1998-99 and the average value was 94 mg/l. The lowest value was recorded at spot 'E' in dry season and highest value at spot 'C' in wet season in the sample water of the study area. The amount of CO_2 present in water is not objectionable for any purpose.

Total Alkalinity (CO_3 & HCO_3):

The presence of bicarbonates, carbonates and hydrates of water are combindly called total alkalinity. Among of this, the bicarbonates were always present in water during the investigation periods while the carbonates were nil. The rages of bicarbonates (HCO_3) was 34 mg/l to 282 mg/l in 1998-99 and the average value was 155 mg/l. The highest and lowest value was found in dry season and the value was 34 mg/l and 282 mg/l respectively. The highest value was observed at spot 'B' and the lowest at spot 'C'. The value above 250 mg/l is objectionable for drinking and irrigation purpose. Casey (1969) observed inverse relation between alkalinity and runoff. Because bicarbonates were normally surface origin.

Dissolved Oxygen (DO):

Dissolved oxygen means mixed oxygen of water. The variation of DO value might be depended on temperature, photosynthesis and sediment concentration. Ellis et. al (1946) and Elmore (1961) stated that an increase in temperature of water results in the increase of DO value and an increase in sediment concentration hampers the photosynthesis and reduces DO value in water. The average DO value in 1998-99 in the study area was 3.09 mg/l. The variation of DO value was recorded from 1.20 mg/l to 5.79 mg/l in1998-99. The lowest value was 1.20 mg/l at spot 'F' in dry season and highest value was 5.79 mg/l at spot 'B' in dry season. The standard DO value of USPH (1962) ranges from 4.0 mg/l to 6.0 mg/l. The DO value of spots A, D, E and F was less than the standard level. So the DO value of the most sample is not suitable for every works.

Chloride (Cl):

The presence of chloride of water increase the soluble salt as an alkalimetal like sodium chloride (Nacl) or increase acidity like hydrochloric acid (Hcl). It was observed that the average chloride content in the study area was about 76 mg/l. The range of chloride was 38.34 mg/l to 134.90 mg/l in 1998-99. The highest value of chloride was found 134.90 mg/l at spot 'E' in dry season and lowest value was38.34 mg/l at spot 'A' in wet season. To compare the results of chloride from table-6.4 and 6.5, it was found that the chloride in water is satisfied for most purpose in water works.

Total Hardness, Calcium (Ca) Hardness and Magnesium ((Mg):

Total hardness in water is mainly present due to Ca^{++} and Mg^{++} ions, though the other polyvalent ions such as Al, Fe, Mn, and Zn also contribute to the hardness of water (Gautam, 1990). Among of these ions, the calcium

(Ca) always dominated over magnesium (Mg). During the study periods, the total hardness varies from 68 mg/l to 184 mg/l, calcium hardness varies from 37.8 mg/l to 79.8 mg/l and magnesium hardness varies from 1.22 mg/l to 28.22 mg/l in 1998-99 respectively. The average value of total hardness, calcium hardness and magnesium hardness was 151.66 mg/l, 60.7 mg/l and 15.66 mg/l respectively. The lowest value of total hardness, calcium hardness and magnesium hardness was 68 mg/l, 37.8 mg/l and 1.22 mg/l at spot 'A', 'C' and 'A' in dry season respectively. The highest value of total hardness and magnesium hardness was 184 mg/l and 28.79 mg/l in wet season at spot 'B' and calcium hardness was 79.8 mg/l in dry season at spot 'F'. To compare the value of total hardness, calcium hardness and magnesium hardness from the table-6.4 and 6.5, it is found that the water of the study area is not objectionable for the most purpose of human activities.

Biological Oxygen Demand (BOD_5):

The amount of oxygen requires from the oxidation of organic material by bacteria be called biological oxygen demand (BOD). The average value of BOD was 0.79 mg/l in this study. The fluctuation of BOD value in water was found 0.79 mg/l to5.79 mg/l in 1998-99. The lowest value was recorded 0.79 mg/l at spot 'A' in wet season and highest value was 5.79 mg/l at spot 'F' in dry season. The normal value of BOD is up to 3.00 mg/l given by SIS. It was suggested by John (1952), Robert (1969) and Richard (1966). So it is clear that the BOD value of the study area is hampered only in the dry season and wet season is suitable for any purpose of human conjumption.

Silicate (SiO_2) and Phosphate (PO_4):

Silicate and phosphate is an important constituent of cell wall of diatoms. Only silicate was present in the sample water in wet season in

1998-99 and the presence of phosphate was nil. The range of silicate was 0.0001 mg/l to 0.002 mg/l in wet season but there is no silicate in dry season. The highest value of silicate was 0.002 mg/l at spot 'A' and lowest value of silicate was found 0.0001 mg/l at spot 'C' in wet season. The standard value is 0.1 mg/l, which is given by USPH (1962). The position of silicate and phosphate was standard level in sample water during the study period.

Oxidation Reduction Potential (Eh):

Oxidation reduction potential is a potential constituents of water which is combindly measured by DO value of chart, P^H value with 0.058 and log PO_2 with 0.0145 and the formula is $Eh = Eo - 0.058P^H + 0.0145 \log PO_2$. The oxidation reduction potential value vary from 0.30 to 0.58 in 1998-99. The average value was recorded 0.43 which is the normal value according to the standard level. The lowest value of Eh was 0.30 at spot 'C' in wet season and highest value was 0.58 at spot 'F' in dry season. The oxidation reduction potential values are suitable for every purpose in the study area.

Oxidation Reduction Index (rH_2):

The oxidation reduction index is a quick and efficient measurement for the oxidation reduction conditions of fresh water in open water bodies (Voznaya, 1981). When a continuos addition of organic materials take place, a continuos decrease in Eh and rH_2 occurs. If any ecosystem has organic material, the concentration of reduced form is higher which results lower Eh and rH_2 values. The values of rH_2 in this study range from 26.85 to 31.55 in 1998-99. The highest value of rH_2 was found at spot 'F' in dry season and lowest value was found at spot 'C' in wet season. The average value of rH_2 was 29.94 and the neutral point is 28. To compare the table-6.4 and neutral point, it is clear that only one spot was less than the neutral point and five spots were higher than the neutral point. The position of rH_2 value in sample water in the study area was not fit for all water works in human activities.

Total Dissolved Solids (TDS):

Total dissolved solids means the solids, which are dissolved by different materials in water and measured by different chemical methods. The concentration of total dissolved solids in water gives general indication of its suitability for any types of water works. Repeated uses of water with high TDS concentration for irrigation will built-up mineral deposit in soil and thus the productivity of the soil is likely to be destroyed. During the study periods, the average value of TDS was observed 573.05 mg/l in 1998-99. The value of TDS varies from 149.44 mg/l to 360.90 mg/l. The highest value was recorded at spot 'E' in dry season and lowest value was observed at spot 'C' in wet season. To comparing the standard value (Table-5.3) and observed value (Table-5.2), it was found that spot 'B' and 'E' was higher than the standard level. The concentration of TDS less than 500 mg/l is suitable for domestic, agricultural and other water works. The average value is suitable and less than the standard level.

CHAPTER-6

SUMMARY AND CONCLUSION

6.1: SUMMARY:

Bangladesh has mainly irrigation based agricultural land where water plays a vital role in agricultural and economic development. An attempt has been made here to focus on the hydrological characteristics of the Barind Tract within Bangladesh in view of drinking and domestic uses, agricultural development, especially intensive agriculture and enhancement of crop yield in Tanore thana.

From chapter two, it is evident that the area of Tanore than is 295.39-squire kilometer. It is located between $24^0 29$ to $24^0 43'$ north Latitude and $88^0 24'$ to $88^0 38'$ east Longitude. Tanore thana has 6 Unions, 21 Mauzas, 333 Villages and the thana headquarters is about 25 kilometers from Rajshahi and accessible by roads.

Physiographically, the study area is divided into three types. There are (a) Barind Tract, (b) Ganges Flood Plain and (c) Tista Flood Plain. 80.32% of the total land is covered by Barind Tract in the study area. In the southwestern and western side of the study area, the elevation of land surface is about 40 meters. The elevation of land ranges from 12 to 40 meters and the land level is divided into four units as (a) High land, (b) Medium high land, (c) Medium low land and (d) Low land. The soil of the study area may be identified as (1) Reddish brown terrace soil, (2) Flood plain soil and (3) Soil of the marshes.

The Sib-Baranai river and her tributaries & distributaries make up the drainage system of the thana which form an intricate network of narrow meandering courses exhibiting dendritic pattern. Geologically the study area is an old landform in the Bengal basin and the formation is both from Recent flood plain and Pleistocene sediments.

Climatically the study area falls under tropic-humid monsoon climate with high temperature (average 37^0c in the month of May), quite a good amount of humidity (average 80%), moderate rainfall (average 1447.31mm of the last 27 years) and fairly marked seasonal variation.

