I. INTRODUCTION OF THE STUDY AREA

1.1 Background

Groundwater is one of the principal sources of drinking water, irrigation and other municipal water supply through out the world. In many cases, ground water is not only the least expensive but the only available source. Hence the importance of ground water for domestic, irrigation and industrial purpose is increasing day by day. Like many natural resources, groundwater is being exploited at increasing rate all over the world.Groundwater is generally preferred as a source of potable water in the developing world because of its ready availability and natural protection from contamination. The importance of groundwater irrigation in terai and Dun valley region of Nepal is ever increasing as surface water irrigation facilities are very much limited. The study was carried out to meet the requirement of partial fulfillment for the degree of M.Sc in Geology.

1.2 Objectives

The prime objectives of the study are:

- To study the hydrogeology and groundwater condition of the area.
- To identify groundwater potential for the shallow and deep tube well irrigation as an supplementary for Narayani Lift irrigation system
- To evaluate water balance and groundwater reserve of the area

1.3 Location and accessibility

The study area lies in Chitwan District the Narayani Zone Central Development Region of Nepal between longitudes 83°54′ 45’’to 84°48’15″ East and latitudes 27°21′45’’ to 27°52′ 30’’North The district boundaries are marked by Nawalparasi District on the west along the Narayani River and Makwanpur District on the east and Parsa district and Bihar, India in the south. It has Tanahun, Gorkha and Dhading Districts to the north (Fig 1.1). Bharatpur is the administrative headquarters of this district, and is served by the national East—West Highway and the Mugling --Narayanghat Highway. It lies approximately 146 km southwest from Kathmandu, the capital city of the country. The Chitwan Dun valley is shown in the Fig. 1.3. The total area of the Chitwan is about 2,218 km^2.

The study area covers about 70.8 Km^2. Narayanghat, Bharatpur, Baruawa Parasnagar, Gauriganj, Mangalpur, Kailashnagar, Narayanpur, Torikhet, Rambag, Krishnapur are the main locations in the study area.The area includes ward nos. 2,7,8,9,11,13 & 14 of Bharatpur municipality and parts of Mangalpur, Phoolbari and Gitanagar VDCs. The airstrip lies in the study area is Bharatpur airport, which has daily flights to Kathmandu. The study area is adjacent to the Chitwan National Park (CNP) which is famous for wild rhinos and west Bengal Tigers. The study area includes the part of command area of the Narayani Lift Irrigation System.

The study area lies in the Western part of Chitwan district of Narayani Zone and is located within latitude N27^{0}36’30” to N 27^{0}42’30” longitude varies from E 84^{0}20’ to 84^{0}27’30” on the maps sheet No. 2784 06A, 2784 06B, 2784 06C and 2784 06 D (1:50,000 Scale Topographical Maps, Department of Survey, Government of Nepal, 1992)

East west highway runs longitudinally in the area and other black topped, gravelled and cart track roads are also connected with the highway and adjacent villages through out the study area. Telephone and post offices are means of communication in the area.

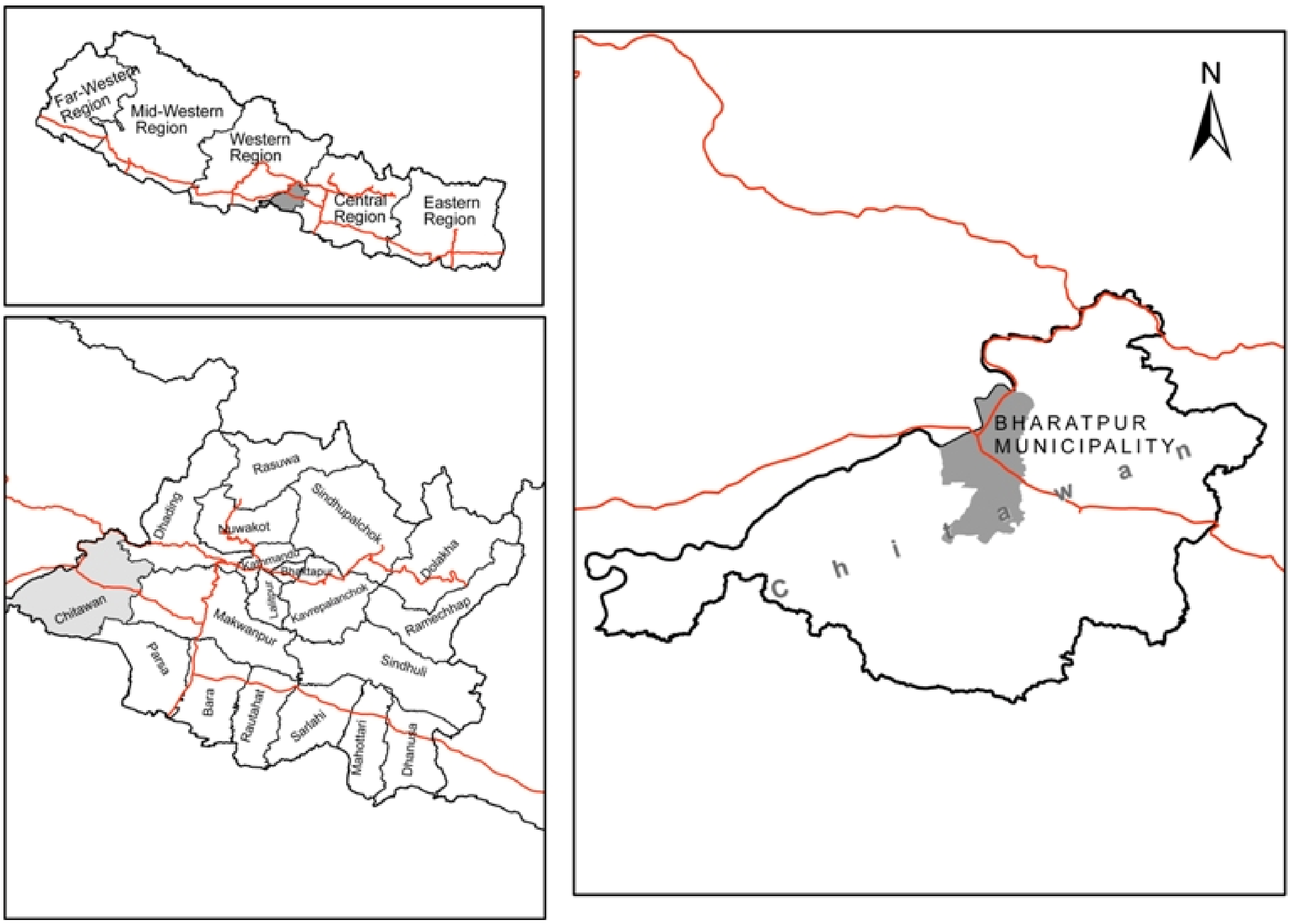


Fig: 1.1 Location Map of the Study Area

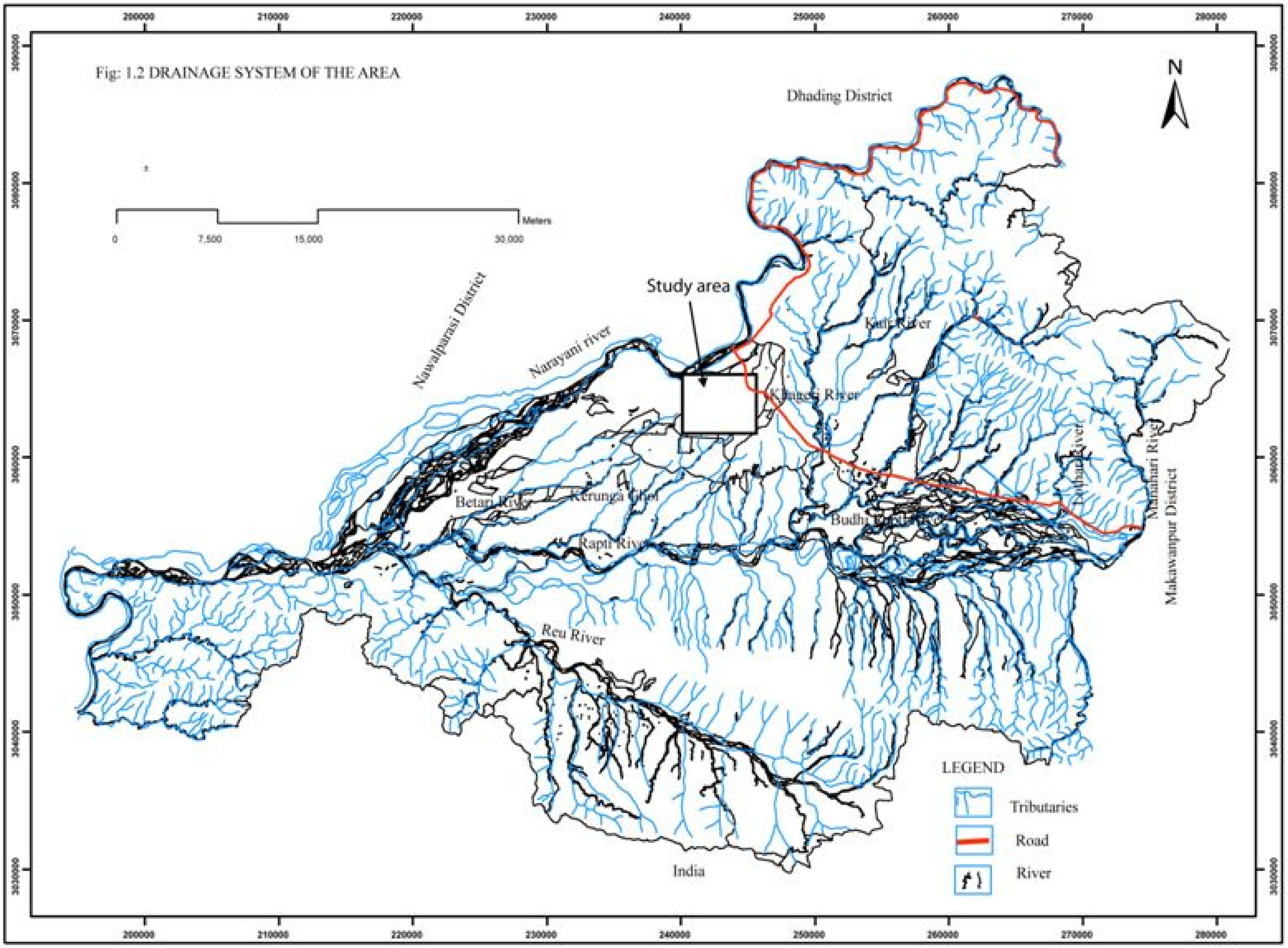


Fig 1.2: Drainage System of Chitawan District

1.4 Topography and Drainage

Chitwan District lies in the Dun valley of Nepal within Siwalik Hills Province in the north and the south. It is elongated from Hetauda in the east to Daunne Hill, Nawalparasi in the west. Topography and drainage are shown in the drainage map in (Fig.1.2) Someswor hill lies in the Southern Siwalik hill ranges. The central part of it lies in the valley (Fig.1.3). The rocks of the Siwaliks are exposed near Jugedi and there is a drastic change in topography from north to southward. The study area is bordered by the Narayani River in the west and Barandabhar forest in the east. East -West Highway in the north and Gitanagar-Kesharbag in the south.

The altitudes in the Chitwan District range from more than 1876 meters in the north to about 141 meters in the middle to 880 meters at the border with India (Kansakar and Amatya, 1993).The altitude in the study area ranges from 170 to 210 meter from mean sea level. The Narayani River is the biggest river in the Chitwan district, which forms the western border with Nawalparasi District. The Rapti river, which is flowing westwards through middle part of District, is the second major River. Several other streams are also a part of drainage system in the District. All of the streams flow from north to south, (Fig 1.2). The area under investigation is bounded by two major rivers the Narayani in the north –west and the Rapti in the south. The Kerunga ghol is drainage flowing from eastern part of the area to south west direction forming a tributary of Rapti River. Many swamps, wetlands and depressions are present in the area.

Plate 1: Braided River channel in East Rapti River at Sauraha

1.5. Climate and Rainfall

The climate of Chitwan is subtropical. The recorded temperature at the meteorological station, at Rampur (Station No 902) is given in Appendix A-1. The average maximum and minimum temperature (1996 to 2006) of the area are: 34.91 ^{0}C in June and 8.08^{0}C in January respectively. High humidity is prevalent except in winter and becomes oppressive in summer. In April- May, hot wind blows which frequently brings violent storms. The south -west monsoon season begins June to September, is the principal rainy season when over 80% of the annual rainfall is received all over the country. The monsoon enters the eastern part of Nepal, in late June from the Bay of Bengal and the Arabian Sea and gradually towards the middle and western part of the country. There are some break periods in the monsoon when rainfall activity over the plains is the least. The mean annual rainfal during 12 years from

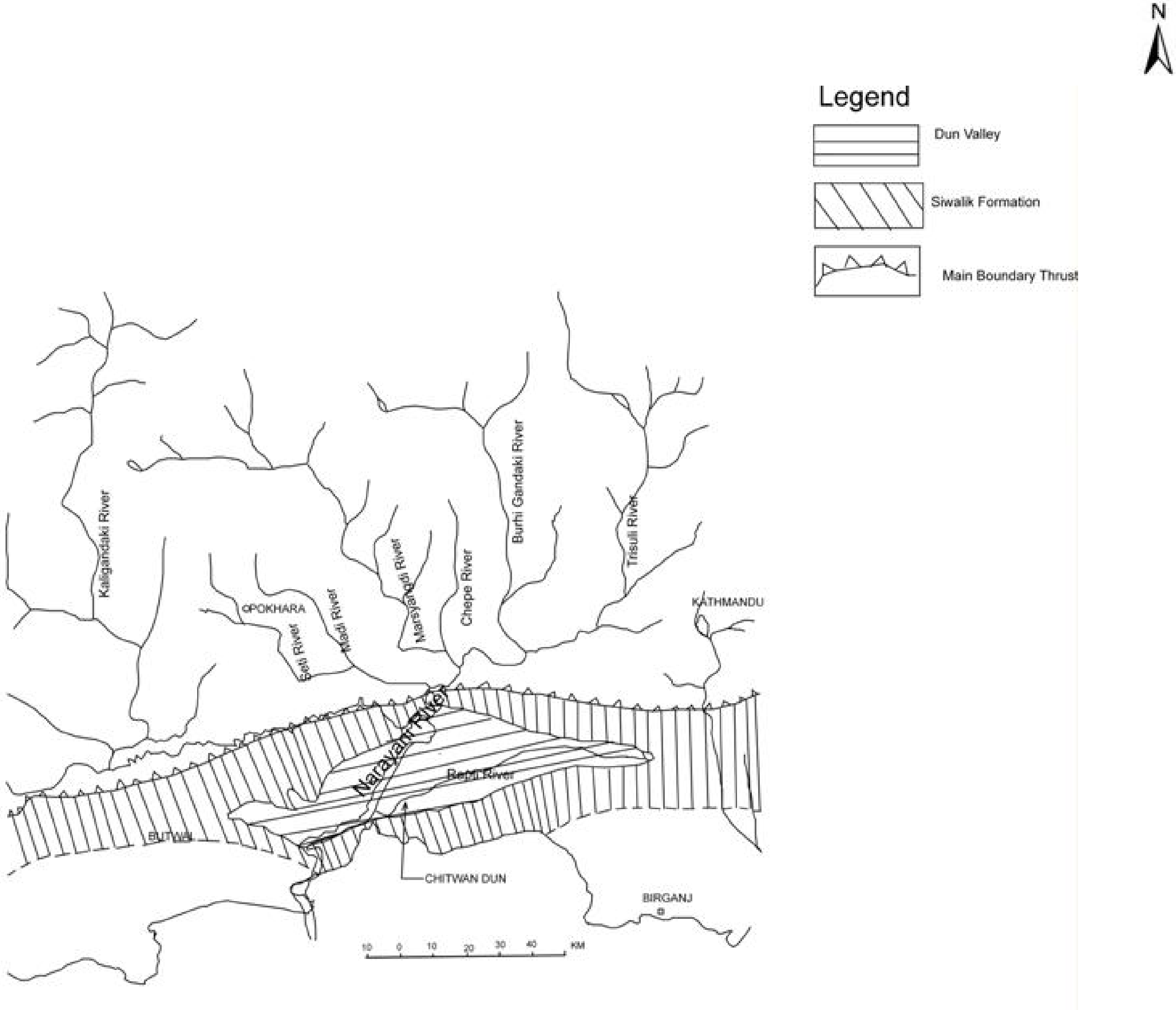


Fig. 1.3 Location of Chitwan Dun in Siwalik(Sub-Himalaya) of Nepal Himalaya

Fig 1.3 Location of Chitwan Dun in Siwalik (Sub-Himalaya) of Nepal *Source: WECS, 1984*

1995 to 2006 as measured at Rampur is 2214 mm. More than 80% of the total annual rainfall occurs during the monsoon season from June to September Appendix A-2 & A-3.

The Koppen system recognizes five principal categories of climate; each category is designated by a capital letter as follows:

A. Humid tropical climates. Winterless climates; it is hot all seasons; all months have a mean temperature above 18^0 C.

B. Dry climates. In these climates evaporation exceeds precipitation; there is a constant water deficiency.

C. Humid mesothermal climates or warm temperature rainy climates; there is a constant water deficiency.

D. Humid mesothermal climates or cold snow-forest climates. These climates have severe winters; the average temperature of the coldest month is below -3^0 C and of the warmest month exceeds 10^0 C.

E. Polar climates. These are summer less climates; the warmest monthly mean is below $10\ ^0$C.

It may be noticed that four of the principal categories of climatic groups (A, C, D, and E) are based on temperature characteristics, while the fifth, B category has precipitation as its fundamental criterion. Each of five categories of climatic groups has been subdivided on the basis of precipitation and temperature characteristics as presented in Table 1.1

General climatic features of the study area:

Table 1.1: Koppen's Climatic Classification (Critchfield, H.J., 1975)

Koppen System of Climatic Classification			
A			Precipitation and Temperature
1st	2nd	3rd	Average temperature of the coldest month is 18º C or higher
	F		Every month has 6 cm of precipitation or more.
	M		Short dry season; precipitation in driest month less than 6cm but to or greater than 10-R/ 25
			(R is annual rainfall in cm)
	W		Well defined winter dry season; precipitation in driest month less than
			10-R/25
	S		Well defined summer dry season (rare)

B			Potential evaporation exceeds precipitation.
			The dry/humid boundary is defined by the following formulas:
			R<2T+28 when 70% or more of rain falls in warmer 6 months
			R<2T when 70% or more of rain falls in cooler 6 months
			R<2T+14 when neither half year has 70% or more of rain
			Note: R is average annual precipitation in cm and T is average Annual temperature
			In º C.
	S		Steppe/ Desert: The BS/BW boundary is 1/2 the dry /humid boundary.
	W	h	Average annual temperature is 18^0C or greater
		k	Average annual temperature is less than 18^0 C
C			Average temperature of the coldest month is under 18^0C and above ---3 ºC.
	W		At least ten times as much precipitation in the wettest summer month as in the driest winter month;
	S		At least three times as much precipitation in the wettest winter month as in the driest summer month;
			precipitation in driest summer month less than 4 cm
	F		Criteria for w and s cannot be met
		a	Warmest month is over 22º C; at least 4 months over 10º C.
		b	No month above 22º C; at least 4 months over 10º C
		c	One to 3 months above 10º C
D			Average temperature of coldest month is ---3ºC or below; average temperature of warmest month is greater than 10º C
	S		Same as under C
	W		Same as under C
	F		Same as under C
		a	Same as under C
		b	Same as under C

		c	Same as under C
		d	average temperature of coldest the month is --38ºC or below;
E			Average temperature of the warmest month is below 10º C
	T		Average temperature of the warmest month is between 0ºC and 10ºC.
	F		Average temperature of the warmest month is between 0ºC and below

By the study of annual temperature data, Rainfall data for 12 years, 1995-2006, at Rampur Station) following calculations were made (Appendix A-1 &A-2):

1. Average annual rainfall(mm), Ra= 184.52
2. Average annual temperature (^{0}C), T =24.57
3. Average driest month rainfall (November) in mm, R_D =12.43
4. Average wettest month rainfall (July) in mm ,R_W=576.15
5. Average temperature of coldest month in ^{0}C,(January) Tcm=15.13
6. Average Summer month temperature, in ^{0}C, (Jul-Aug-Sep) Ts =29.34
7. Average warmest month temperature, in ^{0}C,(June), Tw =30.03
8. Average annual rainfall , in mm =2214.35

According to Koppen's worldwide classification system and the prevailing temperature and rainfalls condition in Chitwan Dun valley by calculation of 12 years result the study area falls under Bw category. i.e, B, Dry Climates. The subdivision is Bwh. where w stands for winter dry season, with at least ten times as much precipitation in wettest month of summer as in driest month of winter and h means hot dry climate. The condition is: Ra <T+14 Summer Rains

i.e. 18.45 < 24.57+14

The condition for Bwh is: Tropical desert, Arid; hot T is greater than 18^{0}C.