In the study area, total population was 158301 in 2001and density per square kilometer is 536. The population increased more than three times during 1951-2001. There are 81.65% Muslims, 10.19% Hindus, 1.54% Christians, 0.21% Buddhists and 6.4% believers in other religions.

The storage of water in the land surface is called surface water. The occurrence, movement, storage and changes in storage of surface water of an area depend upon some factors; such as physiography, drainage, soil type, climatic condition and so on. In the surface water hydrology, three types of surface water bodies have been found in the study area. The surface water bodies are ponds, swamps/beels, khals and river. In 1914-15, the number of ponds was 99 and area was 400.24 acres; in 1965-67, the number of ponds was 2105 and area was 1158.81 acres and in 1998, the number of ponds were 2437 and area was 1375.08 acres. The number and area of ponds are increased during the study periods. There are some biggest ponds i.e. Kashardighi, Taluparadighi, Nananpurdighi, etc. in the study area. Most of the ponds are used in irrigation in the driest months. All the ponds of the study area are used in pisciculture and domestic consumption all the year round.

Among the six unions of Tanore thana, three unions have no beels. The total area of beels was 915.22 hectares in 1914-15 and 1965-67. In 1998, the beels area increased and the area was 990.74 hectors because an embankment was built-up after 1967 along the eastern bank of Sib-Baranai river. For this reason, the lower area of the western bank of Sib-Baranai river has changed into a beel area. The total length of the river was 23 km in the study periods. The length of khals was 92.30-km in1914-15 and 1965-67. In 1998, the length shortened to 90.50 km.

Rainfall is the only source of water in the surface and subsurface of the study area. 80% of total rainfall occurs in the rainy season. The average rainfall of last 27years is 1446.31 mm. The highest rainfall was 2877.5 mm in 1999-2000 and lowest was 765.5 mm in 1994-95 in the study. Seasonal variations of rainfall were 60.50 mm in summer, 1346.47 mm in monsoon and 38.34 mm in winter seasons of the last 27 years. Average number of rainy day was 61 and the highest being 89 days in 1992-93 and the lowest 44 day in 1982-83.

An attempt has been made to analyse the hydrograph of water level and discharge of Sib-Baranai river in the study area. From the monthly water level, it is evident that the river water level is ranges between 9.70 m/PWD to 9.17 m/PWD from the month of January to late April. The river water level reaches the topmost point during the periods from month of July to September and vary between 12.57 m/PWD to 13.54 m/PWD. During the study periods, the trends of maximum, minimum and average water levels of Sib-Baranai river varied from 12.78 m/PWD to 16.02 m/PWD, 8.58 m/PWD to 9.12 m/PWD and 13.307 m/PWD to 11.776 m/PWD respectively. The highest (16.02 m/PWD) water level was found in 1995-96 and the lowest (8.505

m/PWD) water level was found in 1979-80. The monthly average discharge rate varied from 0.589 m^3/s to 66.294 m^3/s at Nawhata station. The highest monthly average (66.294 m^3/s) fell in the month of August of the last 27 years and the lowest (0.589 m^3/s) in the month of April. From 1975-76 to 2001-02, the average, maximum and minimum discharge ranges from 11.70 m^3/s to 59.80 m^3/s, 177 m^3/s to 39.5 m^3/s and 0.07 m^3/s to 29.40 m^3/s respectively during the study periods. The highest discharge rate was 177 m^3/s in 1987-88 and the lowest was 0.072 m^3/s in 1994-95.

There are 16 observation wells in and around of the study area. Among the 16 observation wells, 11 are piezometic wells and 5 are dug wells.Groundwater level is an important hydrologic parameter for study. The depth of the groundwater table from the ground surface average, maximum and minimum elevation of water table with respect to mean sea level, fluctuation of water table during the dry and wet season etc. were determined by analyzing the collected data of the observation wells. Annual average elevation of water table was varying from 3.19 m to 17.74 m. of the last 27 years. The highest value (17.74 m) was observed at Mandumalahat observation well (RJ-040) and the lowest value (3.19 m) was observed at Tanore observation well (RJ-136). Annual maximum water table was varying from 4.90 m to 20.73 m. The highest value (20.73 m) was found at Mandumalahat observation well (RJ-040) and the lowest value (4.90 m) was found at Shamaspur observation well (RJ-039). And annual minimum elevation of water table was ranged from 0.91 m to15.52 m. The minimum highest value was 15.52 m at Mandumalahat observation well (RJ-040) and minimum lowest value was 0.91m at Shamaspur observation well (RJ-039).

Monthly average elevations of groundwater table of seven observation wells were studied in this research work (Table-4.2). At Lalpur observation well (RJ-027), monthly average value was varied from 8.20 m to 11.04 m from mean sea level. The highest value was observed (11.04 m) in the month of May and the lowest value was observed (8.20 m) in the month of October. At the Rastanbarso observation well (RJ-038), monthly average value range from 4.81m to 8.36 m. The highest value was observed (8.36 m) in the month of May and the lower value was observed (4.81m) in the month of October. At shamaspur observation well (RJ-039), monthly average value varied from 3.89 m to 8.27 m from mean sea level. The higher and the lower value was observed 8.27 m and 3.89 m in the month of April and September respectively. The monthly average groundwater elevations at Mandumalahat observation well (RJ-040) range from 12.67 m to 17.67 m from mean sea level. The higher value was observed (17.67m) in the month of May and the lower value was observed (12.67 m) in the month of October. At the Gollapara observation well (RJ086), monthly average elevation of ground water table varied from 6.73m to 912m from mean sea level. The highest and the lowest value was observed 9.12m and 6.73m in the month of May and November. The monthly average ground water table elevation at Tanore observation well (RJ-136) range from 3.50 m to 7.64 m. The highest value was observed (7.64 m) in the month of April and the lower value was observed (3.50 m) in the month of October. And lastly, it was observed that the elevation of ground water table from mean sea level at Mohammadpur observation well (RSS-32) was varied from 4.08 m to 7.54 m. The highest and the lowest value was 7.54 m and 4.08 m in the month of April and October respectively.

The fluctuation of groundwater table takes place with the change of season. The highest water table fluctuation occurs in the month of August to October whereas the lowest water table fluctuation occurs in the month of March to May. Water table fluctuation maps are important in determining annual change in storage and hence annual variation in water level is related to recharge and discharge condition. From the fluctuation map (Map-4.4), it was found that the maximum fluctuation was 6 m in the western part, minimum fluctuation was 3 m in the southeastern and eastern part and about 5 m fluctuation was found in the middle portion of the study area.

The water table contour maps of the study area were prepared with data, which have been manipulated from weekly records of groundwater level from 1977 to 2000. Groundwater contour map is very significant for identifying the direction in which the water moves. Generally the highest elevation of water table occurs in August to October with variation from 2 m in the east to 14 m in the west (Map-4.2). The gradient of contour map with maximum elevation was observed up to 2 m/km in the north-eastern part and 4 m/km in the middle southern part of the study area. The elevations decline from west to southeast and east and outflow of groundwater towards the river Sib-Baranai in the east. Again the minimum elevations of water table generally prevail of March to May. The gradient of contour map with minimum elevation were most gentle near the eastern margin where it was 4 m/km and in the southwestern was very steep where it is about 2 m/km. The gradient was 1 m/km in the middle and northwester part of the study area. The groundwater flow takes place towards the east, southeast and northeast direction and the flow of water was directed towards the Sib -Baranai river in the east

It had been observed that in Tanore thana in1998-99, the physical properties of groundwater were suitable for drinking, domestic uses and irrigation purpose. Most of the chemical properties i.e. P^H value, CO_2, CO_3, HCO_3, CL, Total hardness, Ca-hardness, Mg-hardness, Silicates, Phosphate, Eh, TDS etc. were not objectionable for every water works. The DO values of four spots (among the six spots) were not suitable for every water works. The BOD value in dry season hampers the oxidation-reduction process. The rH_2 values were not fit for all water works in human activities.

6.2: CONCLUSION:

The Barind region is a rich hart-land of agricultural production, which is situated in the north-west parts of Bangladesh. The Barind is an Older Alluvium formation of the Pleistocene Epoch and it is undulating in nature. The Barind region divided into three categories: Higher Barind, flat Barind and Lower Barind. Tanore thana is in the higher Barind in the district of Rajshahi.

For the importance of water resources, a detail hydrological investigation at Tanore thana has been conducted in this research work to identify the nature and pattern of water resources in various mode. The present hydrological study of the investigated area has enabled to arrive at the following conclusions:

Geomorphically, the study area includes both part of uplifted Barind tract of the 'Pleistocene Upland' and Recent Ganges flood plain. Geologically, the study area occupies mostly a horst, where well-oxidized reddish brown clay of Madhupur clay formation of Pleistocene age is exposed. Unconsolidated alluvium of Recent floodplain deposits occurs only in a small part in the eastern side of the study area. A NNE-SSW trending fault might delineate the boundary between Recent flood plain and Uplifted Braind tract in the eastern part of the study area (Bashar, 1990). Climatically, the study area falls under tropical-humid-monsoon climate, characterized by very humid, wet southwest monsoon from June to November. From December to May, a cool dry northeast monsoon blows from central Asia bringing lowest temperature and humidity and its later part, conventional storm.