The prevailing temperature and rainfalls meet the criteria for Koeppen's Climatic condition by the formula: $Rw \geq 10\ R_D$

i.e. $57.16 \geq 10*1.243$

The Himalayan rives are carrying considerably less water during dry seasons that they did in the past. The too little and too much water syndrome is a common feature of the desert country. (K.S. Valdiya, 2001)

1.6. Vegetation

Chitwan valley has humid and subtropical rainy summer and dry winter climate. So the sub – Himalayan tracts south to Siwaliks are dominated by luxuriant Shoria robusta (Sal), (Sissau Dalbergia sossoo (Sissau) Bombax malabarium (Simal), Acacia catechu (Khair), Aegel marmelos (Bayer) , Salmolia Molabolic etc. are major types of vegetation in the area. The other associates like Terminalia Bellirica, T. Chebula, Adina cordifolia, Bauhinia Vahili etc. .Acacia catechu, Dalbergia Sissoo is predominant and riverside Terraces are dominantly covered by Bombax Ceiba, Albizia Procera, Syzygium Cumini, Butea monosperma etc.

The open area and inlands formed by river are chiefly covered by Saccharum Bengalese (Elephant Grass) and Sacchuram Spontaneum (Kans), Tecoma grandis and grasses and sedges. Floodplain with grasses Imperata Sp., Narenga Sp. Phragmites Sp., Sacchuram Sp. Themeda Sp. is a favorite habitat of Rhinoceros Unicornis. Three major types of vegetation occur in the National Park and adjoining area of Chitwan: grassland, riverine forest and Sal forest. The climax vegetation in Chitwan is Sal forest, which covers about seventy percent. In the valley floor, Sal forest is associated with scattered Nepalese elephant apple (tantari), yelloe myrobalan, Indian almond, belleric myrobalan, bauhumas and wild date.

Riverine forest covers less area and is found in the alluvial flood plain and river deposits. Catch tree-Sisoo and Silk cotton-bhelur are the two major river types of riverine forests in Chitwan. Catch tree sisoo grows in the sandy soil and silk cotton – bhelur in the alluvium deposits. The grassland comprises more than seventy percent of species in Chitwan. They are broadly divided into tall and short grasslands. The trees of common fruits such as Mango, Lychee, Peach, Guava, banana, pineapple can be seen everywhere in the area.

1.7 Soil Distribution

The composition of the soil depends on the composition of the parent rocks of the adjacent areas. Sediments comprising the Dun valleys in the Himalaya are thick clastic deposits of Pleistocene and Quaternary age and are accumulating to the present day. Narayani and Rapti River and their tributaries may have transported alluvial deposits like sand, mud and gravel from the adjacent Siwalik and Lesser Himalayan rocks like sandstone, mudstone, conglomerate, schist, quartzite etc. The soils in the area are mostly alluvium and outwash deposits from the hill slopes. The soil of the study area is generally sandy, to loamy. It is coarser towards foothills and finer to the center of the valley. Table 1.2 shows the Soil profile at Rampur Agriculture Farm.

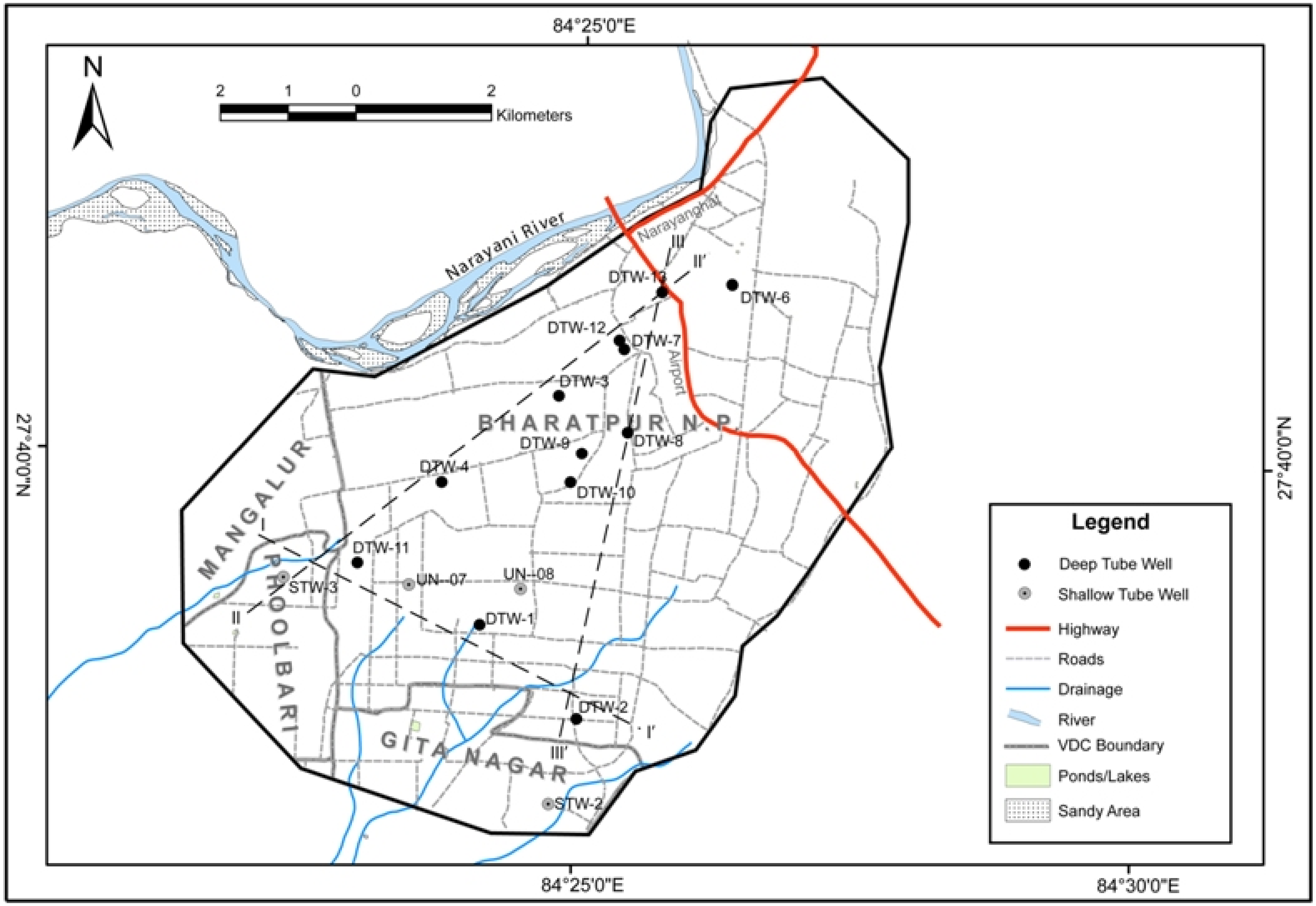


Fig 1.4: Distribution of Shallow and Deep Tubewells in the Study area

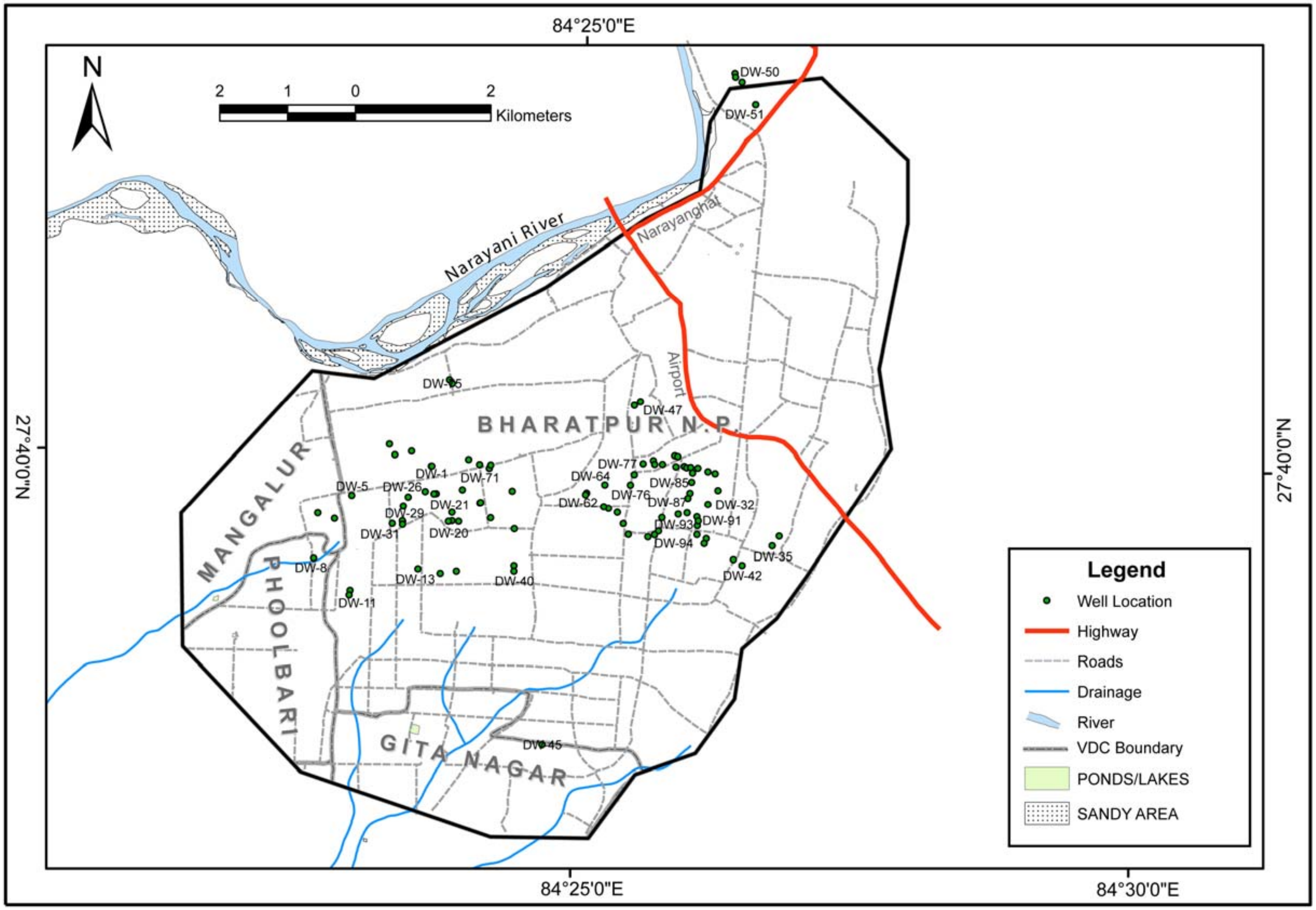


Fig 1.5: Map showing the location of 98 dugwells in the study area.

Table 1.2 Soil Particle and size distribution

Horizon	Depth (cm)	Sand %	Silt %	Clay %	Textural Class
A	0---23	72.50	14.5	13	Sandy loam
B1	23---38	70.50	19.5	10	Sandy loam
B2	38---79	72.75	19.25	8	Sandy loam
C1	79---106	83.00	12	5	Loamy sand
C2	106—119	86.00	11	3	Loamy sand
C3	119 and below	89.00	8.25	2.25	Sand

Source: IAAS, Rampur Campus

Soil of the study area is well drained, developed from moderately coarse textural alluvium in the nearly level land of Narayani river terrace II and terrace III (Iwata & Nakata 1982). The surface soils are 20 to 30 cm thick. They are sandy loam in texture and have a very dark grayish brown or dark grey colour. Below sandy loam there is a B- horizon. The upper part of B-horizon is dark reddish brown loamy sand or sandy loam. The sub—soil is slightly acidic to neutral in reaction. They are medium in organic matter content.

1.8 Population and Socio-economic condition

The estimated population of the study area is about 100,000 on the basis of CBS, 2001. Table 1.3 lists the figures of population. .

Table: 1.3 (a) Population in Chitwan district and Bharatpur Municipality

Location	Total population	Male	Female
Chitwan	472048	235084	236964
Bharatpur	150,000	-----------	------------

Source: CBS, Statistical Year Book of Nepal 2007

Table 1.3(b) Number of Households, population in the households by sex in Chitwan

S. No.	VDC/ Municipality	No of Households	Population		
			Male	Female	Total
1	Gitanagar	2550	5888	6218	12106
2	Mangalpur	2951	7126	7382	14508
3	Phulbari	674	1696	1730	3426
4	Bharatpur N.P.	19922	45858	43465	89323
5	Chitwan District	92851	231857	236842	468699

Source: CBS, Population Census , 2058

Ethnically, there is mixed cast composition Table1.3(c). The major ethnic groups are Brahamin, Kshetri, Tharu, Newar, Tamang and Dalits. Brahamin and Kshetri are dominant caste group. Similarly Hindu, Bouddha, and Islam are the major religions. Gurung, Magar, Newar, Tamang, Darai, Tharu and Chepang are in the minority. Agriculture is the main occupation in the rural side and business and small-scale trade is carried out in the bazaar area and these includes industries, hotels, restaurants, institutes etc.

Table1.3(c) Population Distribution by caste/ethnic Groups for Chitwan

VDC/ N.P.	Ethnic Groups														
	Total	Brahmin	Tharu	Kshetri	Dalit	Tamang	Gurung	Newar	Chepang	Magar	Kumal	Darai	Sanyashi	Muslim	Others
Phulbari VDC	3426	1535	0	756	252	33	264	121	0	201	0	0	0	0	264
Bharatpur N.P.	89323	35953	1616	10843	5204	4646	5409	10062	172	3712	1582	850	583	1071	7620
Gitanagar VDC	12106	5770	657	1677	1510	192	571	613	5	186	41	184	85	23	592
Mangalpur	14508	4187	99	3106	1692	815	1490	689	0	534	200	571	292	60	773
Chitwan District	468699	137732	59835	50723	38775	34584	31655	25450	21233	19388	7503	7205	3657	3610	27349

Source: CBS, population Census, 2058

1.9 Agriculture

The principal crops grown in Chitwan district are paddy, maize, millet, wheat, barley, oilseeds, potato, tobacco, sugarcane, pulses and others. Statistics for crops are listed in Table 1.4

Table: 1.4 Principal Crops Harvested in 2006-2007 in Chitwan

Crop	Area (ha)	Yield (kg/ha)	Production (M ton)
Paddy	28717	2800	80408
Maize	9015	2498	22520
Millet	20650	2800	57820
Wheat	1815	997.2	1810
Barley	260	1000	260
Oilseed	11442	602.34	6892
Potato	1810	15367.40	27815
Sugarcane	16	28125	450

Source: CBS, Statistical year book of Nepal 2007

Chitwan district is considered as one of the largest oilseeds production district in Nepal. Vegetables like cauliflower, cabbage, tomato, ladyfinger, radish and fruits like mango, lychee and guava are also known.

The Chitwan district is in Rapti Dun Valley and the following table gives the irrigation status of agricultural land:

Table 1. 5 Irrigation Status of Agricultural Land

Total Area (Ha)	Cultivable land (Ha)	Cultivated land (Ha)	Irrigable Area (Ha)	Surface and groundwater irrigation, ha	Balance area for year round irrigation, ha
251,000	99,510	52,410	86,550	25,831	33,719

Source:--C.K. Sharma, 1995

Chitwan district contains 251,000 Ha of agricultural land. Water resources, if adequately developed, will provide a large part of the water to irrigate the potential irrigation land.

1.10 Irrigation Development:-

The utilization of both the surface and groundwater resources for irrigation in Chitwan valley is being practiced both by the government and by the local farmers. Several Farmers Managed Irrigation Systems have been rehabilitated under various programs and Projects.

The major Projects are Narayani Lift, East Rapti, Khageri, Panchakanya and Pithuwa Irrigation Projects. In East Rapti Irrigation Project (ERIP) total 72 nos. of FMIS have been rehabilitated with appropriate structures at the critical locations. ERIP has significant impact on irrigated agriculture of the Eastern Chitwan, which provided irrigation facility to 8,516 ha of land. Net command area irrigated by these projects equals 18186 ha. of agricultural land. Similarly groundwater irrigation development has been started since the establishment of GWIP at Chitwan in 1999. ADB/ Nepal and ADPJ have been providing irrigation facilities by constructing shallow and deep tubewells since the very beginning. The net command area developed by groundwater includes 3432 ha. of agricultural land to date.

1.11 Drinking water

The main source of drinking water in the study area is groundwater. Shallow aquifer has been utilized for installing shallow and dugwells. Gravity flow supply is widely used in the northern part where shallow and dug wells are not feasible. In the southern part shallow and dug wells installations for fulfillment of drinking water are increasing per year. Groundwater for domestic use is prior in these areas. In urban areas several deep tubewells have been installed by (DWSS) Office for city supply but it is inappropriate for everyday domestic needs.

1.12 Synopsis

The field work of five weeks was carried out during March 2008 and August 2008 for the collection of hydrogeological information. The present work is mainly concentrated on interpretation of collected data from dug wells, existing data of shallow and deep tube wells and geophysical interpretation of existing data.

The overall work is divided into ten chapters.

1. The **first** chapter introduces the summary on background of study area, location, rainfall, climate and vegetation, description of soil and present irrigation status.
2. The **second** chapter deals with the review previous works. Background of Narayani Lift Irrigation Project and current problems on groundwater research needs are the main task in the second chapter.
3. The **third** chapter includes the methodology applied to perform the task, field survey, locating the monitoring points in the map, Collecting and reviewing of existing data, hydrogeological field survey, inventory of existing wells in the area, Selection of the study area, sedimentological study, data processing and interpretation.
4. Chapter **four** summarizes the calculation of Potential Evapotranspiration (PET) at Rampur and Devghat station.
5. Chapter **five** presents the geological settings of Nepal, aquifer systems of Dun valley and quaternary geology of the study area based on lithologs and field study. It also contains the interpretation and discussion of the geophysical survey studies applying Vertical Electrical Sounding (VES) Schlumberger Configuration in 26 stations in the study area.
6. Chapter **six** approaches Hydrology and groundwater condition of the area comprising the aquifer settings, aquifer properties and ground water movement.

7. Chapter **seven** includes the data analysis, interpretation and discussion of the entire studies
8. Chapter **eight** presents conclusive remarks and recommendations on the study and future plannings

.

II. REVIEW OF PREVIOUS WORKS

2.1 Previous work

Several studies have been carried out in the Chitwan Valley by native and foreign hydrogeologists/ geologist/geophysists and private as well as government organizations.

Shuji Iwata and Takashi Nakata, 1982, studied River Terraces and Crustal Movement in the area around Narayanghat, and classified into six groups. Also they have established the relation between the terrace gravels and the Siwalik conglomerate.

Kanskar et al. 1993, made a reappraisal of hydrogeological study on shallow aquifer in Chitwan and developed a scientific procedure about data collection, presentation and interpretation of hydrogeologic findings

Shreshtha N.R. et al. has carried out Geolectrical Survey for the Investigation of Groundwater Potential for Shallow and Deep Aquifers in Chitwan, in September 1996. The survey area covered the central part of the plain of the district and included entire part from north Siwalik Hills up to Rapti River in the south. Altogether 111 nos. of Vertical Electrical Soundings (VES) were made. Potential areas for shallow, medium and deep aquifers for groundwater development were identified.

Paudyal K.N., 1993, has carried out an electrical resistivity survey in central Chitwan valley south of Krishnapur area to understand the hydrogeological setting for groundwater exploration in the work for his M.Sc. dissertation. This surveyed area includes the parts of the present study area. Altogether 47 VESs were conducted within an area of 150 Sq. km. Electrical Profiling was also conducted in 4 Sq. km. He established two layers sequence. The upper layer has high resistivity (upto 16,500ohm-m), thickness ranging from 2-25m, the lower layer comprises low resistivity (below 1000 ohm-m), composed of sand, gravel and boulder has been considered as good aquifer zone. Most of the aquifer values range 200-800 Ohm-m.

ADPJ, Janakpur, Dhanusha (1993) Ministry of Agriculture has drilled, tested and monitored 22 production deep tube wells for development of irrigation in Chitwan dun valley

NEDRILL/EGEC (1994), carried out geophysical investigation (by Pant and KC), constructed deep tubewells in the study area and made a hydrogeological study for East Rapti Irrigation Project.

Groundwater Development Consultants(GDC) Pvt. Ltd. 1993, made a reassessment of the Groundwater Development Strategy for Irrigation in the Terai and classified the potential area for Shallow and deep aquifer for Terai including Chitwan..

Sharma C.K (1995) mentioned three priority zones based on groundwater availability for shallow tubewells in Chitwan Valley. Top priority area includes Parsa, Meghauli, Bhimnagar, Tikauli and Ratnanagar. Prembasti and Dibyanagar are regarded as medium priority area. He mentioned Bhandara as a low priority area.But these areas are not in the present study area.

Ground Water Irrigation Project (GWIP), since 1999 has drilled 9 production deep tube wells and finally developed into Groundwater Irrigation systems in central and northern part of Chitwan district. Hydrostratigraphy of subsurface formation have been obtained from these wells.

Acharya S.L.2001 studied the hydrogeological settings of Bharatpur -Gaidakot area. He classified that the fluvial sediments of the area into three formations as-Devghat gravel formation, Bharatpur sand formation and Narayanghat formation. Part of the area coincides to the present area.

2.2. The Narayani Lift Irrigation Project

Since 1961, Government of Nepal decided to launch Rapti Valley Multipurpose Development Board in Chitwan valley. In this context, first phase Khageri Irrigation Scheme was launched by the GON and construction started to enhance integrated development of rural area.

The Chitwan Valley Development Project includes the rehabilitation/construction of irrigation and drainage facilities for:-

Western Part

Upper Terrace Canal 'C '--System 2,300ha

Middle Terrace Canal 'B '---System 2,400ha

Middle Terrace Khageri System

(Rehabilitation and Supplement) 3,900ha

The area of 8,600 ha on two terraces, namely the Upper and Middle terraces along the Narayani river, will be provided with an irrigation supply from the river, on a year round basis. The irrigation system for this area includes two 'staged' pumping stations and two canal system.

This area is under the scope of present study while Eastern part is beyond the scope.

Eastern Part

Panchakanya---Batar Scheme 600ha

Lothar----Rapti Scheme 1,200ha

The irrigation water requirements of the area served by canal B and canal C systems (4,700ha) will be met by pumping water from the Narayani River, for Khageri system (3,900ha) deficit after the use of the year. Available gravity flow of the Khageri stream will be additionally supplementary with the pumped water from canal B.

2.3 Current Problems and Reseach Need:

Department of Irrigation, Government of Nepal has now decided to reformulate the design of all structural units in canal C of Narayani Lift because of rapid increase of the settlements and growing population reduces the culturable command area of agricultural land. DOI has decided to use the alternative water resources for enhancement of net command area round the year irrigation. These alternatives may be proper development of groundwater.

For surface irrigation major problem is getting the water during the dry season when river flow is at a low and water demand is at high. Hence irrigation project which havenot reservoir will command less area during the dry season is 12 to 50 times as compared to high flow and 7 to 25 times as compared to average flow. (C.K.Sharma, 1995)

The study area lies in the western part of Chitwan is home to more than 1 million people. The rapid rise in the urban population is a major constraint for development of infrastructure and services, including water supply, sanitation, sewerage and drainage services.

The population in the area dependent primarily on groundwater for the urban and domestic water supply; about 90% of the present population rely on groundwater for daily use.The dependence on groundwater for domestic, irrigation industrial,and commercial water supply is increasing in recent years. The number of private boreholes has also substantially increased and abstraction through these wells remains unquantified but is likely to be significant.

Though the area is largely dependent on groundwater, currently there is no management plan in place. Lack of proper understanding of the groundwater system is one of the major constraints of sustainable development of groundwater in the area. The objectives of this work are to study groundwater condition and to quantify the abstraction in relation to recharge and aquifer storage.

Having realized the importance of irrigation in the national economy GON has given top priority to the irrigation sector in the national development plans. Emphasis has been given in the Irrigation Policy 1992 on proper development of irrigation sector, which states:

“Conjunctive use of surface and groundwater sources shall be continued and the size and types of small, medium, and large surface and groundwater irrigations which are in use shall be technically and managerially adjusted giving highest priority to the objective of efficienand maximum development of the irrigation sector”.

Therefore the basic problem is to manage the ground water of the area, so that the available resources are exploited to their maximum potential in a rational and optimal manner for raising net benefit and better life. Groundwater development can contribute significantly food security and reduction in poverty in Nepal. In the study area surface water supplies and rainfall are inadequate to meet the irrigation water requirements. This deficiency is being fulfilled by development of irrigation by groundwater.

III. MATERIALS & METHODOLOGY

The present hydrogeological study was completed by various methods such as collection and reviewing of existing data, hydrogeological field survey, sedimentological study, data processing, analyzing and interpretation.

3.1 Reviewing of existing data.

The available literature, reports, maps, and relevant well data related to present study were collected from various sources. Well logs, pumping test data, monthly well observation data were collected from the GWRDB.. The meteorological data like monthly temperature record and rainfall record of the area were collected from the DHM, GON. Similarly Deep Tubewell records in Chitwan are collected from ADPJ---Naktajhij, Dhanusha, National Drilling Company ((NADCO) Pvt Ltd. and Nissaku Drilling Company, Katmandu. Topographical map of the study area were acquired from the Department of Survey, GON.

The published relevant literatures, reports, and well lithologs, electric logs were thoroughly reviewed. Interpretations of hydrogeological condition of the study area and Geophysical data were made on the basis of these well lithologs and pumping test data of the shallow as well as deep tube wells.

3.2 Field survey

Based on review of existing literature, reports and data, field survey and well inventory survey were designed and questionnaires field format were developed. The inventory survey was conducted with the help of these questionnaires (Appendix A-i). During the field survey, the data collected from secondary sources were verified and additional new data were generated.

Field survey was carried out in the study area for four weeks in April-May and August-September 2008. During the field visit, identification of appropriate target sites was done by means of a hand-held Garmin eTrex Summit Global Positioning System and additional geological /hydrogeological data and relevant information were observed and measured. Various well locations was plotted on the toposheet of 1:25,000 in the field (Fig: 1.4 and Fig.1.5} with their respective symbols.

3.3 Well location of the study area.

The deep tube and shallow tube wells were marked on the toposheet (Fig.1.4) with their respective symbols. The location of dug wells was clearly indicated in the location map (Fig 1.5).

3.4 Well information.

Information required to prepare well inventory such as depth of well, diameter of well, and depth to water level from ground surfacefor dugwells and depth to water level in case of shallow and deep tubewells and water level fluctuation were collected during the field survey. In the case of deep tube wells and shallow tube wells, all the information was obtained from GWRDB, ADPJ Naktajhij and GWIP, Chitwan. Vertical Electrical Sounding

(VES) data were provided by GWRDB.

3.5 Desk study and Report writing

Desk study and report writing also have several stages. Documentation, data computation, processing, analysis, interpretation, preparation of maps, charts, tables, figures and finally report writing were the main stages. After the collection of the primary and secondary data, different types of maps like groundwater level contour maps, geological map, drainage map and location maps were prepared. Similarly lithologs of the bore well, dug wells and Vertical Electrical Sounding logs were prepared. The maps were prepared by using computer aided programme like Macromedia Freehand, Surfer, Adobe Illustrator and ILWIS.

Finally, analysis and interpretation were made based on geological and hydrological data, maps and figure as well as field work data. The methodology adopted for the study is summarized below as shown in Fig. 3.1.

Methodology of the Study

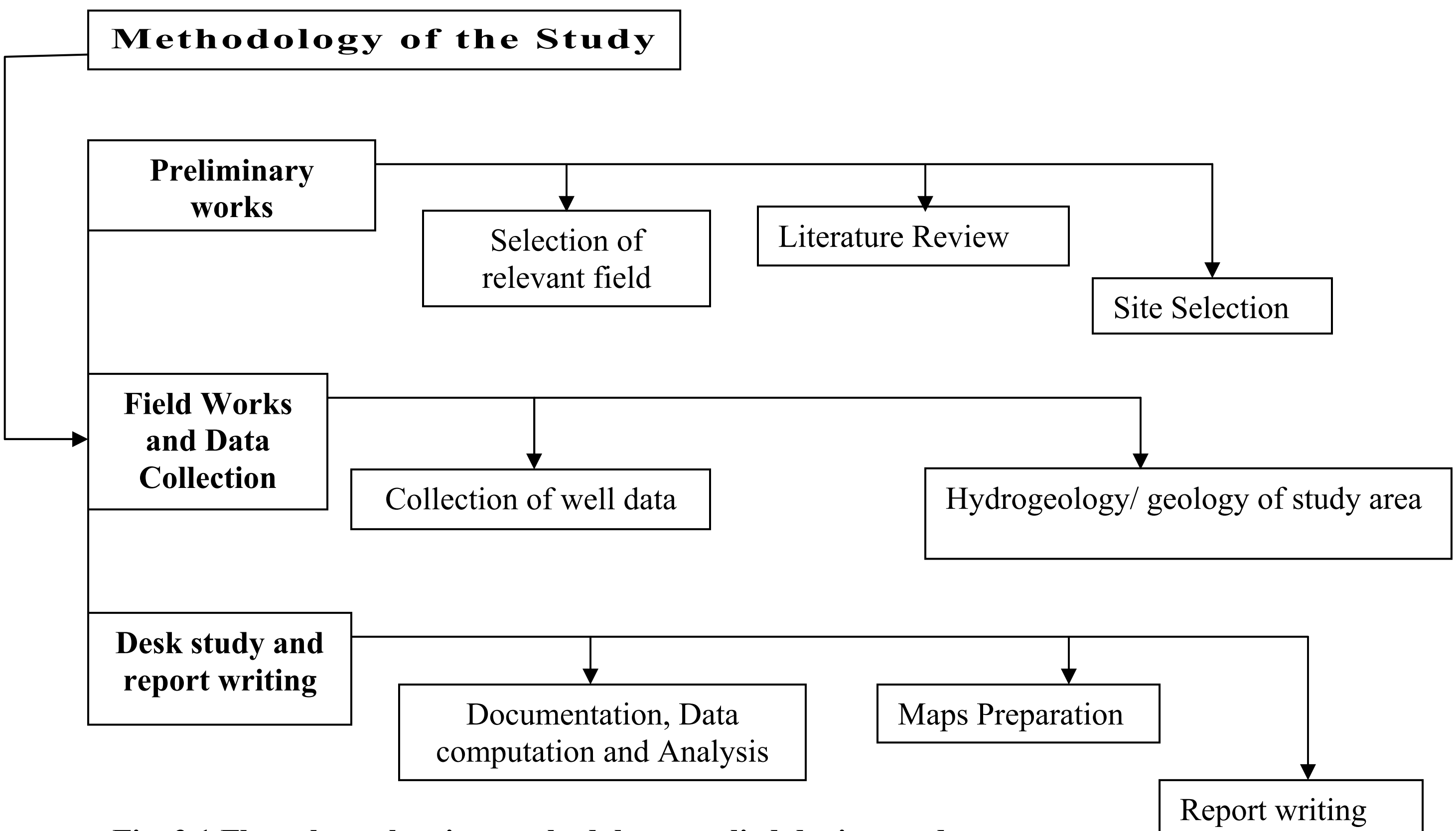


Fig. 3.1 Flow chart showing methodology applied during study

IV. EVAPOTRANSPIRATION

4.1 Introduction

Plate 2: The Famous 'Bis hazari Lake' in Barandabhar Forest

The lack of reliable field data and the difficulties of obtaining reliable evapotranspiration data have given rise to a number of methods to predict potential evapotranspiration (PET) by using meteorological data. Large numbers of formulae are available: they range from purely empirical ones to those backed by theoretical concepts. Two useful equations are given below.

4.2 Penman's Equation

Penman's equation is based on sound theoretical reasoning and is obtained by a combination of the energy –balance and mass transfer approach . Penman's equation, incorporating some of the modifications suggested by other investigators is

$$PET = \frac{AH_n + E_a\gamma}{A + \gamma} \qquad \text{------------ (4.1)}$$

Where

PET= daily potential evapotranspiration in mm per day

A= slope of the saturation vapour pressure vs temperature curve at the mean air temperature, in mm of mercury per ^0C

Hn= net radiation in mm of evaporable water per day

Ea= parameter including wind velocity and saturation deficit

γ = psychometric constant= 0.49 mm of mercury/ ^OC

The net radiation is the same as used in the energy budget and is estimated by the following equation:

$$Hn = Ha\,(1-r)\left[a + b\frac{n}{N}\right] - \sigma T_a^{\,4}\,(0.56 - 0.092\sqrt{e_a})\left[0.10 + 0.90\frac{n}{N}\right] \text{-----(4.2)}$$

Where

Ha = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day (it is function of the latitude and period of the year as indicated in Tables in Appendix-4)

a = a constant depending upon the latitude ϕ and is given by a = 0.029 cos ϕ

b= a constant with an average value of 0.52

n= actual duration of bright sunshine in hours

N= Maximum possible hours of bright sunshine (it is function of latitude as indicated in Appendix-4)

r = reflection coefficient (albedo). Usual ranges of values of r are given below

σ = Stefen –Boltzmann constant = 2.01×10^{-19} mm/day

T_a = mean air temperature in degrees Kelvin = 273 ^{0}C

Ea= actual mean vapour pressure in the air in mm of mercury

The parameter Ea is estimated as

$$E_a = 0.35\left[1 + \frac{u_2}{160}\right](e_{w} - e_a) \quad \text{-----------} \quad (4.3)$$

Where, u_2 = mean wind speed at 2 m above ground in km/day

e_w = Saturation vapour pressure at mean air temperature in mm of mercury (Appendix-4)

e_a = actual vapour pressure, defined earlier

For the computation of PET, data on n, e_a, u_2 mean air temperature and nature of surface (i.e. value of r) are needed. These can be obtained from actual observations or through available meteorological data of the region. Equations 4.1, 4.2 and 4.3 together with Tables in Appendix-4 enable the daily PET to be calculated. It may be noted that Penman's equation can be used to calculate evaporation from a water surface by using r= 0.05. Penman's equation is widely used in India, the UK, and Australia and in some parts of USA.