In the study area, surface water is very limited. A large number of water bodies have been found but most of them are dry-up during the dry season. Ponds, khals and river are the most important surface water bodies. In the rainy season, they contain a lot of water in their bodies and some times they overflow the lands. During the dry season, they gradually losses water in their bodies by means of horst land surface and longer dry season. Rainfall is the main source of water, which recharge the aquifer. Mudcracks accelerate the percolation of rainwater to the aquifer. The aquifer also receives recharge from the rivers in the late monsoon when the river stage remains at a higher level than the ground levels. But throughout the dry season, the rivers receive groundwater from the aquifer as base flow. The discharge and water level of Sib-Baranai river are not measured 5-7 month during the dry season because the river contain a little or scanty of water in her body. Only the rainy season, the water level and discharge are measured. The peak position of water level and discharge of the river is found in the month of August. The river cannot excite the flood level during the last 27 years. So, the surface water bodies are not placed to role irrigation purpose during the dry season. At that time the surface water bodies are used only for pisciculture and domestics consumption.

The depths of groundwater table varied from ground level in different parts of the study area. The maximum depth to ground water table does not exceed 6 meters in the eastern and south central part of the study area during dry season. In the most parts of the study area, the maximum depth of water table below ground surface is more than 6 meters. So, most of the area is not suitable for shallow tube-well irrigation throughout the whole dry seasons. Deep set shallow tube-wells are suitable for the eastern and south-central part of the study area to extract water from the aquifer. Deep tube-well is not suitable for irrigation for a larger part the study area for irrigation. Due to lower water table below 12 meters during dry season, deep tube-well irrigation is not applicable for the north-western and central part of the study area throughout the whole dry seasons. The hydrograph of the potentiometric surface for the last 24 years show that the trend of groundwater level is changed in this time interval. High rate of rising and declination of water level and high fluctuation of water level in the observation wells adjacent to the rivers are caused by the influence of the river. The western, northwestern, southwestern and central part, which, include the Pleistocene Upland of the Barind Tract is found to be not favourable for large-scale groundwater development. Here the depth of aquifer, depth of water level, aquifer characteristics etc. are not suitable for groundwater extraction in large quantity. Only the eastern part of Recent flood plain part of the study area can be suggested for large-scale water exploitation.

Actual total annual recharge has been estimated to be about 93.95 million cubic meters. As most of the study area lies above the flood plain, so the value of rejected recharge may be considered negligible. That is why, the actual recharge is roughly equal to the potential recharge of the study area. Useable recharge, which is 75% of the potential recharge is about 70.5 million cubic meters. About 10.3 million cubic meters of water is removed from the aquifer as base flow before the beginning of the irrigation season. So, the available recharge is 60.2 million cubic meters. Very recently Barind Integrated Area Development Project (BIADP) was established to explore the groundwater resources and to take proper initiatives for maintaining ecological balance. A large number of tube-wells were set-up in the study area by BIADP in the recent years. If all the tube-wells operate properly then the average annual abstraction of groundwater from the aquifer during the dry season will be about 113.20 million cubic meters. Of them annual abstraction of groundwater is about 94.33 million cubic meters by deep tube-wells, 18.65 million cubic meters by shallow tube-wells and about 0.22 million cubic meters by hand tube-wells. As a result the annual abstraction of groundwater by tube-wells will exceed the available recharge in future. This over draft of groundwater may decline the water table permanently and mining of water might take place in future.

It has been observed that in the study area, the over increasing population pressure on the limited arable lands forced to exploit subsurface water resource by means of tube-wells. For this purpose the unknown groundwater quality i.e. physical and chemical quality are to be investigated properly and the data represented in the table (Table-5.1 and 5.2) to have a vivid picture of the area for future planning of large-scale water utilization.

The tube-well sites should be obtained from groundwater resources. Therefore, groundwater is one of the earht's most widely distributed resources and its role in the very existence of lives on the planet needs hardly any elaboration.

The overall finding of water quality observation, the average values of the physical and chemical properties are not objectionable. The effective use of groundwater irrigation will help the farmers for intensive farming, which will generate increasing production. The quality of groundwater in the study area has no impact on the environment and human health. The assessment of large-scale utilization of water is also necessary prior to the formulation of water resource development. If these steps are taken, the physical environment and human health of this area will be effectively protected from degradation.

It is reveled from trend analysis that the groundwater occurrence is highly related with rainfall during a particular year or session but trend of groundwater table and fluctuation through year to year is not related to annual rainfall variation in the study area. It is related with artificial heavy groundwater exploitation from the study area. After all, the study area shows the alarming declining condition of depth to water table and high fluctuation of water table.

It is revealed from above discussion that the investigated area becomes surplus area in food grains due to groundwater resources. Although the study area is located within the Barind region where the top clayey stratum is thinner. In spite of suitable aquifer, there have been made a declining water table condition in the recent years when artificial exploitation with high rate has been practice from the year 1985-86 because of unplanned abstraction and lack of appropriate investigation of groundwater resources.

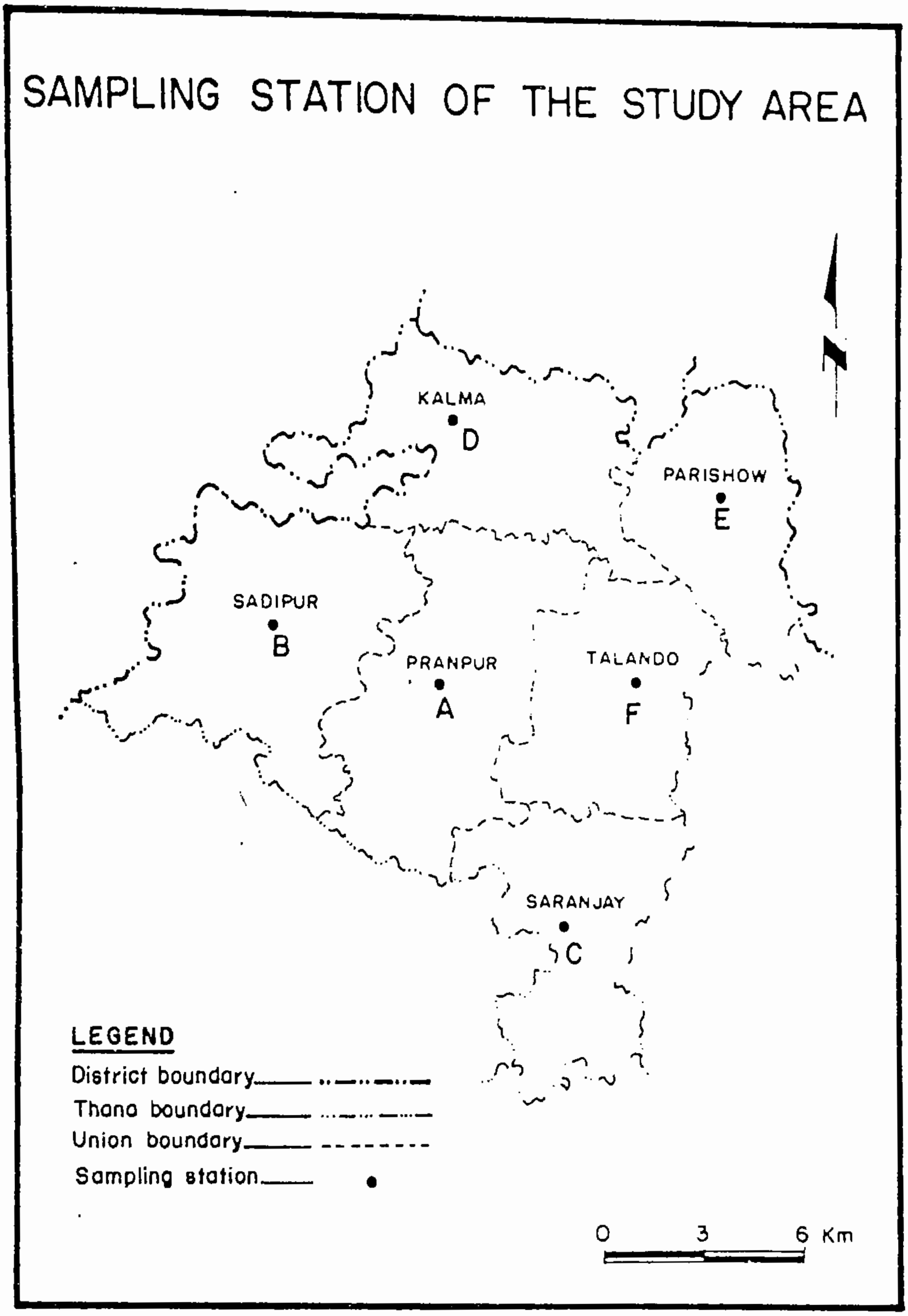
It is mentionable that Geographically, man-land-nature and resources are closely related with one another by a chain system that refers to balance of environment. Merely unplanned human intervention on the nature makes the environmental degradation. That is, for the unplanned human intervention on the surface and groundwater resources and consequently the water table declines through year to year, which refers to an alarming condition. Since the study area confined, semi-confined and unconfined aquifer, so there any land subsidence may be occurred with the span of time for the cause of water table declination. The resultant land subsidence is not a predicted version. Substantial subsidence resulting from reduction of groundwater storage have been recorded in California, Texas, Georgia and Nevada, while outside of the united states important examples include Mexico City and London (Ward, 1967). For the cause of the development of cone of depression, drastically water table can be lowered and rate of pumping of wells can be reducing through passing the time. Qualitative problem may be occurred due to water table depletion. For the example, in the well No.-RJ040 at Mundumalahat Mauza in Badhair union, lowest water level declined 3.69 meters in 1982 and highest water level declined 11.74 meter in1993 during the last 24 years. If it is continuing, after 30 years passing from 2006, the ground level will remain below mean sea level in the considering well. Consequently, saline water will move towards the study area. In deep terrace soils, like Madhupur and Barind Tract, weathering in the substratum has taken place under the influence of seasonally fluctuating water table (Brammer, 1986). It is revealed that the study area comprises the