4.3 Calculation format of PET

1990, January

Potential Evapotranspiration	Station: 0902, Rampur	Station: 450, Devghat
Latitude:	$27^0 37'$ = 27.6^0	$27^0 42' 30''$ = 27.7^0
Elevation:	256 m	179 m
Mean monthly air temperatures:	22^0C	
Mean relative humidity	98%	
Mean observed sunshine hours (n)	5.7hr/day	

Wind velocity at 2 m height (u_2)   0.8 km/hr = 19.2km /day

Nature of surface cover (r)   0.25 (close ground crop)   0.05 (water surface)

Solution: From Table (Appendix-4)

$A = 1.20 mm/ ^0C$

ew = 19.86 mm of Hg

Ha = 9.05 mm of water /day

N = 10.56 hrs/day

n/N =5.7/10.56 = 0.54

From given data

ea =ew x RH% = 19.86 x 0.98 = 19.47 mm of Hg

$a = 0.29\cos\phi = 0.29\cos 27.6^0 = 0.26$

b= 0.52

$\sigma = 2.01 \times 10^{--9}$ mm /day

Ta = 273+ 22 = 295 K

$\sigma Ta^4 = 2.01 \times 10^{-9} (295)^4 = 15.23$

r = albedo for close ground green crop is taken as 0.25 and 0.05 for water surface

From eq. (4.2)

$Hn = Ha (1-r) (a+bn/N) - \sigma Ta^4 (0.56-0.092 \sqrt{ea}) (0.10+0.9n/N)$

$= 9.05(1-0.25) (0.26+0.52 x0.54) - 15.23(0.56-0.092 \times \sqrt{19.47} (0.10+0.90 \times 0.54)$

$= 3.671-15.23 \times 0.155 \times 0.586$

= 2.29 mm of water/day for Rampur

$Hn = 9.05 \times 0.95 \times 0.5408 - 15.23 \times 0.1540516 \times 0.586$

= 4.64-1.37

=3.27 mm of water/day for Devghat

From eq (4.3)

$Ea = 0.35(1+u_2 / 160) (ew-ea)$

$= 0.35(1+19.2/160) (19.86-19.47)$

$= 0.35 \times 1.12 \times 0.39$

=0.16 mm/day

From eq (4.1), noting the value of γ =0.49

$PET = (AHn+Ea\,\gamma) / A+ \gamma$

= (<u>1.20 x 2.29+0.16x 0.49</u>)   = <u>1.202x3.27+0.16x 0.49</u>

(1.20+0.49) 1.20+0.49

=2.8309 = 4.00894

1.692 1.692

=1.68 mm of water at Rampur = 2.37 mm of water at Devghat

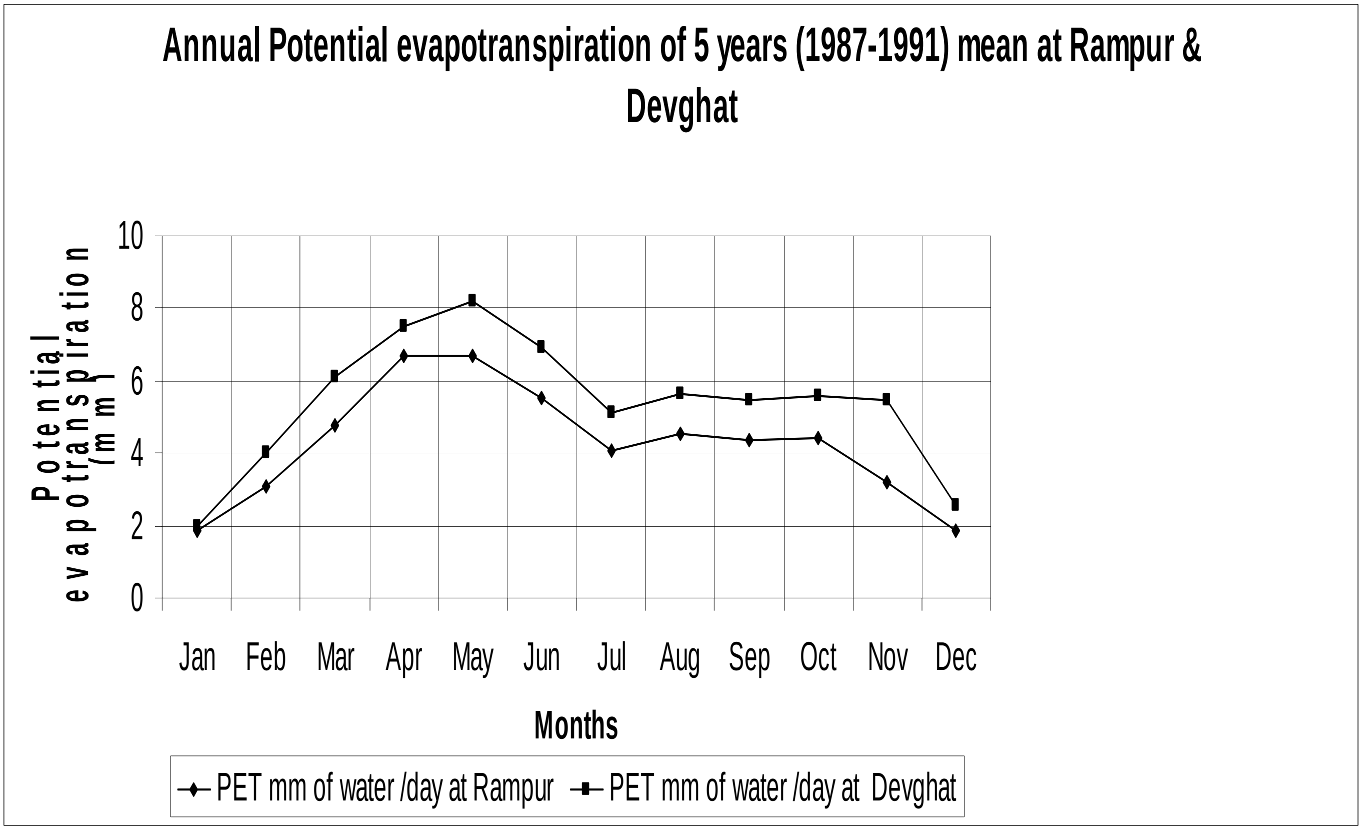


Fig: 4.1 Annual Potential evapotranspiration of 5 years mean at Rampur & Devghat

4.4 Empirical Formulae

A large number of empirical formulae are available for the estimation of PET based on climatological data. These are not universally applicable to all climatic areas. They should be used with caution in areas different from those for which they were derived.

4.4.1 Blaney—Criddle Formula

This is purely empirical formula based on data from arid western United States. This formula assumes that the PET is related to hours of sunshine and temperature, which are taken as measures of solar radiation at an area. The potential evapotranspiration in a crop-growing season is given by

$$E_T = 2.54\ KF \quad \text{………………..} \quad (4.4)$$

$$F = \sum P_h \bar{T}_f / 100 \ldots\ldots\ldots\ldots\ldots (4.5)$$

Where E_T = PET in a crop season in cm

K = an empirical coefficient depends on the type of the crop

F =Sum of monthly consumptive use factors for the period

P_h = monthly % of annual day – time hours, depends on the latitude of the place

$\bar{T}_f$ = mean monthly temperature in ^{0}F

Values of K depend on the month and locality. Average value for the season for selected crops is given in Table (Appendix A-4). The Blaney-Criddle formula is largely used by irrigation engineers to calculate the water requirements of crops (Appendix -4), which is taken as the difference between PET and effective precipitation. Blaney-Morin equation is another empirical formula similar to Eq. (4.4) but with an additional correction for humidity.

Table 4.1 Estimation for PET for different crops at the study area

Crops	**Periods of growth**	**Calculated E_T value**
Paddy (Transplanted Rice)	Jul—Nov	105.80
Maize	Jun—Sep	55.13
Wheat	Nov—Feb	37.40
Sugarcane	Feb—Dec	201.97
Potatoes	Oct—Feb	52.99
Natural vegetation:		
a. Very dense		291.74
b. Dense		269.29
c. Medium		224.41
d.Light		179.53

4.4.2 Thornthwaite Formula

This formula was developed from data of eastern USA and uses only the mean monthly temperature together with an adjustment for day-lenths. The PET is given by this formula as

$$E_T = 1.6\, L_a \left[\frac{10\bar{T}}{{}^{I}I\,t_T} \right] \qquad \text{----------------------} \qquad (4.6)$$

Where E_T = monthly PET in cm

L_a = adjustment for the number of hours of daylight and days in the month related to the latitude of the place

$\bar{T}$ =mean monthly air temperature in ^{0}C

It= the total of 12 monthly values in heat index i = $\sum_1^{12} i$ where i = $(\bar{T}/5)^{1.514}$

a= an empirical constant

= $6.75\text{x}\ 10^{-7}\ \text{x}\ I^3t - 7.71\text{x}10^{-5}\ \text{x}\ I\ t^2 + 1.792\text{x}10^{-2}\ It + 0.49239$

PET using Thornthwaite formula method of five years mean (1987—1991) (Table Appendix -4)

Latitude = 27.6^0

$E_T = 1.6\ La\ \left(\frac{10T}{It}\right)^a$

E_T = monthly PET in cm

La = adjustment for the numbers of hours of day light and days in the month, related to latitude of the place (Table)

It= 191.04 (from table)

a = an empirical constant

=$6.75\text{x}\ 10^{-7}\ \text{x}\ It^3 - 7.71\text{x}10^{-5}\ \text{x}\ I\ t^2 + 1.792\text{x}10^{-2}\ It + 0.49239 = 5.81$

Table 4.2 PET using Thornhwaite Formula Method of 5 Years Mean (1987-1991) at Rampur Station

Month	Mean monthly Air Temperature in ^{0}C		Adjust-ment Factor (La)	Heat Index i= $\sum (\bar{T}/5)^{1.514}$	It = $\sum_1^{12} i$	10 $\bar{T}$	10 $\bar{T}$ / It	(10 $\bar{T}$ /It) ^{a}	Et.
	$\bar{T}$	($\bar{T}$/5)							
Jan	23.0	4.60	0.91	10.07	191.04	230	1.20	2.89	4.21
Feb	26.7	5.34	0.87	12.63	191.04	267	1.40	7.07	9.84
Mar	31.5	6.30	1.03	16.22	191.04	315	1.65	18.35	30.24
Apr	36.4	7.28	1.07	20.19	191.04	364	1.91	42.94	73.51
May	36.5	7.30	1.16	20.28	191.04	365	1.91	42.94	79.70
Jun	34.5	6.90	1.15	18.62	191.04	345	1.81	31.41	57.79
Jul	32.3	6.46	1.18	16.85	191.04	323	1.69	21.09	39.82
Aug	33.1	6.62	1.13	17.48	191.04	331	1.73	24.16	43.68
Sep	32.8	6.56	1.025	17.25	191.04	328	1.72	23.36	38.31
Oct	32.2	6.44	0.985	16.77	191.04	322	1.69	21.09	33.24
Nov	28.4	5.68	0.899	13.87	191.04	284	1.49	10.15	14.60
Dec	24.1	4.82	0.894	10.81	191.04	241	1.26	3.83	5.48

V. GEOLOGY & GEOMORPHOLOGY OF THE AREA

5.1 An Outline of the Geology of Nepal

The continental collision of the Indian and Eurasian continents during the early Cenozoic initiated the Himalayan orogeny and upliftment of the Tibetan Plateau and at the same time formed a Himalayan foreland basin. The Himalaya, the world's youngest and highest mountain range, is morphologically still active today. It extends for about 2400 km from the Punjab Himalaya in the west to the North-East Arunanchal Himalaya in the east along West Northwest direction bordering the southern edge of the Tibetan plateau (Kizaki, 1994). These long series of several of nearly parallel ranges with width ranging from about 230 to 320 km have been divided into several regional units. Gansser (1964) divided theHimalayan chain into regional and geographical unit from east to west.

a)Salt Range

b)Punjab Himalaya

c) Kumaon Himalaya

d)Nepal Himalaya

e) Sikkim-Bhutan Himalaya

f)) NEFA (North-East Frontier) Himalaya

The Nepal Himalaya occupies a nearly central part forming a wide arch along the southern border of the Tibetan Plateau.

5.2. Nepal Himalaya

The Nepal Himalaya is situated in the central part of the Himalayan arc extending to about 800 km. It covers the whole of country from Mahakali River in the West to the Tista River in the East. The Nepal Himalaya includes several of the highest mountains in the world with many peaks above 5000m.

The Nepal Himalaya has been divided from north to south, throughout most of its length into five distinct tectonic divisions (Fig.5.1) which are separated by major thrusts (Gansser, 1964, Hagen 1969, Sharma, 1990). Each unit is separated by a tectonic structure from the other. They are from north, the Tethys-Tibetan Himalaya, the Higher Himalaya, the Lesser Himalaya with the Mahabharat Range at the southern border, the Sub-Himalaya (Siwalik or Churia Group) and the Indo-Gangetic Plain or Terai.

Geologically Nepal is divisible into following natural divisions along a north to south traverse:

---------------------**Indus Tsangpo Suture (ITS)** ---------------------------------

Tibetan- Tethys Himalaya

---------------**South Tibetan Detachment Fault System (STDFS)** ---------------

Higher Himalaya

----------------**Main Central Thrust (MCT)** --

Lesser Himalaya

----------------------**Main Boundary Thrust (MBT)** -------------------------------

Sub -Himalaya (Siwalik or Churia Group)

---------------------**Main Frontal Thrust (MFT)** ------------------------------------

Indo-Gangetic Plain or Terai

5.2.1 Lesser Himalaya

The folded and faulted region of the Lesser Himalaya is separated from the south by the MBT and from the Higher Himalaya in the north by the MCT .The area is with wide valleys and the peaks of which are elevated from 1500m to 3000m in altitude. The age of the Lesser Himalayan rock ranges from Pre-Cambrian to Early Miocene.

Morphologically, this zone can be divided into two zones, Mahabharata Range and Midland zone. Both zones are composed of unmetamorphosed to low-grade metamorphic rocks with the higher-grade metamorphic rocks on the top, called the Lesser Himalayan Crystalline. The Lesser Himalaya rocks comprise of metasedimentary sequences as slates, limestone, phyllites, dolomite, quartzite, marble, schist and gneiss. The general strike of the Lesser Himalayan rocks is NW-SE; the dips are moderate to steep towards the NE or SW as the rocks are folded into synclines and anticlines.

5.2.2 Sub-Himalaya (Siwalik Group)

The Siwalik forms the southern foothills of the Himalaya, also locally known as the Churia Hills in Nepal, is characterized by rough and youthful topography. It is located between the Indo-Gangetic Plain to the south and the Lesser Himalaya to the north. The Siwalik Group is bounded by the MBT/MBF to the north by the MFT to the south. The MFT is equivalent to the Himalayan Frontal Thrust (HFT) or Frontal Churia Thrust (FCT) of Tokuoka et al. (1988) .The Siwalik rocks represent deposition took place during Neogene (Middle Miocene to Early Pleistocene) age. Topographically, it is low lying area and, lithologically it is composed of molassic sediments consisting fluviatile sedimentary sequence of conglomerate, shale, sandstone, siltstone and mudstone. The Mid-Miocene to Pleistocene aged Siwalik rock sequences coarsening upward and is rich for both flora and fauna fossils.

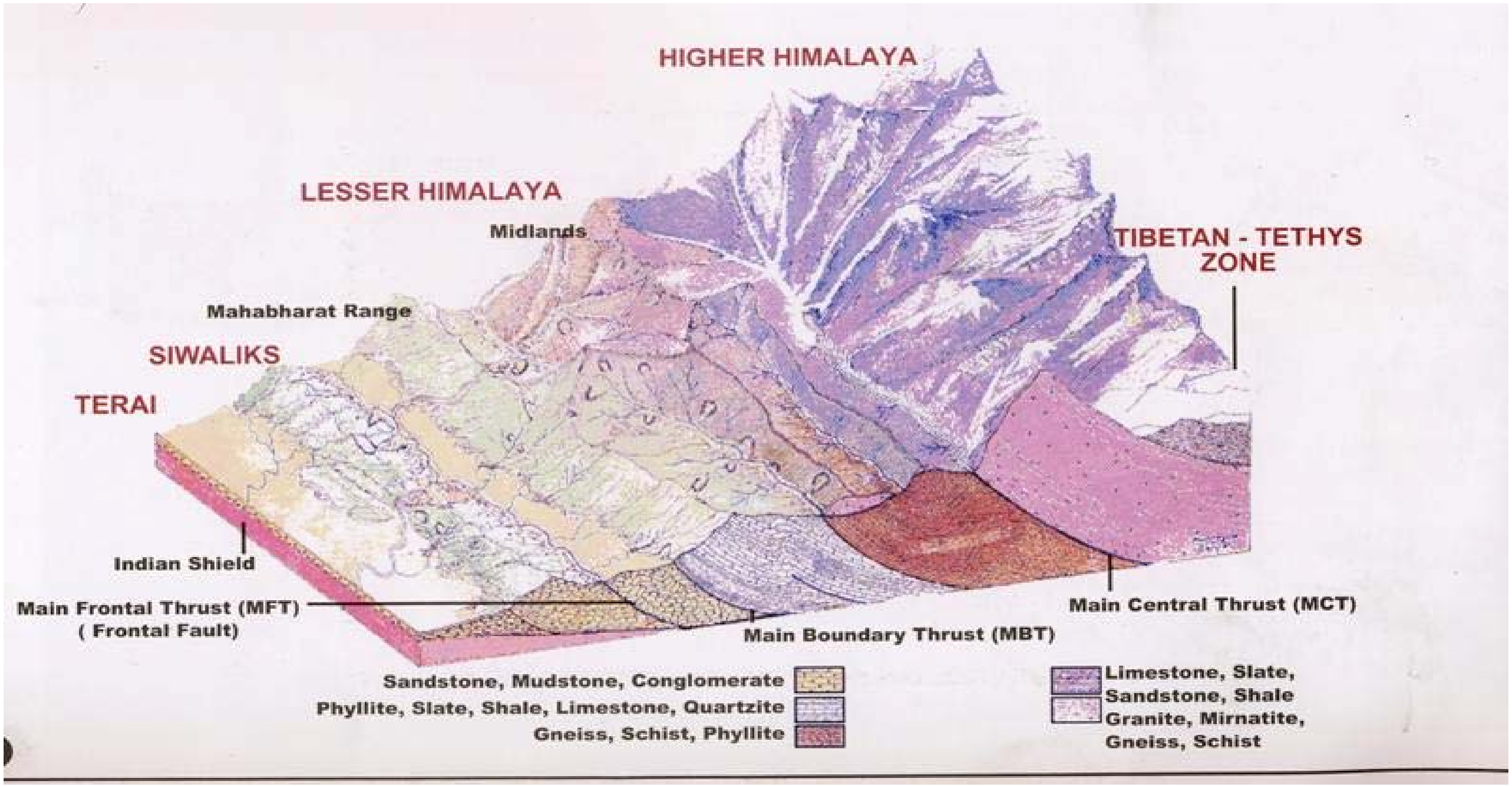


Fig 5.1. Geological Subdivisions of the Himalaya (*Source: Dhital & Uprety, WECS, 2003*)

5.3 Evolution of 'Duns' in the Siwalik:

The Siwalik domain, like the main Himalayan province, was affected by neotectonic movements in the last 1.6 m.y. , that brought about the dismemberment of the Himalayan Foreland Basin into the Siwalik and Indo –Gangetic domains, profoundly affected the Siwalik terrane itself. New faults appeared and older ones reactivated. Wherever anticlinally –folded rocks popped up or the ground moved up sideways along active faults, there was considerable disruption and interruption of drainage. The uplift of the downstream blocks caused the blockage of streams and rivers, leading to the formation of lakes or marshes in the Siwalik. Swift flowing torrents rapidly filled these impoundments (Fig 5.2.). The sediment fills eventually emerged at flat stretches in the valleys of the hilly Siwalik domain. These flat stretches are known as 'Dun'—such as the Dehradun in Uttaranchal , Chitwan (Rapti) dun in Nepal.

Intermontane flat stretches called 'Duns' were formed in this manner. Chitwan Dun is the typical example of dun valleys in Nepal. The Duns were formed in the Late Pleistocene to very Early Holocene about 22,000 to 7,000 yr. B. P. The floor of the Indo- Gangetic Basin

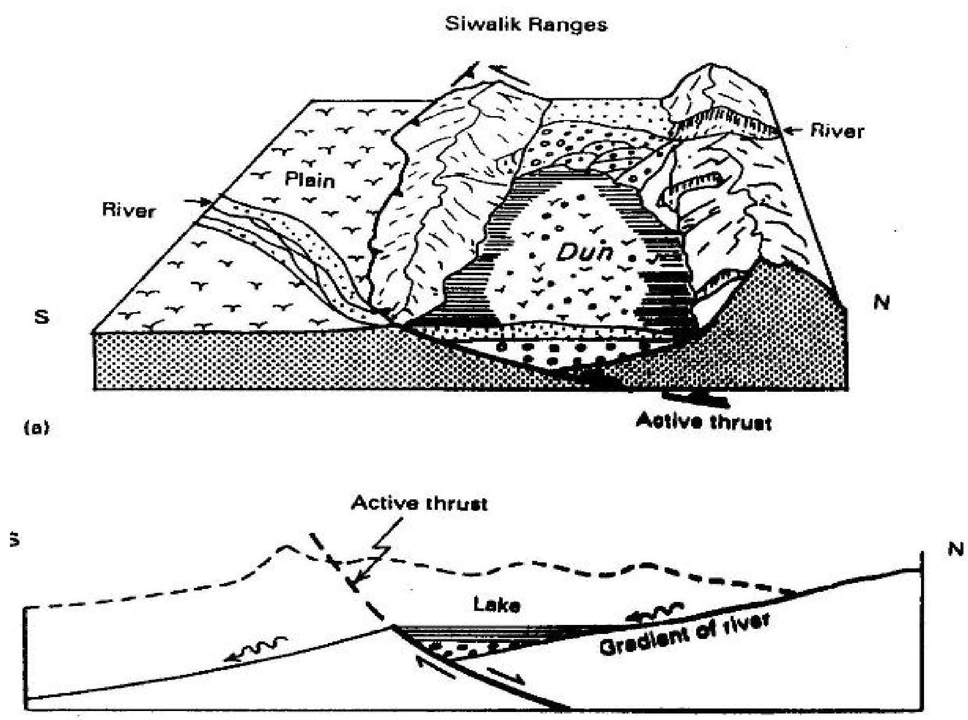


Fig 5.2: Swift filling up of the impoundment gave rise to a flat stretch of sediments called 'dun' within the hilly terrane. (Valdiya, 2001)

formed south of the active HFT. The surface of the flood plain today stands 30 to 100 m above mean sea level. The thickness of the detrital accumulations is varying from 500m to 2500m from south to north.