Barind Tract in physiographic nature. If seasonally high fluctuation is continuing in the study area, it will become a desert for the cause of subsoil weathering with the span of time.

After all, if it is desirable to free from environmental degradation such as land subsidence, qualitative problems, high magnitude of cone of depression, dissertation and so on, it is very important to stop unplanned and inappropriate artificial groundwater exploitation from the study area. It is suggested only not for the study area but also for the whole Barind Tract and Madhupur Tract. Because, water table declined and seasonal fluctuation increased at an alarming condition in Dhaka city (BWDB: WSP-455, 1984) and Adhamdighi thana of Bogra district (UNICEF and DPHE, 1994). Except this, in the northern district i.e. Rajshahi and Bogra, the groundwater level has experienced a depletion of 9-12 meter from the original groundwater level (Mirza and Bhoumik, 1986). So immediately, reduction of groundwater exploitation is very necessary to save the general geographical as well as cultural and physical environmental balance with supplying water specially for irrigation purposes from other sources or by inventing crop seeds which have a poor demand for water that is enough with spreading water supplies.

However, considering all the facts and reasons discussed above, particularly the overdraft condition prevailing in the area it is recommended that the installation of tube-wells by different agency should be stopped immediately. Any further installation of wells should be very much selective. Moreover, the spacing of the wells should be selected cautiously not to influence two wells in common. So, care must be taken for the uniform distribution of tube-wells. Pumping efficiency will increase if proper maintenance of the well is made. It is also recommended that great care must be taken to supplying water for irrigation from other natural sources immediately.

Appendex – A


SAMPLING STATION OF THE STUDY AREA
KALMA
D
PARISHOW
E
SADIPUR
B
PRANPUR
A
TALANDO
F
SARANJAY
C
LEGEND
District boundary
Thana boundary
Union boundary
Sampling station
0
3
6 Km

Appendix- B

BANGLADESH WATER DEVELOPMENT BOARD
SURFACE WATER HYDROLOGY
Daily Rainfall in mm

Station : 219 ,Tanore Subdivision: Rajshahi Year : 1975-76

Date	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	30.5	4.8	0.0	0.0	18.3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	0.0
6	0.0	0.0	0.0	18.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	35.6	0.0	20.3	0.0	0.0	0.0	2.5	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	14.7	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	22.9	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	6.6	0.0	20.3	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	14.0	0.0	0.0	0.0	16.3	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	10.2	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	17.8	0.0	8.9	0.0	55.9	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	73.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	59.7	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	29.2	0.0	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0
20	0.0	8.9	32.5	0.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	30.5	13.2	66.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	15.2	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	25.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	50.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	31.8	8.9	2.5	0.0	0.0	0.0	0.0	0.0	0.0
26	6.4	0.0	0.0	48.1	0.0	29.2	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	71.1	0.0	40.6	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	31.8	0.0	28.4	16.5	0.0	0.0	0.0	0.0	0.0	----	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	----	0.0
31	----	0.0	----	0.0	0.0	----	0.0	----	0.0	0.0	----	0.0
Monthly Total												
Mtot.	6.4	183.0	76.2	445.8	155.1	197.4	64.0	0.0	0.0	0.0	7.6	0.0
Rday	1	9	3	14	7	8	5	0	0	0	2	0

Annual Maximum=73.7, date: 15/7/1975

Annual Minimum2.5 , Date: 25/9/1975

Annual Rainfall=1135.5

Annual Rainy Day=49

Appendix- C

BANGLADESH WATER DEVELOPMENT BOARD
SURFACE WATER HYDROLOGY
Mean Daily Discharge (Cubic Meter/ Second)

Station : 261 Nawhata River : 98 Sibu-Baranai-Gurnai Year : 1975-76

Date	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.972	0.396	1.98	11.0	40.8	27.5	31.4	19.6	1.78	1.73	4.41	5.69
2	0.764	0.369	1.61	11.2	40.8	26.9	30.8	18.9	1.70	1.78	4.53	5.52
3	0.764	0.396	2.21	11.1	40.8	26.0	31.4	18.1	1.64	1.81	4.56	5.36
4	0.764	0.340	2.07	11.3	40.8	25.5	31.4	17.1	1.53	1.84	4.73	5.29
5	0.736	0.340	1.75	12.0	40.8	25.2	32.0	16.3	1.42	1.84	4.84	5.21
6	0.708	0.340	1.44	12.7	40.5	25.5	32.0	15.7	1.39	1.90	5.01	5.09
7	0.679	0.340	1.27	13.2	40.2	25.4	32.5	14.7	1.33	1.92	5.04	5.04
8	0.651	0.340	1.16	13.7	40.2	25.8	33.1	13.9	1.30	1.92	5.04	5.04
9	0.651	0.340	1.10	14.5	39.6	25.8	32.8	13.2	1.25	1.98	5.12	4.95
10	0.651	0.368	1.02	14.5	38.8	25.6	32.8	12.3	1.25	1.98	5.21	4.87
11	0.651	0.340	0.934	14.5	37.6	25.1	32.5	11.9	1.19	1.92	5.35	4.75
12	0.651	0.324	0.821	14.3	36.8	24.6	32.3	11.3	1.16	1.92	5.43	4.73
13	0.679	0.368	0.736	14.0	35.4	24.6	31.7	10.8	1.16	2.01	5.52	4.61
14	0.764	0.340	0.679	13.6	34.5	24.6	31.4	9.76	1.16	2.01	5.52	4.56
15	.0764	0.340	0.651	13.3	33.7	28.3	30.3	9.42	1.16	2.07	5.69	4.44
16	0.651	0.340	0.623	15.6	32.8	30.6	30.0	8.57	1.19	2.09	5.72	4.41
17	0.566	0.368	0.623	19.9	31.7	31.4	28.9	7.10	1.19	2.21	5.80	4.27
18	0.566	0.368	0.623	19.9	31.7	31.4	28.9	7.10	1.19	2.21	5.80	4.02
19	0.481	0.453	0.623	21.2	31.4	31.1	28.3	6.57	1.27	2.32	5.89	3.91
20	0.453	0.509	0.736	21.0	30.8	30.8	27.5	6.06	1.36	2.38	5.89	3.91
21	0.453	0.566	1.56	22.6	30.6	31.4	27.2	5.35	1.39	2.55	5.89	4.10
22	0.5.9	0.566	2.24	25.8	30.3	31.4	26.6	4.67	1.39	2.77	5.89	4.08
23	0.453	0.792	2.46	27.6	29.7	31.4	26.3	4.19	1.44	3.03	5.80	4.08
24	0.453	0.679	2.55	27.5	29.1	31.4	25.8	3.82	1.47	3.20	5.89	3.99
25	0.453	0.651	3.31	29.4	29.4	31.4	24.9	3.31	1.53	3.37	5.89	3.82
26	0.453	0.651	4.41	31.1	31.3	31.7	24.1	3.03	1.56	3.51	5.89	3.68
27	0.396	0.651	5.60	35.4	29.4	32.5	23.5	2.75	1.56	3.68	5.89	3.82
28	.0368	0.623	7.84	40.5	28.3	32.5	22.9	2.46	1.56	3.88	5.80	3.62
29	0.340	1.27	10.0	41.6	28.0	32.5	21.7	2.24	1.61	4.08	5.40	3.32
30	0.340	3.68	10.0	42.2	28.0	31.7	21.0	1.95	1.67	4.13	----	3.51
31	-----	2.60	-----	41.3	27.5	-----	20.3	-----	1.73	4.27	----	3.45
Monthly Means and Extremes												
Max.	0.792	3.68	10.8	42.2	40.8	32.5	33.1	19.6	1.78	4.27	5.89	5.69
Mean	0.587	.0.647	2.45	21.1	34.3	28.7	28.6	9.43	1.40	2.52	5.44	4.43
Min.	0.340	0.324	0.623	11.0	27.5	24.6	20.3	1.95	1.16	1.73	4.41	3.45

Annual Maximum=42.2, date: 30/7/1975 Annual Minimum=0.324 , Date: 12/5/1975

Annual average=11.7

Appendix- D

BANGLADESH WATER DEVELOPMENT BOARD
SURFACE WATER HYDROLOGY

Mean Daily Water level (Meter/ PWD)

Station : 261 Nawhata River : 98 Sibu-Baranai-Gurnai Year : 1994-95

Date	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	9.150	9.168	9.290	11.962	10.396	11.684	12.758	11.788	9.692	9.580	9.922	9.680
2	9.150	9.190	9.296	11.702	10.368	11.588	12.638	11.676	9.644	9.636	9.882	9.680
3	9.150	9.190	9.310	11.642	10.352	11.438	12.530	11.570	9.620	9.654	9.752	9.652
4	9.150	9.190	9.320	11.598	10.378	11.310	12.434	11.490	9.600	9.676	9.696	9.592
5	9.150	9.200	9.442	11.518	10.348	11.220	12.388	11.412	9.590	9.690	9.680	9.530
6	9.150	9.186	10.118	11.388	10.300	11.140	12.286	11.410	9.580	9.718	9.666	9.492
7	9.150	9.170	10.188	11.300	10.242	11.070	12.250	11.310	9.570	9.810	9.650	9.464
8	9.150	9.172	9.838	11.322	10.198	10.968	12.286	11.246	9.560	9.868	9.636	9.460
9	9.150	9.226	9.632	11.350	10.172	10.880	12.374	11.180	9.560	9.908	9.596	9.446
10	9.150	9.252	9.536	11.230	10.232	10.880	12.868	11.124	9.550	9.970	9.562	9.430
11	9.140	9.270	9.644	11.118	10.378	10.850	13.100	11.106	9.550	10.022	9.528	9.406
12	9.130	9.280	10.730	11.008	10.380	10.820	13.130	11.076	9.540	10.058	9.508	9.386
13	9.120	9.280	10.930	10.898	10.376	10.850	13.130	11.048	9.540	10.070	9.490	9.380
14	9.120	9.290	11.156	10.758	10.350	10.882	13.102	11.022	9.496	10.070	9.488	9.380
15	9.120	9.288	11.234	10.658	10.490	10.922	13.062	10.950	9.476	10.070	9.458	9.376
16	9.116	9.262	11.048	10.560	10.660	10.950	13.018	10.860	9.460	10.070	9.440	9.360
17	9.114	9.230	10.832	10.470	11.022	10.948	12.910	10.770	9.450	10.070	9.458	9.364
18	9.140	9.218	10.740	10.378	11.340	10.900	12.830	10.670	9.440	10.088	9.480	9.380
19	9.140	9.200	10.678	10.336	11.474	10.884	12.740	10.590	9.430	10.100	9.446	9.390
20	9.140	9.190	10.622	10.260	11.462	10.894	12.640	10.530	9.420	10.100	9.416	9.390
21	9.140	9.180	10.526	10.182	11.498	10.970	12.530	10.430	9.420	10.090	9.400	9.390
22	9.130	9.180	10.502	10.116	11.490	11.304	12.434	10.320	9.420	10.090	9.400	9.390
23	9.130	9.170	10.472	10.054	11.480	12.022	12.392	10.300	9.420	10.080	9.508	9.390
24	9.130	9.182	10.446	10.008	11.522	12.450	12.330	10.230	9.420	10.066	9.548	9.390
25	9.130	9.202	10.422	9.968	11.740	12.740	12.248	10.150	9.420	10.044	9.608	9.390
26	9.130	9.230	10.372	9.950	11.934	12.870	12.130	10.092	9.420	10.030	9.654	9.390
27	9.130	9.240	10.330	9.950	11.960	12.966	12.030	10.042	9.430	10.024	9.680	9.390
28	9.130	9.240	10.382	9.962	11.970	12.962	11.950	9.942	9.440	10.006	9.680	9.390
29	9.130	9.280	10.754	10.042	11.918	12.912	11.888	9.838	9.450	9.992	------	9.390
30	9.130	9.290	11.314	10.248	11.850	12.858	11.842	9.760	9.450	9.964	------	9.390
31	----	9.290	----	10.388	11.778	-----	11.820	-----	9.450	9.946	------	9.390

Monthly Means and Extremes

Max.	9.150	9.290	11.530	11.710	11.970	12.970	13.130	11.800	9.700	10.100	9.930	9.680
Mean	9.136	9.224	10.303	10.711	10.970	11.504	12.518	10.798	9.500	9.954	9.580	9.436
Min.	9.110	9.160	9.290	9.950	10.170	10.820	11.820	9.740	9.420	9.560	9.400	9.360

Annual Maximum=13.130, date: 11/10/1994 Annual Minimum=9.110 , Date: 17/4/1994

Annual average=10.307

Appendix- E

BANGLADESH WATER DEVELOPMENT BOARD

Groundwater Table Below Measuring Points In Meter.

District: Rajshahi

Thana: Tanore

DATE	STATION NO.: RAJ-027	STATION NO.: RAJ-039	STATION NO.: RAJ-040	STATION NO.: RAJ-086	STATION NO.: RAJ-0136	STATION NO.: RAJ-S32
0.3-01-94	8.63	5.25 *	9.20	6.44	4.22	5.05
10-01-94	8.73	5.37	9.58	6.40	4.41	5.13
17-01-94	8.83	5.68	9.70	6.38	4.63	5.21
24-01-94	8.93	5.70	9.93	6.40	4.82	5.30
31-01-94	9.03	6.05	10.10	6.38	5.13	5.41
07-0294	9.12	6.55	10.28	6.32	5.45	5.80
14-02-94	9.21	7.30	10.54	6.28	5.92	5.87
21-02-94	9.30	7.55	10.88	6.19	6.40	6.18
28-02-94	9.40	7.80	11.07	6.10 *	6.90	6.28
07-03-94	9.51	8.35	11.40	6.15	7.10	6.45
14-03-94	9.73	9.15	11.76	6.20	7.22	6.61
21-03-94	9.95	9.26	11.96	6.26	7.35	6.76
28-03-94	10.17	9.35 #	12.16	6.34	7.52	6.90
04-04-954	10.39	9.33	12.40	6.48	7.90	6.95
11-04-94	10.63	9.22	12.64	6.56	8.08	6.98
18-04-94	10.87	Missing	12.65	6.69	8.19	7.02
25-04-94	10.91	Missing	12.81	6.77	8.20 #	7.23
02-05-94	10.91	Missing	13.00	6.90	7.85	7.37
09-05-94	11.00	Missing	13.15	7.05	7.70	7.60
16-05-94	11.04	8.75	13.45	8.15	7.62	7.46
23-05-94	11.08	8.60	13.75	8.27	7.55	7.64
30-05-94	11.13	8.72	13.94	8.44	7.47	7.79 #
06-06-94	11.17	8.87	14.08 #	8.58	7.22	7.48
13-06-94	11.21	8.42	14.00	Missing	7.05	7.40
20-06-94	11.26	8.05	13.49	Missing	6.85	7.14
27-06-94	11.30 #	7.92	13.15	8.73	6.60	7.13
04-07-94	11.10	7.40	12.62	8.79	6.60	6.83
11-07-94	10.91	6.95	12.20	8.82	6.62	6.57
18-07-94	10.91	7.32	11.78	8.86	6.64	6.57
25-07-94	10.90	7.35	11.69	8.90	6.65	6.58
01-08-94	10.89	7.28	11.77	8.92	6.65	6.69
08-08-94	10.88	7.42	11.88	8.94	6.17	6.62
15-08-94	10.86	7.53	12.25	8.95	5.70	6.63
22-08-94	10.86	7.15	11.80	8.98	5.90	6.57
29-08-94	10.72	6.85	11.15	9.00	4.15	6.07
05-09-94	10.60	6.87	10.70	9.03	3.82	5.95
12-09-94	10.48	6.94	10.45	9.05	3.60 *	5.95
19-09-94	10.36	6.57	10.00	9.08	3.75	5.91
26-09-94	10.24	6.20	9.59	9.06	3.90	5.60
03-10-94	10.24	6.05	9.27	9.04	4.03	5.41
10-10-94	10.02	6.85	8.87	9.00	4.10	5.27
17-10-94	9.83	5.81	8.52	9.96#	4.21	5.02 *
24-10-94	9.63	5.74	8.46 *	9.93	4.33	5.03
31-10-94	9.43	5.81	8.85	9.89	4.70	5.11
07-11-94	9.49	6.00	8.92	9.85	4.95	5.26
14-11-94	9.55	6.03	9.16	9.81	5.40	5.35
21-11-94	9.61	6.05	9.45	9.77	5.53	5.50
28-11-94	6.66 *	6.02	9.68	9.72	5.50	5.57
05-12-94	9.71	5.96	9.99	9.69	5.42	5.70
12-12-94	9.76	5.99	10.31	9.60	5.41	5.83
19-12-94	9.81	6.05	10.55	9.61	5.37	5.95
26-12-94	9.88	6.17	11.05	9.69	5.29	6.09
H. Parapet	0.45	0.45	0.45	0.30	0.45	0.45
R.L	22.80	20.67	33.74	19.56	18.51	20.26

Legend: # =year's maximum, * = year's minimum.