5.4 Geological Setting of the Chitwan Dun Valley:

Chitwan Dun valley is a NNW-SSE trending Synclinal intermontane valley (about 140 km long and 60 km wide) formed within the outer/sub-Himalaya (Siwalik) of Nepal Himalaya.The Siwaliks of the Sub-himalayan belt consist of molassic sediments,mainly conglomerates,sandstones and clays of Neogene period (Upper Miocene to early pleistocene).This lenticular shaped longitudinal valley in Siwalik range represent the active front of the Himalayan chain and represent tectonic or structural depression in the post Siwalik time.

These youngest formations of the Himalaya, that were here caught up in final phases of folding and rising, so that they run in a strike direction parallel to the Himalaya(Haffner,1979:6f;Hagen,1959,1969). In the lower and middle Siwaliks, these deposits are slightly consolidated sandstones; the upper Siwaliks consist of conglomerates. The broad valleys in the Himalayan foothills, the so-called duns, represent geological depressions (synclinals) in the Siwaliks.The cross-section of geological map of Chitwan Valley (Fig 5.3 & 5.4) illustrates the geological condition of the valley.

Upper Siwalik is comprised of well sorted round to subround clast-bearing conglomerates and lesser of indurated coarse to fine grained sandstones. The lower part consists of pebbly conglomerates and upper part consists of boulder conglomerates.

Middle Siwalik is comprised of thick bedded, less indurated, medium to coarse grained "salt and pepper" sandstone with lesser proportion of mudstone beds. The salt and pepper texture in sandstone is due to presence of biotite and feldspar.

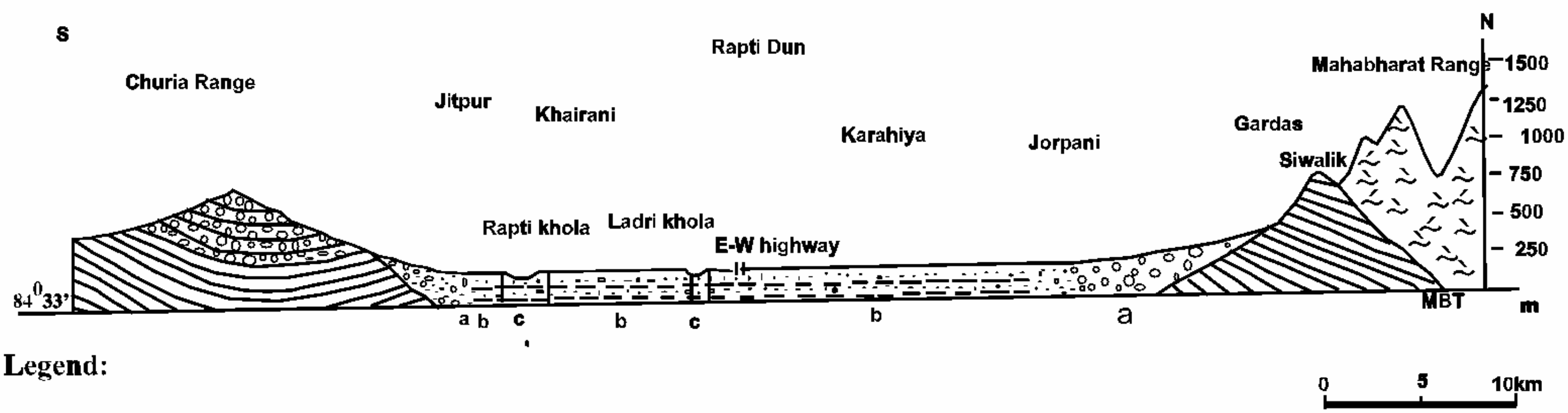
Lower Siwalik consists of thick bedded variegated mudstone with subordinate fine to very fine grained sandstone beds and psuedoconglomerate.

The Lower and Middle Siwaliks occur continuously all along the Himalaya, but the Upper Siwaliks occur intermittently in some areas only. The sediment size increases upwards and becomes conglomeratic in the Upper Siwaliks.

The Siwalik Range, which borders the Rapti valley in the south, attaining to heights of upto 800 m, consists in the east of conglomerates of the upper Siwalik strata, while formations from the lower Siwaliks predominate in the west (Hagen, 1959,1969).To the north of the Siwaliks is the Rapti valley, which steadily widens from east to west. The eastern valley floor is covered by the broad alluvial fans of tributary rivers emerging from the Mahabharat Range.In the west, the floor of the basin consists of alluvial deposits of the Narayani (Haffner, 1979:51f).The yearly monsoon flooding and the frequent migrations of the riverbeds contribute to the continual change in the mosaic-like landscape. In the north, the Rapti valley is bordered by the Mahabharat Range. Positioned in front of it is a mountain range built up from middle Siwalik strata (Hagen, 1969, Fig.91)

Hagen recognized ten natural divisions along a north to south traverse in Nepal Himalaya. Dun Valleys are one of these divisions. These tectonic Dun Valleys are considered to be part of the Siwalik.

The geology and geomorphology of this valley has been studied by few researchers.



Legend:

- Conglomerate of upper Siwalik formation
- Pebbles, Sand and sandstones of the middle Siwalik formation
- Precambrian basement of the lower Himalaya
- alluvial sediments
- alluvial sediments, high groundwater level
- gravels and sediments of alluvial fans

a alluvial fans
b river terraces
c riverbed

MBT Main Boundary Thrust

Sources: Hagen,1969:Fig85,91;Haffner,1979:56;
GoN-map No.35,1:125000;
GoN-geological map No. 72-A-B 1:125000
Graphics: K.Wegner

Fig.5.3Geological Cross-Section of Chitwan Dun Valley

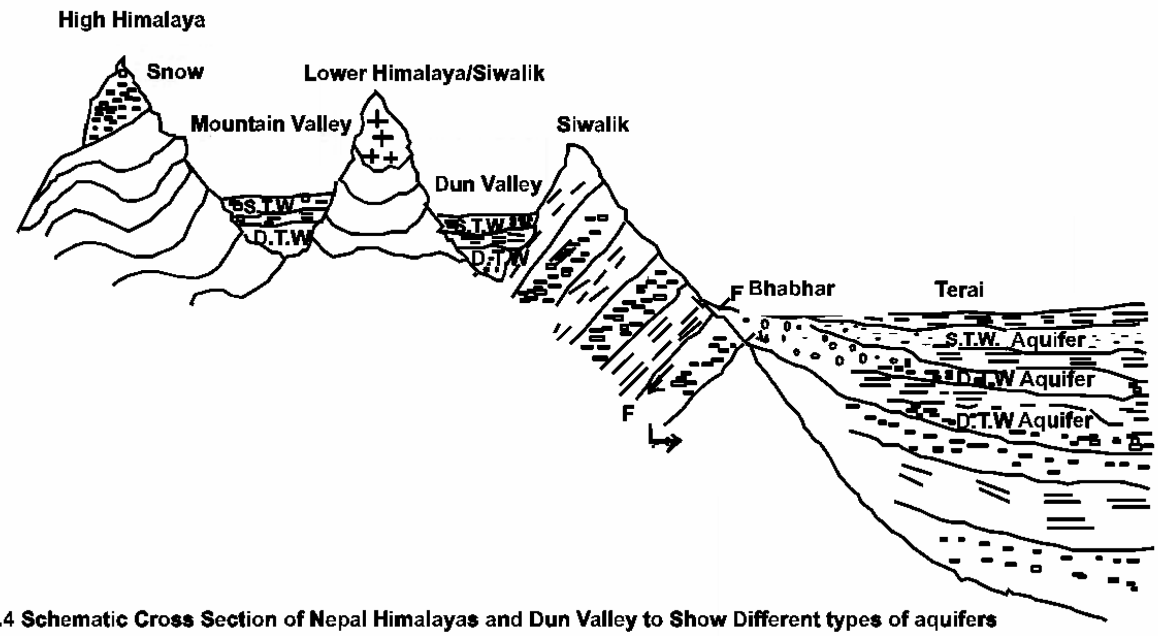


Fig : 5.4 Schematic Cross Section of Nepal Himalayas and Dun Valley to Show Different types of aquifers

Source: C.K. Sharma, 1995

5.5 Geomorphology:

Shuji Iwata and Takashi Nakata in 1985 have done a detailed work on geomorphologic aspect of the Rapti dun, Chitwan in the area around Narayanghat. The river terraces and hill landforms have been surveyed in the Siwalik Mountains around Narayanghat in order to understand the nature of regional crustal movement. They have classified the fluvial terraces in to six groups by air photo interpretation and field survey.

They have found the conclusions that the river terraces around Narayanghat are classified into six groups: the highest, Higher, Middle 1 (M1), Middle2 (M2), Middle 3 (M3), and Lower Terrace groups. The highest and Higher Terrace groups were formed during Pre- Last Interglacial time. The Higher Terrace situated between Jugedighat and Narayanghat is slightly inclined to the north. There exists a hilly area in the Siwalik Mountains. The area is an ancient riverbed of the Kaligandaki and its relative height above the present riverbed attains to 170 m Accordingly, the Siwalik Mountains in the area have up heaved since pre- Last Interglacial time.

Highest Terraces are located at higher places than 150 m in altitude above the present riverbed. Their surfaces are sloping by erosion and covering with scree materials. Red soils occur on them. **Higher Terraces** occupy considerable extent at Kota in the Kali Gandaki and at the left bank of the Trisuli Gandaki near the Kali—Trisuli confluence. The latter shows the morphology of a terraced fan. Small fragments of higher terraces scatter on the higher positions along the valley, shows round ridge- like forms. The higher terraces are covered with red soil, which is about 1 m thick. **Middle Terraces** are subdivided into three groups: from the high M1 terrace group to the low M3 terrace group. Among them the M2 terrace group extensively develops on the upper course from the confluence, but the low M3 terrace groups are better developed than the M2 terrace group below the confluence. On the M3 terraces one can find some irregular topography inferred to the past channels and bars. **Lower Terraces** mainly develop in the dun valley and occupy an extensive area as recent fans.

The relatively fresh topography with brown coloured soil indicates the ages of the Lower Terraces are the Holocene. The dissected topographies and red coloured soil suggest that the Highest and Higher terraces formed during the pre- Last interglacial time. Accordingly, the Middle Terrace groups are likely to be corresponding with terraces formed during the Last Glacial and/ or Last Interglacial time.

Large higher terraces are distributed between Jugedighat and Narayanghat has a weakly reverse sloping surface. Accordingly, this terrace deformation suggests that the uplift of the Siwaliks has persisted since at least pre- Last Interglacial Glaciation in which period the deformed terrace might have been formed.

5.6 Quaternary Geology of the Study Area:

In Dun valleys of Himalayas, Plio—Pleisticene sequences of fluvial sediments are found. The Pleistocene deposits are predominantly made up of coarse materials—gravels and sand. The general thickness Pleistocene loose sediments with Holocene are about 150 m thick. The sediments found are comprised of rock fragments from Siwaliks and are the result of depositional process of the Narayani River. The fluvial deposits include alluvial fan deposits, channel deposits and flood plains of Pleistocene and Quaternary age and are being accumulated to the present day.

Pleistocene sediments of Chitwan Dun has been classified into six groups: the Highest, Higher, Middle (M_1) Middle (M_2), Middle (M_3) and Lower Terrace (Iwata and Nakata, 1984). Referring to the above classification, the present study area falls under Lower Terrace and lower parts of the Middle Terraces.

Middle and Lower Terraces are mainly developed in the Chitwan Dun and occupies an extensive area of sand facies. The relatively fresh topography with brown coloured soil indicates that the age of the Lower Terrace is the Holocene.

The surface geology of the area follows the geomorphic expression of the area.

By the brief investigation has revealed that the stratigraphy of fluvial sediment of the study area can be classified into four formations (Fig 5.5) as follows:

a) The Devghat gravel formation

b) The Bharatpur sand formation

c) The Narayanghat sand formation

d) The Narayani flood plain or alluvium

a) The Devghat gravel formation:

The Devghat gravel formation is well exposed in the northern part of the study area at Ramnagar and Devghat. The thickness of the exposed sediment in this area is about 15 to 20 m. The geology of the formation consists of aquifer materials of boulders, cobbles and pebbles with fine to medium grained red sand. The boulders, cobbles and pebbles are mainly of quartzites and sandstones with rare dolomite, schist and gneisses.

Horizontally laminated pebble-cobble-gravel (facies code, Gh) and trough cross-bedded pebble-cobble-gravel (facies code, Gt) facies are observed around Ramnagar. The latter facies is generally found along the erosional bottom surface. Horizontally laminated pebble cobble-gravel (facies code, Gh) facies may be due to longitudinal bed forms and lag and sieve deposits whereas trough cross-bedded pebble-cobble-gravel (facies code, Gt) facies may be due to minor channel fills (Mial A.D., 1996) . This formation forms the main part of the deep aquifer on the study area.

b) Bharatpur sand formation:

The Bharatpur sand formation is well exposed at Bhojad, Gondrang, Krishnapur, Sharadpur Gauriganj, Kathsikri and Naurange area. This formation consists of the coarse, unsorted brown to grey sand with cobble, pebbles and few boulders. Along the road cut area of Krishnapur, trough cross-bedded coarse grained sand (facies code St) and horizontal lamination parting or streaming lineation (facies code, Sh) facies were observed. The latter facies may be due to plane-bed critical flow (Mial A. D., 1996). Most of the shallow aquifer material of Bharatpur and adjoining area falls under this geological formation.

c) The Narayanghat sand formation:

This geological formation is well exposed the large area around the Narayanghat including the main Bazaar of Narayanghat, Kshetrapur, Lanku, Yangapuri,Kalyanpur , Gulafbagh, Rambag , Gitanagar, Prasnagar , Kesharbagh , around the Kerunga ghol area, Phulbari, , Radhapur ,Sripur, Gopalganj, Mangalpur ,Rampur Gadhichowk ,Barhaghare, Laxmipur, Mohanpur and the area around the Khageri Canal passing through western canal. This formation consists of fine to coarse sand facies (facies code, Sm) with massive or faint laminated sedimentary structures. This kind of facies may be due to sediment-gravity flow deposits (Mial A.D. 1996). Side bars are also observed along banks of the Narayani river.

d) Narayani flood plain or alluvium:

The Narayani River is now flowing through these channels could have cut through the overlying clay aquitard and in some places may be connected with the aquifer by semi permeable materials. The present bed level of Narayani River is 179m in the area. This formation is believed to be eroded and/ or subsided within the flood plain and depressed areas are filled up by Holocene sediments known as the Recent Narayani flood plain or Alluvium. The elevation differences reflected by the distinct landforms: high lands, flood plains and abandoned channels and depressions.The ground surface elevation of the lowlands and abandoned channels and depressions varies the surface datum which makes the area vulnerable to the monsoon flooding.

Although the aquifer in the study area (Narayanghat –Bharatpur-Gitanagar) is relatively homogenous, spatial continuity and the connection of the aquifer with the surrounding Holocene flood plain aquifer is same in nature.It is understood that the hydraulic conductivity of the Holocene flood plain aquifer should be higher than the Pleistocene aquifer due to digenetic differences. At the land surface, Pleistocene alluvium occupies the dissected uplands, and alluvium of recent river—borne deposits or Holocene alluvium covers low-lying flood plains. The area is characterized by thick unconsolidated sequence of fluvial deposits Plio- Pleistocene to Holocene age. The generalized stratigraphy of the area is given in Table 5.1

Since the study area is mainly deposited by fluvial sedimentary deposits, there are various architectural elements of fluvial deposits which directly influenced the hydrogeological parameters such as transmissivity, Hydraulic conductivity, Specific capacity and Yield.Clast rich debris flow, minor channel fills, pebbly bars, transverse bedforms, sediment-gravity flow deposits, overbank, channel and flood deposits are the architectural elements that are common in different places within deep to shallow aquifers.

The sedimentological study within the study area clearly shows the distribution of the sediments therein. Both the areal and vertical extent of the sediment distribution can reveal the extent of the aquifer.