APPENDIX - F

Monthly maximum, minimum and average rainfall at Tanore Thana from 1975-76 to 2001-02.

Year ▼	Month →	A	M	J	J	A	S	O	N	D	J	F	M
1975-76	Mix.	6.4	31.8	32.5	73.7	35.8	55.9	20.3	0	0	0	5.1	0
	Min.	6.4	8.9	13.2	4.8	8.9	2.5	5.1	0	0	0	2.5	0
	Ave.	6.40	20.33	25.40	31.84	22.15	24.67	12.80	0	0	0	3.80	0
1976-77	Mix.	34.3	109.2	53.3	104.1	11.3	26.7	40.6	0	0	0	13.2	0
	Min.	3.8	8.9	24.1	6.4	5.1	2.5	40.6	0	0	0	2.5	0
	Ave.	19.05	39.03	38.34	33.97	28.95	14.98	40.60	0	0	0	7.60	0
1977-78	Mix.	31.0	54.6	130.8	63.5	73.7	57.2	32.5	0	38.1	2.5	0	30.5
	Min.	6.4	5.6	6.4	6.4	2.5	3.8	5.0	0	6.4	2.5	0	11.4
	Ave.	21.40	25.42	34.05	20.68	28.00	29.63	17.06	0	22.25	2.50	0	17.70
1978-79	Mix.	48.3	26.7	158.8	38.1	57.2	95.5	24.1	41.9	0	17.8	14.0	0
	Min.	11.4	7.6	6.4	3.3	6.6	3.0	11.4	41.9	0	8.9	14.0	0
	Ave.	23.22	17.20	33.30	18.20	22.92	39.05	17.33	41.90	0	13.20	14.00	0
1979-80	Mix.	21.6	0	58.6	44.4	118.1	83.3	53.3	0	35.6	35.6	14.0	3.8
	Min.	10.7	0	7.6	3.0	2.5	3.8	2.5	0	35.6	2.5	14.0	3.8
	Ave.	17.53	0	27.87	15.73	40.95	26.57	22.32	0	35.60	19.05	14.00	3.80
1980-81	Mix.	0	43.7	194.3	48.3	54.6	29.2	120.6	0	0	19.6	16.5	26.7
	Min.	0	17.8	3.8	6.3	4.3	2.5	10.2	0	0	19.6	16.5	18.3
	Ave.	0	32.47	30.39	22.35	24.81	19.00	51.66	0	0	19.60	16.50	22.50
1981-82	Mix.	48.3	69.1	63.5	101.6	152.4	127	0	0	1.5	0	0	5.1
	Min.	10.2	3.8	63.5	12.7	2.5	12.7	0	0	1.3	0	0	5.1
	Ave.	30.22	33.81	63.50	49.42	28.68	38.55	0	0	1.40	0	0	5.10
1982-83	Mix.	10.7	19.0	107.9	41.1	48.8	19.3	29.7	38.1	0	9.4	0	5.6
	Min.	10.7	14.7	4.8	7.4	2.5	5.1	29.7	31.0	0	9.4	0	5.6
	Ave.	10.70	16.46	33.54	37.43	20.43	12.20	29.70	31.55	0	9.40	0	5.60
1983-84	Mix.	16.5	21.1	19.6	85.1	49.5	63.5	99.6	0	5.8	10.2	0	0
	Min.	1.3	10.2	7.1	6.6	4.3	4.3	11.4	0	5.1	6.9	0	0
	Ave.	7.63	12.21	10.74	32.60	25.50	27.44	47.62	0	5.42	8.50	0	0

Contd.

Year ↓	Month →	A	M	J	J	A	S	O	N	D	J	F	M
1984-85	Mix.	0	24.1	49.5	74.4	69.3	95.3	69.3	0	0	0	1.3	21.6
	Min.	0	5.3	3.8	5.3	3.0	3.6	7.1	0	0	0	1.3	21.6
	Ave.	0	12.37	28.27	30.19	17.73	25.62	32.87	0	0	0	1.30	21.60
1985-86	Mix.	16.8	26.7	59.7	61.0	50.8	49.5	37.3	0	0	0	6.1	0
	Min.	9.4	2.5	2.8	3.8	37.6	4.6	21.3	0	0	0	6.1	0
	Ave.	12.20	11.29	14.60	28.76	42.06	21.80	28.75	0	0	0	6.10	0
1986-87	Mix.	33.3	32.3	45.7	55.9	31.0	63.5	203.2	0	0	0	0	7.6
	Min.	1.8	9.4	2.5	3.8	3.6	3.8	5.6	0	0	0	0	7.6
	Ave.	9.65	15.85	16.00	22.10	15.38	23.31	59.77	0	0	0	0	7.60
1987-88	Mix.	25.4	49.5	50.8	43.2	171.5	40.6	26.7	0	7.6	0	17.8	20.8
	Min.	12.7	17.8	25.4	15.2	11.4	5.1	26.7	0	7.6	0	2.5	2.5
	Ave.	18.15	30.90	38.93	33.92	62.43	24.59	26.70	0	7.60	0	7.60	11.70
1988-89	Mix.	36.8	38.1	124.5	68.6	129.2	63.0	61.4	45.3	0	0	0.6	0
	Min.	1.3	0.5	1.3	10.2	10.2	34.0	22.5	0.5	0	0	0.6	0
	Ave.	11.32	11.91	37.72	37.86	46.23	53.28	42.63	2.90	0	0	0.60	0
1989-90	Mix.	0	70.0	70.0	75.3	70.0	60.0	50.3	0	0	0	10.0	30.3
	Min.	0	5.0	30.0	4.3	10.0	20.3	30.0	0	0	0	0.8	0.3
	Ave.	0	39.50	42.16	26.05	35.15	41.65	40.20	0	0	0	3.90	10.37
1990-91	Mix.	1.1	45.3	45.4	60.0	30.0	25.0	25.0	0	0	0	0	10.0
	Min.	0.3	0.1	0.1	0.5	0.3	0.5	0.5	0	0	0	0	0.3
	Ave.	0.60	19.53	16.64	24.74	14.76	12.20	13.55	0	0	0	0	5.15
1991-92	Mix.	20.0	70.0	70.0	30.0	71.0	60.0	30.5	0	30.0	0	15.0	0.5
	Min.	0.5	0.4	0.7	0.5	0.5	0.5	10.0	0	0.5	0	10.0	0.5
	Ave.	9.05	27.09	25.70	15.50	22.54	18.57	17.62	0	15.52	0	12.50	0.25
1992-93	Mix.	0.5	30.5	40.0	80.0	70.0	70.0	21.0	0	0	20.0	0	50.0
	Min.	0.5	10.0	0.5	0.5	0.5	0.5	14.0	0	0	0.5	0	15.0
	Ave.	0.50	17.10	21.50	25.55	24.13	26.50	17.50	0	0	10.25	0	32.50
1993-94	Mix.	40.0	30.0	40.0	70.0	60.0	40.0	30.0	50.0	0	10.0	15.0	0
	Min.	0.4	10.0	0.5	0.3	0.5	0.3	0.5	20.0	0	10.0	10.0	0
	Ave.	15.08	17.50	16.25	24.52	17.20	14.13	13.50	25.00	0	10.00	12.50	0

Contd.

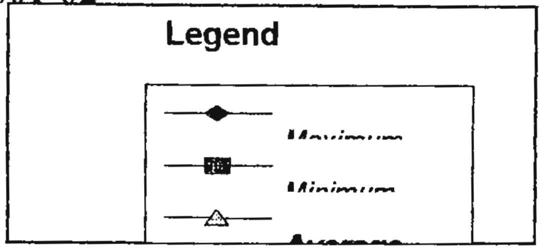
Year ↓	Month →	A	M	J	J	A	S	O	N	D	J	F	M
1994-95	Mix.	25.0	25.0	40.0	30.0	30.0	20.0	15.0	0	0	10.0	20.0	10.0
	Min.	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0	0	0.5	0.5	10.0
	Ave.	11.10	11.55	19.32	13.41	14.42	7.75	8.50	0	0	5.25	10.25	10.00
1995-96	Mix.	20.0	30.0	35.0	80.0	55.0	95.0	95.0	25.0	0	15.0	11.0	10.5
	Min.	10.0	0.5	0.7	0.5	0.5	0.5	30.0	0.5	0	15.0	15.0	10.0
	Ave.	15.00	16.92	18.90	25.20	21.06	23.71	68.33	15.16	0	15.00	13.00	10.05
1996-97	Mix.	35.0	45.0	45.0	40.0	75.0	85.0	25.0	0	0	15	20	10
	Min.	10.0	0.5	10.0	5.0	0.5	10.0	0.5	0	0	0	10.0	0
	Ave.	25.00	18.57	23.50	18.57	18.15	30.83	25.16	0	0	15.00	15.00	10.00
1997-98	Mix.	20.0	30.0	35.0	75.0	85.0	75.0	0	20.0	0	0	10.0	45.0
	Min.	10.0	0.5	10.0	0.5	0.5	0.5	0	10.0	0	0	0	20.0
	Ave.	13.66	16.22	16.50	18.88	28.25	34.32	0	16.66	0	0	10.00	32.50
1998-99	Mix.	20.0	25.0	15.0	95.0	95.0	85.0	30.0	20.0	0	0	0	15.0
	Min.	0.5	10.0	0.5	0	10.0	10.	0.5	0.5	0	0	0	0
	Ave.	10.25	25.00	08.50	35.00	37.17	32.30	10.03	10.16	0	0	0	15.00
1999-00	Mix.	15.0	97.0	95.0	95.0	60.0	95.0	25.0	40.0	0	0	45.0	75.0
	Min.	0	10.0	10.0	10.0	0.5	10.0	0.5	0	0	0	10.0	0.5
	Ave.	15.00	34.72	27.30	30.38	20.39	54.42	12.83	40.0	0	0	23.00	28.10
2000-01	Mix.	55.0	70.0	70.0	55.0	60.0	95.0	20.00	0	0	0	0	0.5
	Min.	0.5	10.0	10.0	10.0	10.0	0.5	10.0	0	0	0	0	0
	Ave.	32.58	49.00	28.63	22.14	30.00	44.06	13.75	0	0	0	0	.050
2001-02	Mix.	0.8	45.0	45.0	45.0	55.0	55.0	110.0	0	0	0	0	15.0
	Min.	0	0.50	0.5	0.5	0.5	10.	10.0	0	0	0	0	0.5
	Ave.	0.80	18.90	19.73	18.10	17.33	20.78	70.71	0	0	10.00	0	8.16

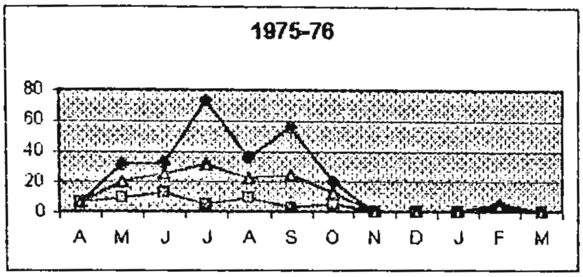
Source: BWDB

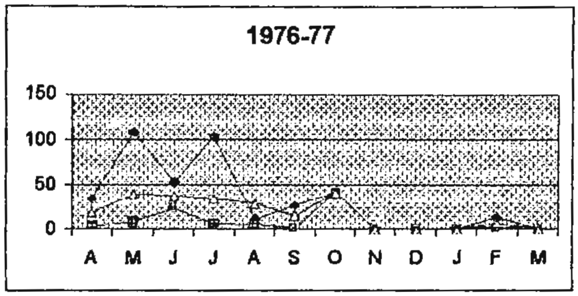
APPENDIX -G

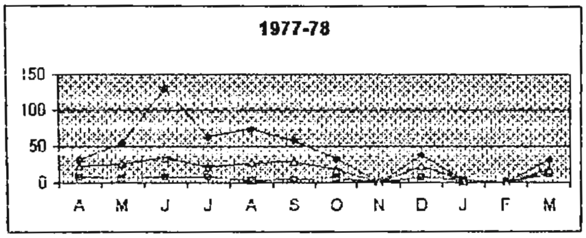
Monthly Maximum, Minimum and Average Rainfall at Tanore Thana from 1975-76 to 2001-02

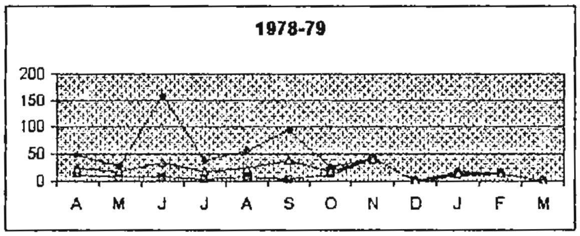
X-Axis = Months
Y-Axis = Rainfall (mm)