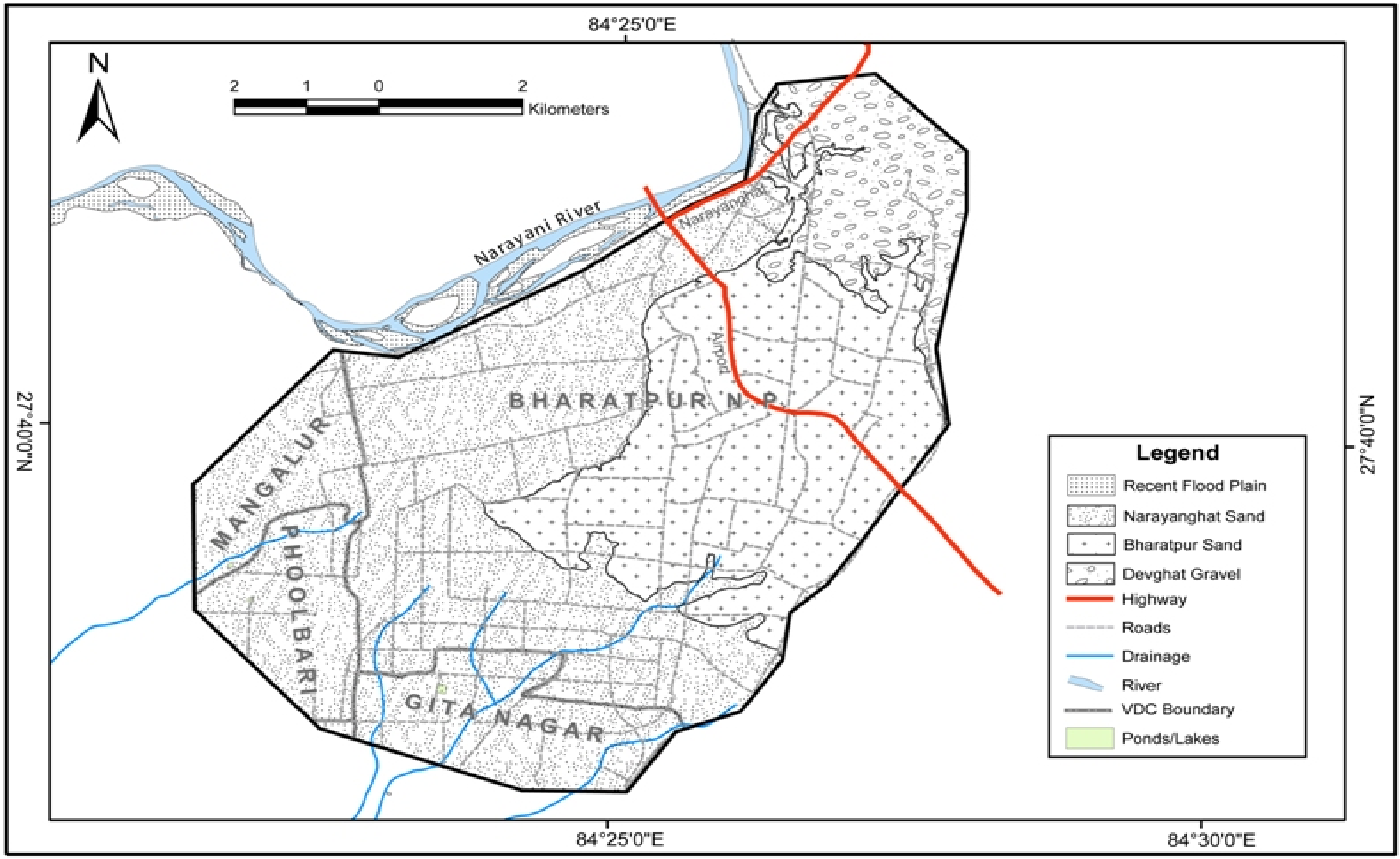


Fig 5.5 Quaternary Geological map around Narayanghat –Bharatpur-Gitanagar Area (modified after Acharya 2000,)

Table 5.1 Stratigraphic profile of the Holocene and Pleistocene Series in the study area (Based on Morris et. al.2003)

Stratigraphic Age	Stage	Stratigraphic Name	Lithology	Depth (m)	Thick-ness(m)	Function in aquifer system
Holocene	Post Glacial Stage	Narayani Alluvium	Swamp, levee and riverbed sediments.	0-5	5	Upper aquitard
		Narayanghat Sand	Fine to coarse Sand	5-10	5	Aquifer shallow
		Bharatpur Sand	Unsorted sediments Boulder/cobble/ Pebble	10-20	10	Aquifer shallow
Pleistocene	Last Glacial Stage	Devghat Gravel	Boulders/cobbles/ pebbles	20-120	100	Deep Aquifer

Table 5.2: Facies classification (Modified from Mial 1978c)

Facies code	Facies	Sedimentary Structures	Interpretation
Gmm	Matrix –supported, Massive gravel	Weak grading	Plastic debris flow (high-strength, viscous)
Gmg	Matrix—supported Gravel	Inverse to normal grading	Pseudoblastic debris flow (low strength, viscous)
Gci	Clast—supported Gravel	Inverse Grading	Clast-rich debris flow (high strength), pseudoblastic debris flow (low strength)
Gcm	Clast—supported Massive gravel	---	Pseudoblastic debris flow (inertial bedload, turbulent flow)
Gh	Clast—supported Crudely bedded gravel	Horizontal bedding, Imbrication	Longitudinal bedforms, lag Deposits, sieve deposits
Gt	Gravel, Stratified	Trough cross-beds	Minor channel fills
Gp	Gravel, Stratified	Planar cross-beds	Transverse bedforms, deltaic Growths from older bar Remnants
St	Sand, fine to very coarse, may be pebbly	Solitary or grouped trough cross-beds	Sinuous- crested and linguoid (3-D) dunes
Sp	Sand, fine to very coarse, may be pebbly	Solitary or grouped Planar cross-beds	Transverse and linguoid bedforms (2-D)
Sr	Sand, very Fine to coarse	Ripple Cross-lamination	Ripples (lower flow regimes)
Sh	Sand, very fine to coarse , may be pebbly	Horizontal lamination Parting or streaming Lineation	Plane-bed flow (critical flow)
Sl	Sand, very fine to coarse, may be pebbly	Low-angle (<15^0) Cross-beds	Scour fills, humpback or washed- out dunes, antidunes

Ss	Sand, fine to Very coarse, may Be pebbly	Broad, shallow scours	Scour fill
Sm	Sand, fine To coarse	Massive, or faint Lamination	Sediment-gravity flow deposits
Fl	Sand, silt, mud	Fine lamination, Very small ripples	Overbank, abandoned channel or waning flood deposits
Fsm	Silt, mud	Massive	Back swamps or abandoned channel deposits
Fm	Mud, silt	Massive, desiccation Cracks	Overbank, abandoned channel or drape deposits
Fr	Mud, silt	Massive, roots, Bioturbation	Rootbed, incipient soil
C	Coal, carbonaceous Mud	Plant, mud films	Vegetated swamp deposits
P	Paleosol carbonate (calcite, siderite)	Pedogenic feature, Nodules, filaments	Soil with chemical precipitation

It is assumed that initially the rivers have the valley with their deposits and created broad plains. Afterwards, changes in conditions have caused the streams to erode into their own deposits, thus carving out a sequence of terraces of different levels.

5.7 Sub-Surface Geology of the Study Area:-

The sediment distribution in the area is relatively uniform and homogeneous (Fig 5.10).The depth of these deep tubewells ranges from 40 m to 126 mbgl respectively.Generally sediment distribution is influenced by local river effects. All these deep tubewells are situated at the elevations of between 184 m to 210 m above mean sea level. In general, the most permeable portions of the Dun valley sediments are the coarse fractions are confined to the northern part which gradually changes to finer sediments towards south. In the northern part of the area there are places where boulder and hard formation is predominantas at Bharatpur.At most of the area predominance of sand and boulders constituting more than 80% of total sediment. They form thick layers in most of the places. Drilling is quite difficult due to presence of hard and large size of boulder formation.

The subsurface lithology is composed of clastic sediments like boulder, cobble, pebble, gravel, sand with intercalation of clays as well as detritus materials of quaternary age. There is relatively uniform distribution of sediments in the underlying alluvial deposits and the sequence shows a little change in lithology from place to place which may be due to fluviatile origin.

5.7.1 Interpretation of Lithological cross-sections:-

The lithoogical cross section in different profiling are prepared and described. Altogether three lithological cross sections are prepared. Based on these cross-sections, variations of these subsurface sediments are described as under (Appendix-6):

a. Lithological Cross-Section along W-E (I-I')

Along this profile, deep tubewells of Rampur, DTW-11 (Rambag), DTW-1 (Torikhet), DTW-2 (Parasnagar) and shallow tubewells at STW-3 (Rambag), UN-07(Narayanpur), UN-08(Prembasti) and STW-2 (Parasnagar) are included. The topographic elevation of the land surface ranges from about 184 m to 210 m.amsl. (Fig. -5.6) .The depth of these deep tube wells varies from 53.6 mbgl at Torikhet (DTW-1) to 75 mbgl at Rambag (DTW-11). The main lithology along this profile comprises of good aquifer sediments like gravel, pebbles, cobbles, boulders and coarse sand. There is a homogenous distribution of sediments from west to east throughout the section. No clay horizons are observed in this section except at top 2 to 3 m layers in few wells. In the upper 2m to 5m section, it consists of top soil to fine sediments like fine to coarse sands. The lowermost section of the profile is at Rampur, the western part of the area while uppermost part of the section is lies at around Narayanpur – Torikhet- Rambag area in the middle part of the section. The percentage of impermeable fractions of sediments like clay, silt, silty clay, sandy clay and gravelly clay to permeable sediments are negligible in the whole area. It cuts almost the southern part of the study area. The thick layers of boulders, pebbles, cobbles, coarse sand bouldery gravel sediments are predominant lithology in this section.

b. Lithological Cross-Section along NE-SW (II-II'):-

It extends from northeast to southwest direction (Fig 5.7) along the parallel course of Narayani River. The section of the profile consists of five deep tubewells and only one shallow tubewells. The land surface elevation varies in range from 194 masl at Rambag to 210 masl at Bhojad. The depth of the deep wells varies from 53.6m to 126 m from ground surface. The distribution of sediments is homogenous and is more or less uniform throughout the section. Good aquifer materials such as gravel, boulders, pebbles, cobbles and coarse sand are the main lithology. At Bhojad, at the depth of 109 m from ground surface a lithology of conglomerate with very hard rocks is encountered. In this profile the upper 2 to 10 meters depth from ground surface it consists of fine to coarse sand with top soils. Beyond this depth from ground surface the whole sequence of sediments are coarser fractions of dun valley sediments are homogenous and uniform throughout the depth of 120 m from ground surface. The thick layers of boulders, pebbles, cobbles, coarse sand bouldery gravel sediments are predominant lithology in this section. The percentage of impermeable fractions of sediments like clay, silt, silty clay, sandy clay and gravelly clay to permeable sediments are negligible in the whole area

c. Lithological Cross-Section along N-S (III - III'):-

Altogether five deep tubewells and one shallow tubewell are included along this profile. (Fig 5.8) They are as follows: Bhojad (DTW-13), Kataharchowk (DTW-8), Cancer Hospital (DTW-9), Cancer Hospital (DTW-10), Parasnagar (DTW-9) and Parasnagar (STW-2) .The topographic surface elevation of the wells varies from 193masl to 210masl along this profile. The depth of the deep wells varies from 70m at Cancer hospital to 126 m at Parasnagar from ground surface. It cuts the middle part of the study area along the north south direction. This section also shows the same lithological composition as coarse fractions of Dun valley sediments like boulders, pebbles, cobbles, coarse sand gravel etc. At Bhojad, at the depth of 109 m from ground surface a lithology of conglomerate with very hard rocks is encountered in the northern part of the section. The thick layers of boulders, pebbles, cobbles, coarse sand bouldery gravel sediments are predominant lithology in this section. The percentage of impermeable fractions of sediments like clay, silt, silty clay, sandy clay and gravelly clay to permeable sediments are negligible in the whole area. The distribution of sediments is relatively homogenous and uniform throughout the section. The sediment distribution pattern in the area is given in Fig 5.9.

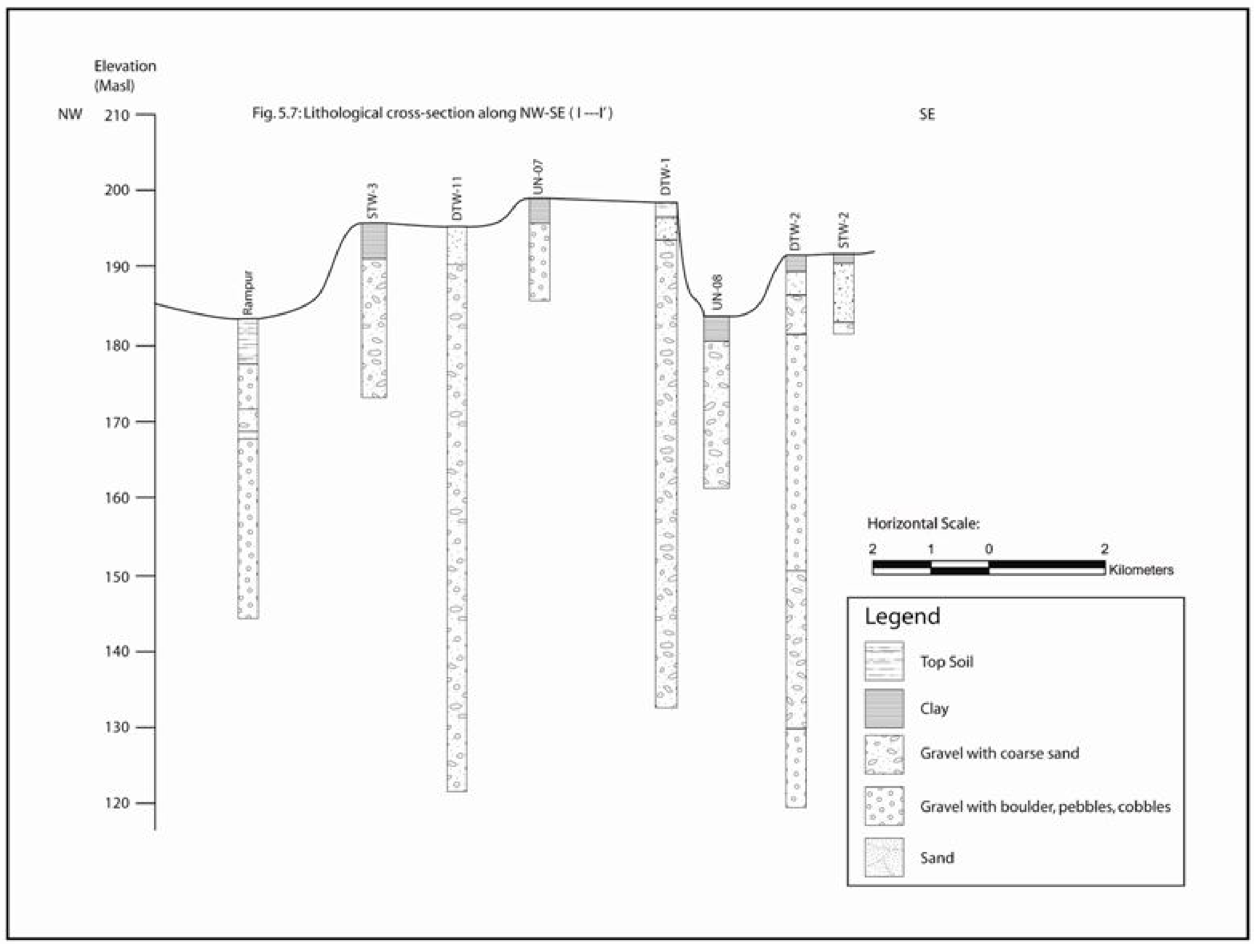


Fig: 5.7 Lithological Cross Section along W-E (I-I')

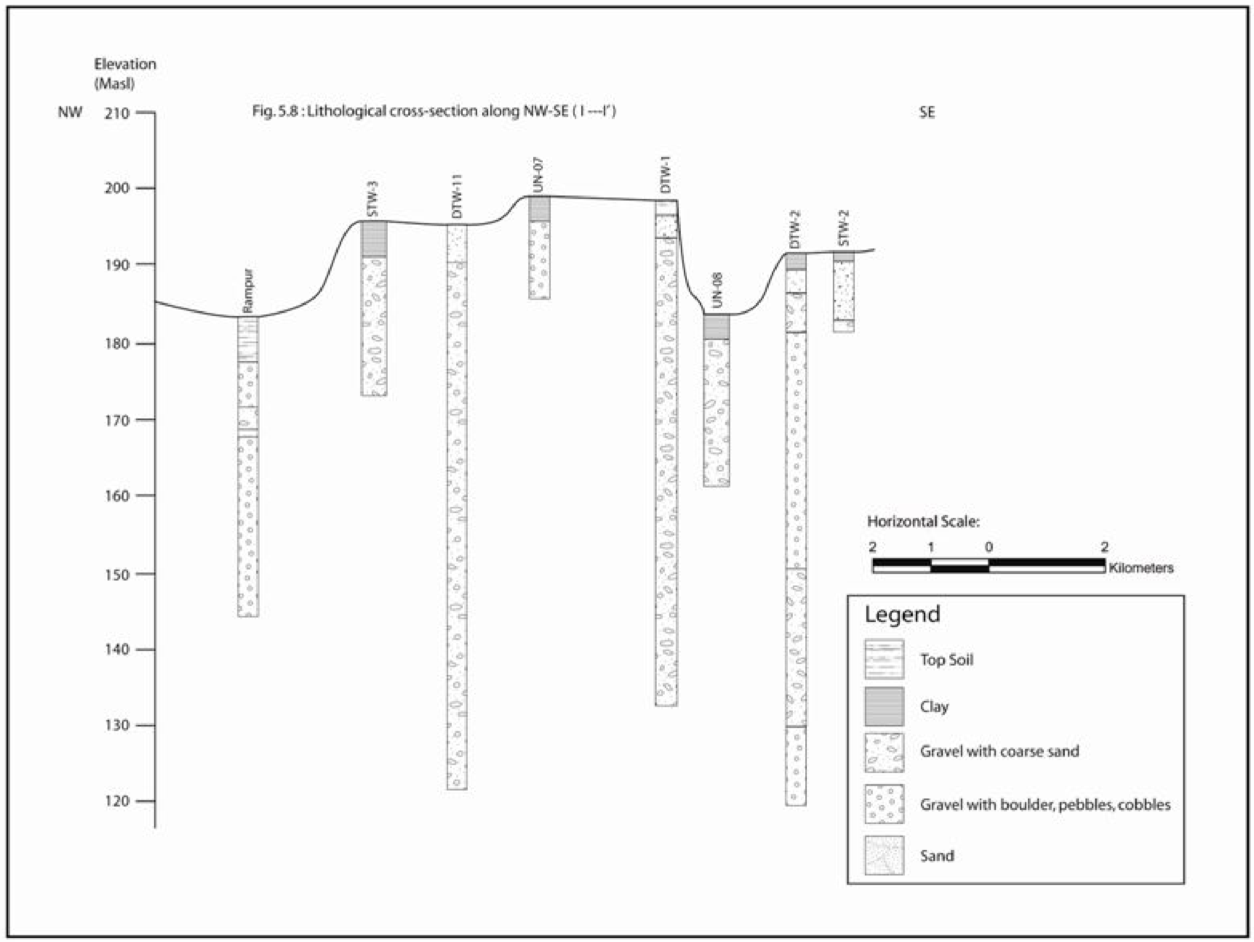


Fig: 5.8 Lithological Cross Section along NE-SW (II-II')

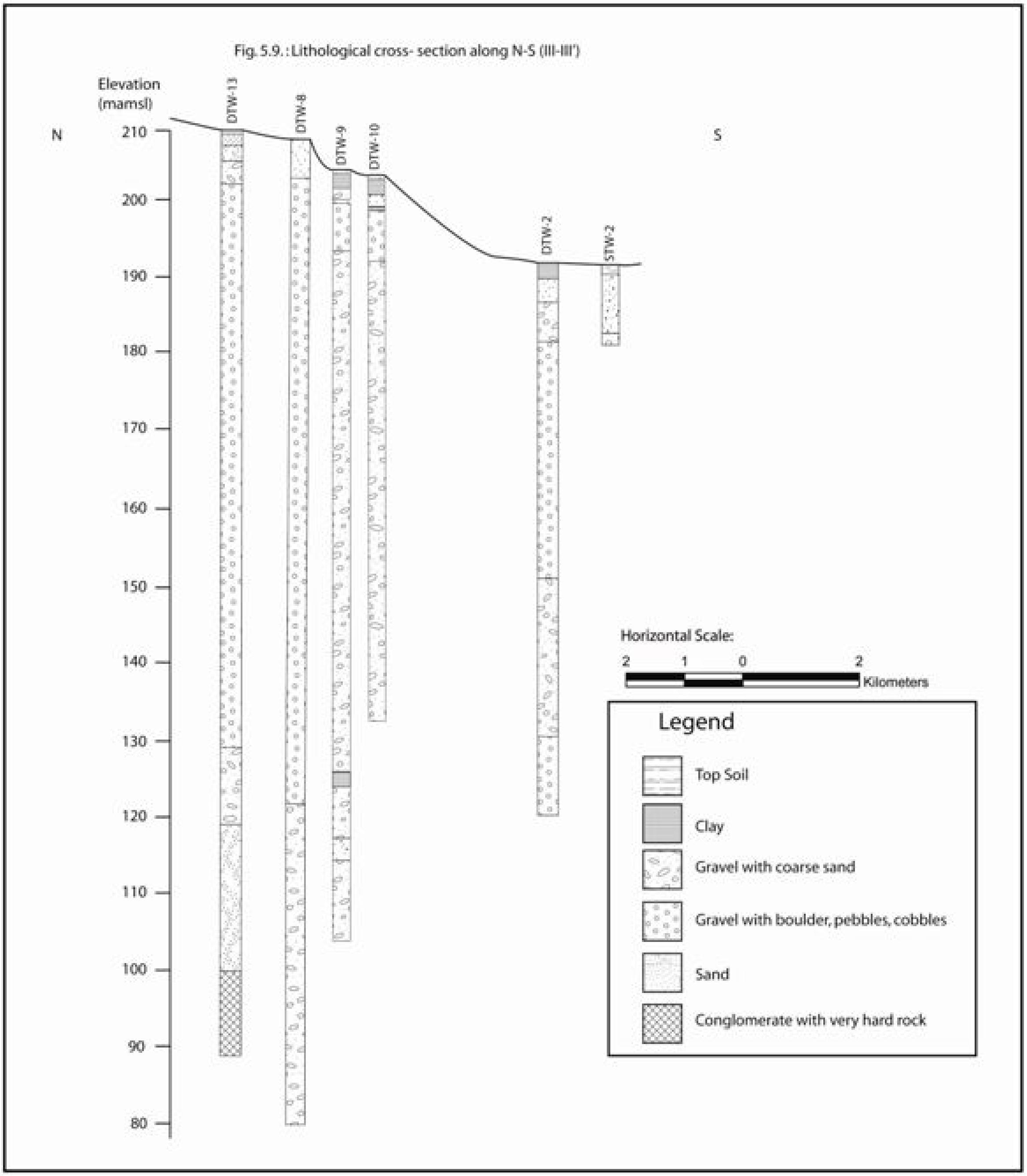


Fig 5.9 Lithological Cross Section along N-S (III-III')