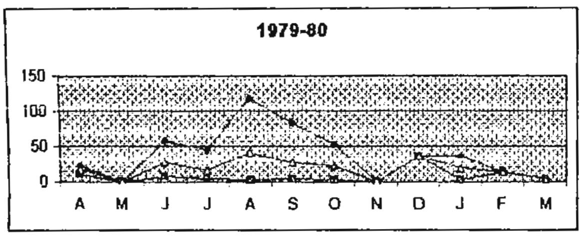


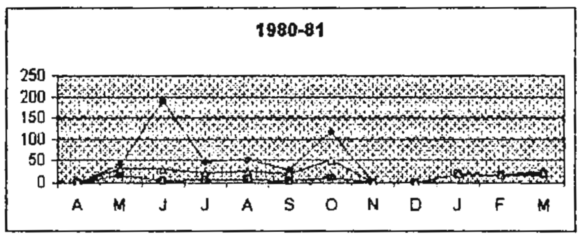


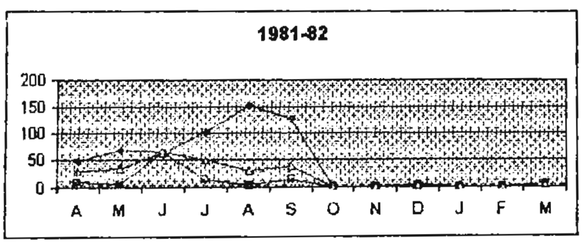


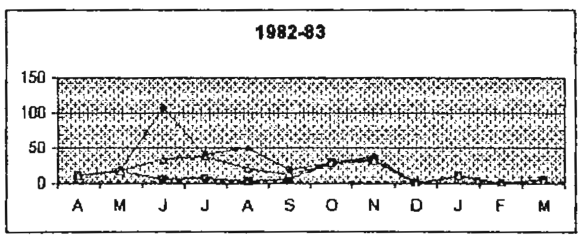


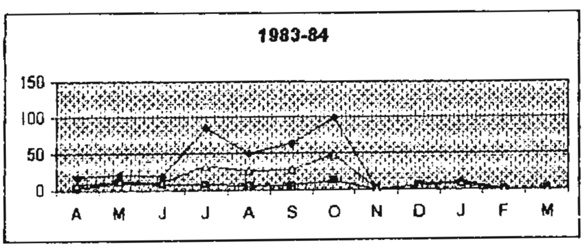


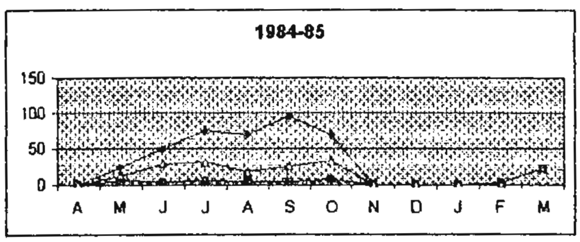


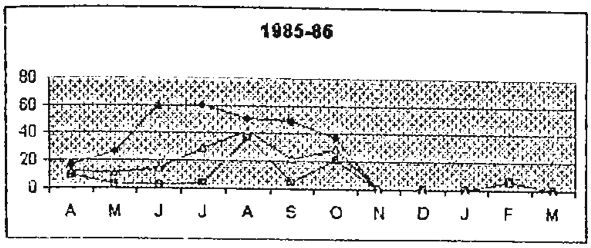








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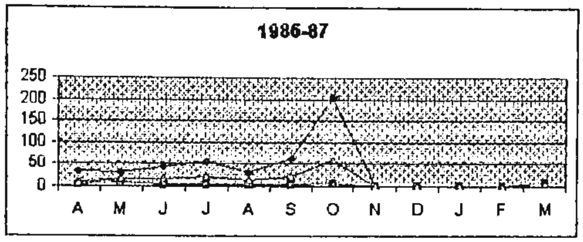
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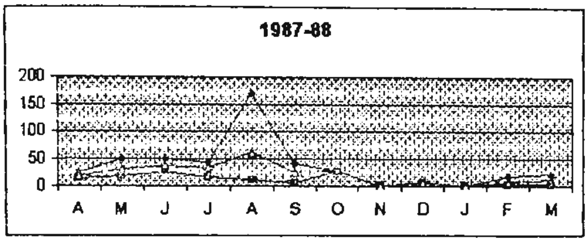
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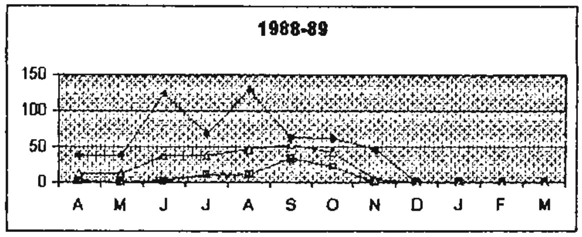
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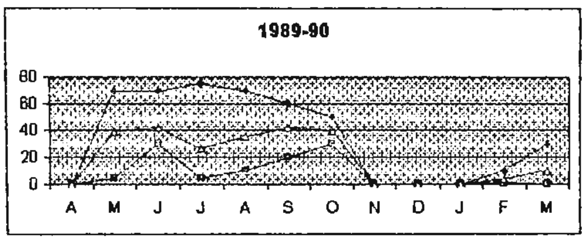
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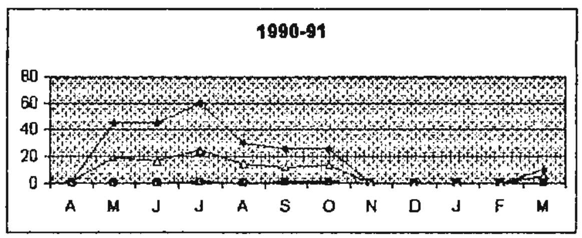
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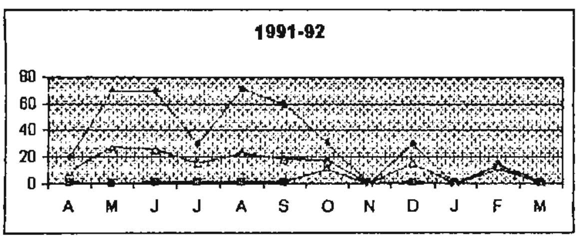
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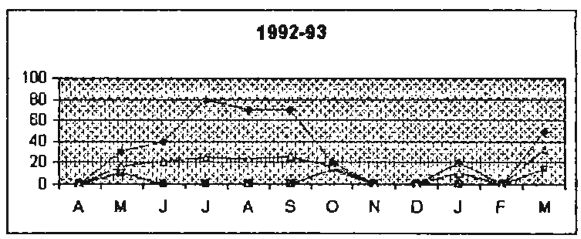
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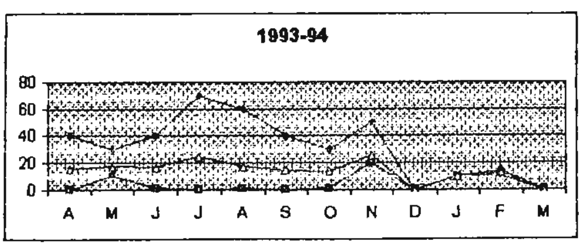
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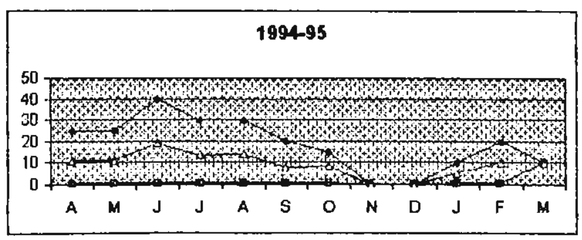
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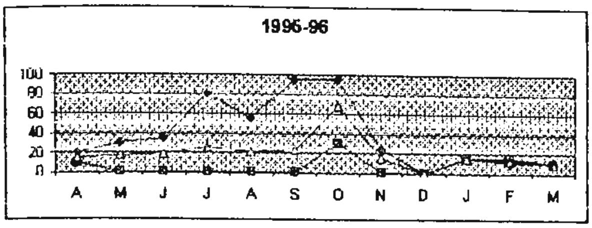
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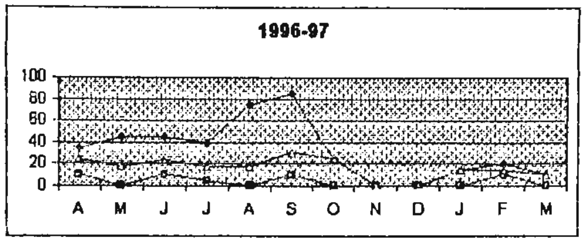
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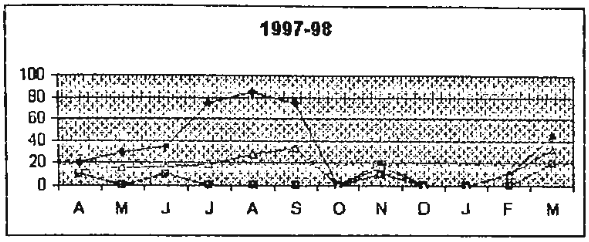
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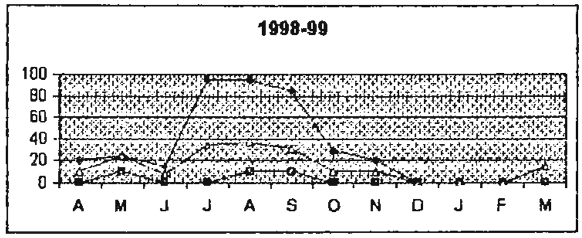
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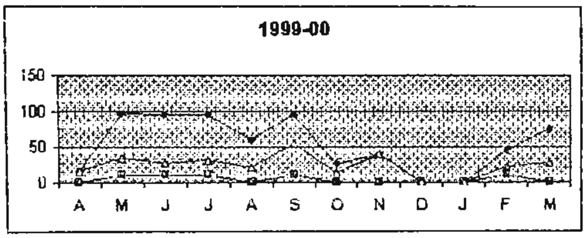
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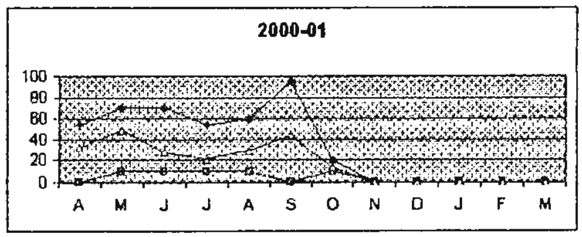
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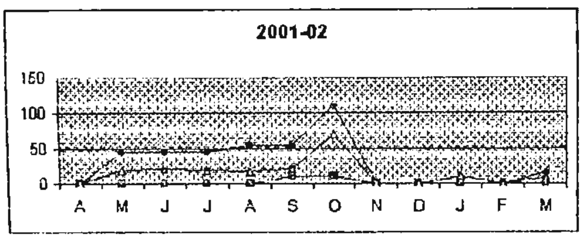
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The fluctuation of groundwater table takes place with the change of season. The highest water table fluctuation occurs in the month of August to October whereas the lowest water table fluctuation occurs in the month of March to May. Water table fluctuation maps are important in determining annual change in storage and hence annual variation in water level is related to recharge and discharge condition. From the fluctuation map (Map-4.4), it was found that the maximum fluctuation was 6 m in the western part, minimum fluctuation was 3 m in the southeastern and eastern part and about 5 m fluctuation was found in the middle portion of the study area.

The water table contour maps of the study area were prepared with data, which have been manipulated from weekly records of groundwater level from 1977 to 2000. Groundwater contour map is very significant for identifying the direction in which the water moves. Generally the highest elevation of water table occurs in August to October with variation from 2 m in the east to 14 m in the west (Map-4.2). The gradient of contour map with maximum elevation was observed up to 2 m/km in the north-eastern part and 4 m/km in the middle southern part of the study area. The elevations decline from west to southeast and east and outflow of groundwater towards the river Sib-Baranai in the east. Again the minimum elevations of water table generally prevail of March to May. The gradient of contour map with minimum elevation were most gentle near the eastern margin where it was 4 m/km and in the southwestern was very steep where it is about 2 m/km. The gradient was 1 m/km in the middle and northwester part of the study area. The groundwater flow takes place towards the east, southeast and northeast direction and the flow of water was directed towards the Sib-Baranai river in the east