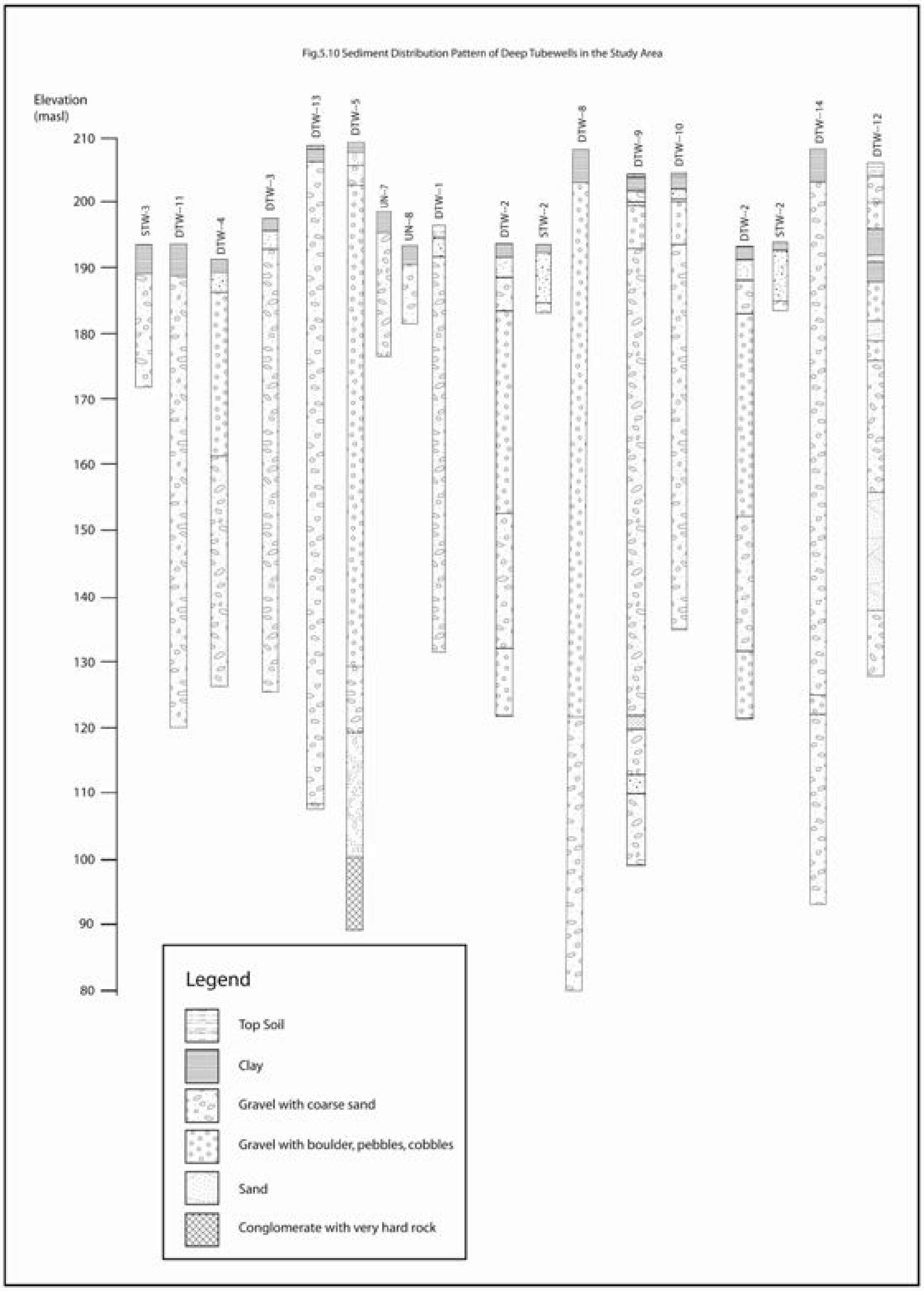


Fig 5.10 Sediment distribution pattern in the study area.

5.8 GEOPHYSICAL STUDIES:

Table 5.3 Approximate Ranges for the resistivity of sedimentary rocks

Resistivity and lithology

Resistivity(Ohm-m)	Lithology
< 50	Clay,Silt
50-100	Silt,Sand
100-250	Sand, Gravel
250-500	Gravel,Pebble
500-2000	Boulder,Cobble,Pebble
>2000	Boulders, Cobbles, Pebblesetc. (above water table,) Bed Rock

During study period, 26 VES field data were collected from GWRDB. Log log plot of apparent resistivity against AB/2 were made. The variation of the field curve from smooth curve is the noise. So these noises were filtered out and the final data were analyzed using computer software. Noise is the result of bad electrode contact.

The information obtained after analysis of all VES data are used to prepare the lithological sections and to understand the groundwater potential of the study area. The lithological sections are discussed below.

5.8.1 Geophysical Studies on the Area

In 1996, a geolectrical survey was carried out for the investigation of ground water potential for shallow and deep aquifers by GWRDB. In this survey there were altogether 111 Nos. of soundings were made. Field soundings data of apparent resistivity were adjusted for the longer potential electrode spacing using the RESIX PLUS Software and the resulted data were used for computer map preparation. Among these 111 nos. of VES stations total 26 stations were in the present study area (Table 5.4). They were the following:

1. VES- Station – No—27—Lanku
2. VES- Station – No—28—Kalyanpur
3. VES- Station – No—29—Sharadanagar—1 N
4. VES- Station – No—30—Sharadanagar—5 S
5. VES- Station – No—32—Rampurbazar
6. VES- Station – No—41 –Gitanagar–
7. VES- Station – No—43—Shivanagar--5
8. VES- Station – No—44—Kiranganj—Sharadanagar--8
9. VES- Station – No—45—Sripur

10. VES- Station – No—46—Narayanpur, Bharatpur--14
11. VES- Station – No—47—Laxmipur, Bharatpur--6
12. VES- Station – No—48—Dhaddighari, Mangalpur--6
13. VES- Station – No—50--Ramnagar
14. VES- Station – No—51--Baseni
15. VES- Station – No—53—Naughare, Bharatpur--4
16. VES- Station – No—54—Sharadpur , Bharatpur--9
17. VES- Station – No—55-Gitanagar--1
18. VES- Station – No—59--Baruwa
19. VES- Station – No—60—Gauriganj--8
20. VES- Station – No—61--Barandabhar
21. VES- Station – No—71—Gondrang E
22. VES- Station – No—72—Gondrang W
23. VES- Station – No—73—Gondrang ,Bharatpur—12
24. VES- Station – No—75—Bhojad, Bharatpur
25. VES- Station – No—76—Gondrang jungle
26. VES- Station – No—110—Mohanpur, Mangalpur

VES—27 Lanku and VES—28 Kalyanpur lies in the western part of the study area. The VES result shows that high resistivity value indicating coarser sediments gravel, boulders and coarse sand. A single layer of gravel of 55 m thickness has revealed in Kalyanpur. At Kalyanpur a 60 m depth deep tubewell has been installed by ADPJ in 1993. (Fig 5.10) Another deep tubewell of 74 m depth has been installed by ADPJ in the same year at Lanku. Dry boulders and top soil have high resistivity values.VES-29 and VES—30 lies at Sharadanagar—1 and –5 north and south which are south west part of the study area. The lithology in this area is boulders, pebbles/ cobbles, coarse sand, gravel etc. In south a single layer of 81 m thickness of pebbles/ cobbles is present. No finer sediments layers are present in this area.

The VES—32 Station lies in Rampurbazar the south – western part of the study area. Dominant subsurface lithology resembles gravel and coarse sand. No fine sediments like clay and silt layers are present. A Deep Tebewell by ADPJ lies in Rampur agri. Campus. VES—41 and UN--06 lies in Gitanagar. In this area low resistivity value indicates predominance of fine sand. VES –43 lies at near west of Gitanagar. Resistivity value indicates dominance of coarse sediments like coarse sand. In Parasnagar area there are many shallow tubewlls installed privately for irrigation by farmers. One deep tubewell of 70 m depth has been installed by ADPJ in 1993. A thick single layer of coarse sand of 90 m present in this station. VES –44 lies in Kiranganj - Sharadanagar between Sharadanagar north and south. Low resistivity value indicates dominance of finer sediments. VES—45 and VES—46 lies at Sripur and Narayanpur at the central part of the study area respectively. Resistivity value indicates the dominant lithology is coarser sediments like gravel, boulders, cobbles/ pebbles etc. UN—07 of the depth of 14 m lie in this location. Two deep tubewells has been installed at Torikhet---54 m depth, at Rambag –75 m depth.

VES—47, VES-48 and VES—110 lies at Laxmipur, Dhaddighari and Mohanpur respectively. As these stations are closer to the recent Narayani flood plains the dominant lithology is boulders and gravel, the coarser materials according to the resistivity values. A high thickness layer i.e. 129 m thick single gravel layer revealed at Mohanpur station. VES –50 Ramnagar and VES—51 Baseni lies at northern part of the study area. The resistivity values at Baseni shows the presence of coarser materials while at Ramnagar the major lithology dominants boulders, pebbles/ cobbles etc. VES---53 and VES—54 lies at Naughare and Sharadpur area of Municipal area. Naughare lies at the left bank of Narayani River and Sharadpur lies at Bharatpur area. Resistivity values in both stations dominant coarser materials like boulders, pebbles/ cobbles etc. coarseness increases to the Narayani River. VES—55, VES—59 and VES—60 lies at Ujjelinagar, Gitanagar—1, Baruwa and Gauriganj—8 at the southern—eastern part of the study area. Resistivity values in Ujjelinagar and Baruwa are same i.e. dominantly finer sediments at shallow depth and gravel in deep layers. While at Gauriganj dominant lithology is coarser sediments in both shallow and deep aquifers.

VES—61 and VES—71 lies at Barandabhar forest area and Gondrang area respectively. There are many wetlands as lacustrine types are present in Barandabhar forest. The famous Bishazari and other associated lakes lie here. The result of resistivity suggests presence of sand pebbles/ cobbles etc. are the dominant lithology. A single layer of 170 m depth layer of coarser materials present here. At Gondrang station dominant lithology is sand. There is one deep tubewell at CocaCola factory and one UN—09 located here. VES—72 and VES—73 stations lies at Bharatpur—12 at north east part of present study area. Resistivity survey results indicate that there is same type of lithology present in both stations. The dominant lithology is gravel, sand coarse to fine the sand dominant area. .VES—75 located at Bhojad, Bharatpur. There are many deep tubewells in this area by Municipality, Nissaku Company, DWSS etc. High resistivity values indicating the dominant lithology is coarse sand and boulders, pebbles/cobbles etc. Deep tubewells at Hakimchowk, Kataharchowk, Hotel Safari Narayani, Municipal complex proves the resistivity value of the same type as revealed by borehole geophysical logging records. There are two deep tubewells at Cancer Hospital.

The area Sharadnagar—Rampurbazar—Dhaddaghari VES No 30-32-110-48 is marked by high resistively values (0ver 400 ohm meter). This maybe due to the presence of dominantly

Table: 5.4 VES Data Analysis Result

The results of Partial Curve Matching of twenty five field curves are given below:

Sounding Station	Resistivity Ohm-m					Thickness/ Depth in , m			
	ρ 1	ρ 2	ρ 3	ρ 4	ρ 5	h 1	h 2	h 3	h 4
VES—27-Lanku	8322	2802	503	----	---	2	17	---	----
VES—28—Kalyanpur	1190	6874	170	542	475	2	4	7	55
VES—29—Sharadanagar	7177	483	1054	232	---	2	11	81	--
VES—30—Sharadanagar	1550	668	350	---	---	1	55	--	--
VES—32—Rampurbazar	755	224	348	493	326	1	6	31	52
VES—41—Gitanagar	2110	668	102	599	--	3	75	112	--
VES—43—Shivanagar	1440	491	371	285	---	2	16	90	--
VES—44—Kiranganj	124	28	89	345	--	1	2	16	---
VES—45—Sripur	3457	173	741	88	--	4	34	108	---
VES—46---Narayanpur	3064	2169	83	1787	293	1	8	30	64
VES—47—Laxmipur	1094	3315	451	----	----	5	14	---	----
VES—48---Dhaddighari	346	96	9650	133	---	1	3	7	---
VES—50—Ramnagar	4891	809	1768	34	244/48	1	2	16	28/48
VES—51---Baseni	1822	968	274	1240	249	2	9	36	54
VES—53—Naughare	1848	465	1923	245	3981	1	3	10	125
VES—54-Sharadpur	1200	2537	183	2018	375	2	13	22	39
VES—55-Ujjelinagar	1193	49	45	256	6609	1	12	27	212
VES—59 –Baruwa	1089	244	68	482	----	2	9	44	---
VES—60-Gauriganj	665	229	622	300	1425	2	10	37	210
VES—61—Barandabhar	164	41	125	707	132	2	13	62	170
VES—68---Khagerinahar	82	22	130	32	1089	4	10	20	46
VES—69----Tikaulijungle	47	267	66	362	----	1	2	44	----
VES—71—Gondranj I	54	143	74	251	---	1	8	37	--
VES—72---Gondrang II	137	29	109	409	--	2	13	70	---
VES—73---Gondrang III	2910	725	74	271	---	1	3	36	---
VES— 75—Bhojad--	1060	454	14	202	1337	3	12	20	186
VES— 110—Mohanpur	1515	4305	468	274	---	2	6	129	---

(Source: GWRDB, 1996)

Gravels (boulders) compared to adjacent area in the south –west to north-east. But in the junction of Devghat-Narayanghat by pass road just below the road section there seems to be a confinement of spring lines. This reveals that two different kinds of layers of lithology intermixing each other forming spring line. The water level in these wells appeared at the top level of the topographic surface.

The area around Narayanghat-Gitanagar-Laxmipur or VES No- 41-46-47 is marked by high value and widely spaced contours. On either side of this area, contour values decreases outwards. The deposition here may consist of dominantly of gravels in the north-east (Gondrang-Bhojad area). But to the South –west there maybe gravels to sands.

The east of Barandahar or VES No 61 is characterized by smaller values (<260 ohm-m) indicates the presence of finer sediments and larger spacing between contours suggest that uniform lithology in lateral direction.

The area west of Barandabhar or north of Dhaddighari –Sripur or VES No. 48, 45 is marked by high values and dense contours. This is the indication of presence of more coarse sediments (Gravels, pebbles etc.) with rapid change in coarseness of sediments in lateral direction. The contour values and its density diminish as we go deeper which suggest that finer sediments present dominantly with more uniform distribution at greater depth.

South of Kiranganj-Rampurbazar-Dhaddaghari or VES No. 44-32-48 contours reach higher values. This indicates that more coarse sediments are present dominantly in this area compared to adjoining areas. The high value contours shift in N-E Indicating shift in deposition of coarser sediments. This may indicate presence of bedrock which can be verified by drilling (Appendix-5)

5.8.2 Hydrogeology:

Hydrogeology in the northernmost part around Ramnagar

Top layer consists of gravels from west to east Gondrang area and dominantly sands everywhere. The layer thick ness varies from about 10m in the west to about ascending order in the east. The underlying section consists of layers of clay, sand, gravels etc.

This section shows that there is fairly good potential for ground water deep aquifer. The water table may however be fairly deep due to presence of very coarse materials at the top of the aquifer.

Hydrogeology of Dhaddighari- Ramnagar area:

It is subparallel course of Narayani River. the lithology here is influenced by the sediment load brought and deposited by this river.

Here is presence of high resistivity in the top layer. The high resistivity (>2,000 ohm-m) indicate rather dry materials due to deep Water table and very coarse sediments like boulders etc. throughout the area. The underlying layer is marked by the resistivity of the order of 200-600 ohm-m .This layer is mainly composed of gravels and extends down to about 30m depth in the south and 60 m in the northern part. The layer underneath this is marked by low resistivity(<200 ohm-m) in the southern part (South of Sharadnagar) and high resistivity (>200 ohm-m) in the north. This variation in resistivity values suggest that lithologically the southern part consists dominantly of sands and northern part consists of dominantly of boulders, gravels.

Because of presence of dominantly coarse sediments (Gravels, boulders) throughout in this section, the water table is expected to be deeper here. The groundwater potential is seems to be fairly good both for deep as well as shallow depths. Comparatively the groundwater potential is better in the south as compared to the north.

Hydrogeology around Gitanagar- Parasnagar area

Kerunga ghol is flowing from northward to southward direction. Top layer contains gravels in the south of Ujelinagar. The area is marked by moist soil and or sand. The north of Ujelinagar is dominated by sand. The depth of this layer varies from about 60m near Devnagar to shallower in the north.

The underlying layers show that alternating layer of gravels dominant and sand dominant ones. The layers show dipping trend towards south.

In the central portion of this section, water table is at shallower depth. It is easy for drinking water by using hand pumps. No dug wells need for drinking purpose. In Gitanagar area water table is at nearer to the surface but in Parasnagar and Kesharbag area it is beyond the suction capacity of Hand pumps.

The top layer consists of gravels in Baruwa, Ghumti, Kesharbag, and Parasnagar area.

The underlying layers are of the gravels as it is marked by high resistivity. Due to the presence of dominantly gravels, the water table in the west is expected to be deep compared to eastern part. The aquifers are present both at the shallow as well as deep aquifer.

5.8.3 Groundwater Resource Potential

Based on the above discussion of the hydrogeological sections, the survey area can be divided into various parts depending upon the type of lithology present.

The area in the east of VES No 60-76 or east of Gauriganj-Gondrang area is different from the western part in terms of lithology of deposited sediments. In this part top gravel, layer may exist to about 10m from surface. Finer sediments like sand, silt etc. and or gravel mixed with clay/ silt is present in the underlying layers as exhibited by lower resistivity values.

Plate 3: Construction of Shallow Tubewell by Sludge Method at Kesharbag

In the western part of the survey area, the northern part is marked by the presence of dominantly coarse sediments (like gravels, boulders etc.) in the top as well as underlying layers.

The presence of comparatively thick gravel deposits in adjacent to Narayani River indicate that the sediment deposition here is influenced by these rivers.

Shallow aquifers may exist mainly in the southern part east of Gauriganj-Gondrang- and south-western part of the survey area. In these areas the water table lies at shallow depth i.e. within the suction capacity of the centrifugal pump. In the western part close to the Narayani River, as the gravels (even boulders) are present dominantly, the Water table may go rather deep for the centrifugal pump to be used successfully. In the northern part, however, the presence of clay with gravels makes the area less potential for shallow aquifer. The western and northern parts the shallow ground water potential is low. Geophysical logging and Well designs of ADPJ Deep Tubewells are presented in Appendix A-ii.

VI. HYDROLOGY AND HYDROGEOLOGY

6.1 Hydrology of the Narayani River Basin:

The area of Narayani River basin is of about 31,100 km^2 in central Nepal above the confluence of the two major tributaries, the Kaligandaki and the Trisuliganga. The main stream is the Kaligandaki River flows from Mustang. The river enters into the Inner Terai plain about 3 km downstream therefrom. It has an abundant streamflow. Its annual average runoff amounts to about 1,500 m^3/sec equivalent to around 50 BCM per annum. The catchment of 90% area lies in the Nepalese territories.Major tributaries are the Trisuli, Marsyandgdi, Seti, Budhi Gandaki, Madi, Chepe, Daraudi and Kali gandaki etc.

The basin characteristic is as follows:

Basin Area:--31,100 km^2 at Narayanghat

Basin length: -300km

Recorded Discharge: - 15,400 m^3/s

Mean Basin Elevation:-3000m

Elevation at Narayanghat: - 179m

Plate 4 Saptagandaki (Narayani) River flowing at the confluence of Devghat

Catchment area in Nepal:-25766km^2 (at Narayanghat)

In China:-5334km^2

Snow covered area in the basin: 6,900 km^2

Minimum daily flow: 156 m^3 /s

The maximum daily flow: 22,500m^3/s

The ratio of maximum and the minimum daily flow: 133

(Source—Department of Hydrology & Meteorology)

Water quality of Narayani River at Narayanghat:

Quality of surface water and groundwater is one of the major aspects essential to be carried out. Determination of the physical, bacteriological and chemical quality of water assesses the suitability of water for various purposes like drinking, domestic, industrial and agricultural.

Excess of the chemical constituents like chloride, fluorite and iron in water indicates pollution. Excess of salts in water harms the agricultural product and excess of salinity, hardness and silica contained in water, if used for industrial purposes reduces life of the automobiles. Besides this study of water quality helps in interpreting the geological environment source direction and movement of groundwater recharge discharge relationship, climatic influence, presence of ore bodies etc.

The physical quality of water includes temperature, colour, turbidity, odour, and taste. The chemical quality of water involves pH, Electrical Conductance, Chlorides, Bicarbonates, Total hardness, Calcium, Magnesium, Iron, Sulphate, Sodium etc.

The water quality data of Narayani River studied by DHM is shown in following table:

Table 6.1: Water Quality of Narayani River at Narayanghat

Parameters	Units	Average value	Safe limit
Conductivity	µs/cm	217	1500*
PH	---	7.1	6.5—8.5*
DO	mg/l	7.5	>5
Hardness (Caco$_{3)}$)	Do	79.6	500*
NH_4__N	Do	0.6	1.5*
NO_3___N	Do	1.7	50*
NO_2__N	Do	2.4	1
Cl	Do	3.4	50
Fe	Do	6.5	250*
Coliform	Do	0.5 > 1200	0.3* 0

***National Drinking Water Quality Standard, 2007**

(Source: DHM, Government of Nepal)

6.1.1 Run off Characteristics of Narayani River:

A study of the annual hydrographs of Narayani River (Fig.6.1) shows this river to be the perennial river in which there is considerable amount of groundwater flow throughout the year. Even during the dry season the water table will be above the bed of the stream. The

Plate 5: Automatic Gauge recorder on Narayani River at stationno 450, Ferry

flow duration curve is plotted on the basis of Annual Discharge data for the years 1963-2006 on Appendix-12. The seasonal variation of rainfall is clearly reflected in the runoff. High stream discharges occur during monsoon months (June-September) and low flow which is essentially due to base flow is maintained during the rest of the year. The annual runoff volume (yield) of a stream is mainly controlled by the amount of rainfall and evapotranspiration. The shape of the storm hydrograph and hence the peak flow is essentially controlled by the storm and physical characteristics of the catchment. The geology of the catchment is significant to the extent of deep percolation losses.

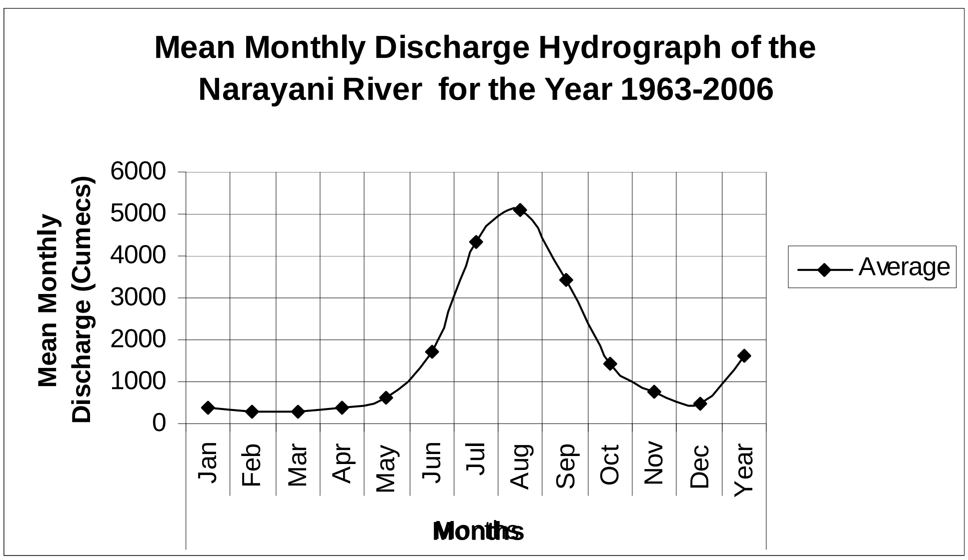


Fig.6.1 Mean Monthly Discharge Hydrograph of the Narayani River, from 1963-2006.

6.1.2 Precipitation Analysis:

Rampur rain gauge station provides data of daily rainfall analysis from the year 1971-2006. The available data are used for rainfall analysis. The monthly rainfalls of the year 1971-2006 are determined by adding the daily rainfall of the entire month. The monthly rainfall data for these periods is presented in Appendix-2. The monthly rainfall curves are shown in Fig 6.2, the maximum rainfall occurs during June and September each year. The mean monthly rainfall (MMR) is average of the total rainfall of (1971-2006) i.e. 36 consecutive years that occurs within a particular month it is shown in the last row of table. With the help of MMR normal, abnormal and draught month of the year were defined.

Rainfall data analysis provides an estimate of future rainfall trend that determines the rainfall intensity and occurrence of flood producing storms (Fig 6.2). The estimation of mean monthly rainfall is very important for studying the rainfall variation with respect to the month of a particular year. Similarly, the occurrence time and rainfall distribution during different months of the year is also dealt with the mean monthly rainfall amounts. In addition it is also helpful for assessing the quality for irrigation and hydropower generation projects.

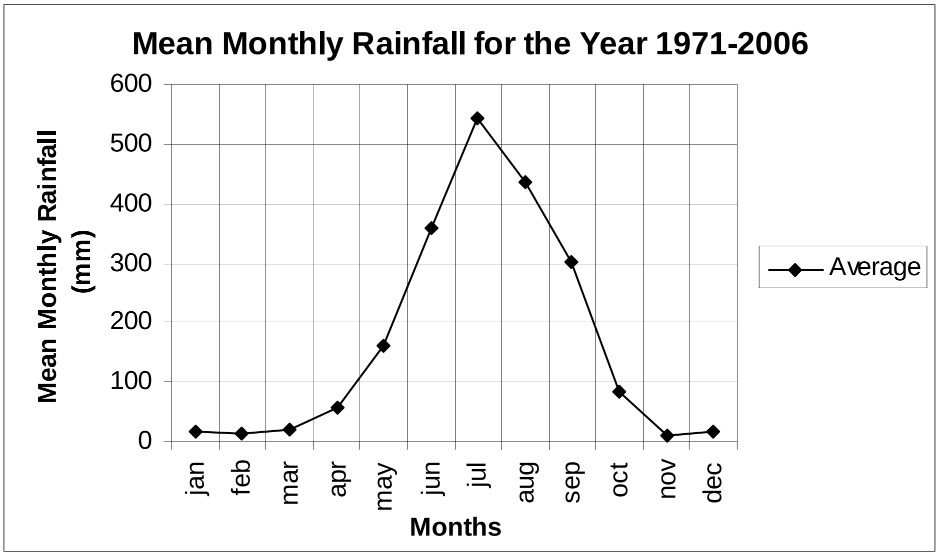


Fig 6.2.Mean Monthly Rainfall for the year of 1971-2006

6.1.3 Recent shifting trend of Narayani River

Just after crossing the Mahabharat Range, the Trisuli and Kaligandaki River's confluence at Devghat, and forms the Narayani River. The River takes an eastward course from Devghat. While reaching Narayanghat, the River follows the southward trend (Fig 6.3). There is a sharp bend at Mangalpur and then flows in the westward direction. The bend displays a contrasting sharpness. On the other hand, the land use information from the map and imageries show several parallel depressions that could be part of an abandoned channel. There is a distinct depression close to the western end of the Barandabhar forest. Similarly, the remnant of past river course are also observed at Gitanagar, where they are known as the Gitanagar Ghol. Another distinct depression begins at the western part of the Lonkhu Tandi and continues upto Sukranagar and the Rapti River. The areal distance from the first eastern depression to the present river channel is over 32 km. Present river also has various braided channels are extending to the western part close to the Nawalparasi district, where the channel is 10-12 km wide. Every year, eastern Nawalpur faces an acute flooding problem, indicating the westward shifting trend of the Narayani River.

The westward migration of the Narayani River near the Bharatpur Municipality and the western margin of the Mangalpur VDC were detected from the study of satellite imageries (Dongol et. al).

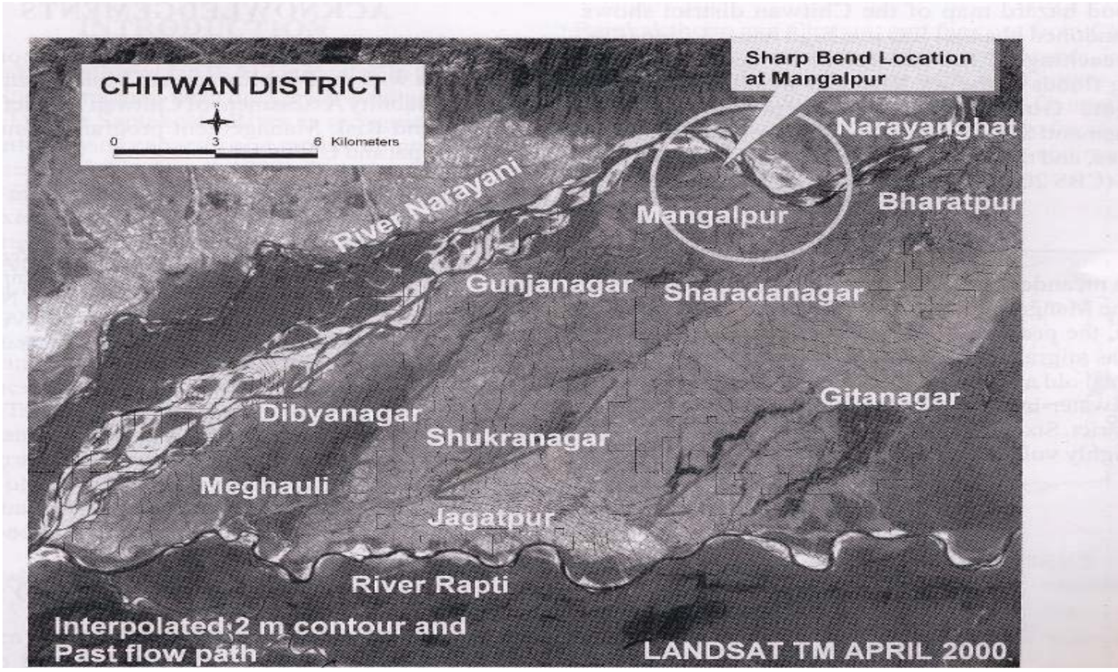


Fig 6.3 Parallel alignment of depressions in west Chitwan (Dongol , 2004)

6.1.4 Formation of Lakes, Marshes and Wetlands in Chitwan Dun

Plate 6: Kerunga Ghol flowing southwards at Gitanagar

Rivers, oxbow lakes and marshes are the major types of wetland in Chitwan district. Narayani, Rapti and Reu are the major rivers and Devi Tal, Lami Tal, Tamar Tal, Munda Tal are the major lakes found in the surroundings of National Park area. These lakes are situated in the left bank of the Rapti River. Other oxbow lakes and wetlands are: KabreTal, Dhakre Tal, Kamino Tal, Laxmi Tal located at the adjacent to the Khageri Canal.

Gaduwa lake, Nanda Bhaujyu lake, Tikauli lake etc. Gitanaghar ghol is flowing as a small tributary in the southern part of the study area Th.e presence of abundance of these swampy lands, wetlands, ghols and marshy lands are the characteristics of oxbow lakes made by Khageri, Narayani and Rapti river system flowing at the very ancient times in this area.

6.2 Hydrogeology:

The main Dun valley aquifer is mainly filled with highly porous and permeable unconsolidated to poorly –consolidated piedmont alluvial or fan deposits of Late Pleistocene to Holocene age, which form the large aquifer system underlying the study area. These unconsolidated valley- fill deposits consist of thickly bedded conglomerates with pebble- to-boulder clasts in a fine-grained matrix, and are locally called the Dun Fan Gravels or Dun Gravels The valley fill deposits in the area form the main aquifer system characterizes homogeneous in nature evident in the tubewell logs and hydraulic properties. Aquifers in this dun valley are considered as Bhabar deposits by the previous researchers. River fans and ancient river terraces are found mainly in the valley. The Bhabar Zone area in Chitwan district is estimated as 280 km^2 (C.K.Sharma, 1995) while area of Dun valley is estimated as 800 $km^{2.}$ Chitwan Dun lies at a slightly higher elevation than Terai.

Chitwan dun valley is located entirely in the Siwaliks, a region characterized by comparatively high net system losses because of the high secondary porosity characteristic of its sedimentary rocks. Cyclic storage of shallow ground-water and bank storage lead to some baseflow in the major rivers which cross this geological formation. The high net system losses that occur in this region, however, suggest that seepage below the base levels of streams occurs; this seepage is thought to supply some of the recharge of the Terai's aquifer systems. In the study area, surface water –groundwater interaction generally occurs within local flow systems. The River Narayani is a gaining stream in upper reaches but it may be losing along most of its length and recharges shallow aquifers in downstream. Deeper groundwater generally has insignificant interaction with the surface water bodies, and the deeper aquifers have restricted recharge.

6.3 Aquifer System:

The study area faces some multilayered and multiple aquifers in the different depths. There also consists of thick impermeable layer of clay and fine sand. Based on these depositional patterns of aquifer material, an attempt has been made to describe the aquifer system. Two types of aquifers are encountered in the study area:

--- Unconfined Aquifer and

---Confined or semi-confined or leaky Aquifer

The porous and permeable piedmont deposits form the main large aquifer system in this area. The aquifer system is multilayer in nature, as commonly found in alluvial deposits. Groundwater is under unconfined or water table type conditions in shallow aquifers and under semi-confined or leaky confined conditions in deeper aquifers. Perched water –table conditions also present in places at a considerable depth.The deeper aquifers are productive and have been tapped through hundreds of tube wells (borewells with slotted or perforated casings) for meeting domestic and irrigation requirements. Hundreds of dug wells are dugged in the lower part of piedmont area, tapping the shallow unconfined or perched aquifer.

6.3.1 Unconfined Aquifer

Plate 7 The fig is showing the static water level in a Dugwell at Gaurinj.

The study area comprises alluvial fans, alluvial deposits and river terraces. The northernmost part consists of fan deposits whereas central and Southern part of the area comprises alluvial deposits and river terraces.The fluviatile origin sediments range from cobble, pebble, gravel, sand and even boulder at some places. A few layers of finer sediments like clay and silt are also found. Almost all parts of study area encounter unconfined aquifer at a depth range of 20-80 m below ground surface (Appendix: A-i). Shallow tubewells and dugwells are completely tapped within unconfined aquifer zone. Deep aquifers are tapped within semiconfined layers.

6.3.2 Confined or semi-confined or leaky Aquifer:

Confined aquifers occur where groundwater is under pressure greater than atmospheric by overlying relatively impermeable strata (Todd, 1980). Such aquifers are also known as artesian aquifers. Fluctuation of water levels result due to changes in pressure rather than change in storage volume. In a well penetrating such an aquifer, the water table rises above the bottom of the confining bed.

Generally in the area wells are found to be semiconfined with admixtures of gravel and fine sediments as aquitard or leaky confining layer and sand, gravel, cobble, pebble, boulder or their mixtures serve as aquifer material. Generally, for the screen positioning , aquifer materials found at depths of 20-50 m at Torikhet, 36-66m at Parasnagar, 35-71m at Lanku, 24.5-36.5m at Kalyanpur, 42-72m at Rambag respectively. Confined aquifers have ranges of depth of 20-112m. The confining nature of deep aquifer zones is revealed from their potentiometric head. Confining nature is developed in the granular beds from a depth of 18m onwards. Piezometric head which includes the fluid potential above the uppermost aquifer screened is in the range of 18.5 m to 51m. Piezometric surface of the confined and semiconfined aquifers is at a depth range of 6.1m to 22m (exception of DTW-14).

From a general hydrogeologic point of view, these sediments have been categorized as aquifer (sand and gravel) and aquitard (clay). The position of the sandy clay is ambigious: it can act as either less permeable aquifer or higher permeability aquitard. Its exact category will vary from locality to locality based on the sand / clay ratio and permeability. Although the less permeable sediments like clay transmit some groundwater, they separate the overlying aquifers from lower aquifers by hydraulic conductivity (K) contrast.

6.3.3 Water Wells in the Study area

In the study area there are several deep tubewells and shallow tubewells for drinking water by DWSS Offices in Municipal area. Six deep tubewells are drilled by ADPJ in Rampur, Torikhet, Parasnagar, Lanku, Rambag and Kalyanpur area and other five deep tubewells were constructed for drinking water supply.

Fig: 6.4 Water Level Contour Map of Dugwells (mbgl) in Post-Monsoon (August-September),2008

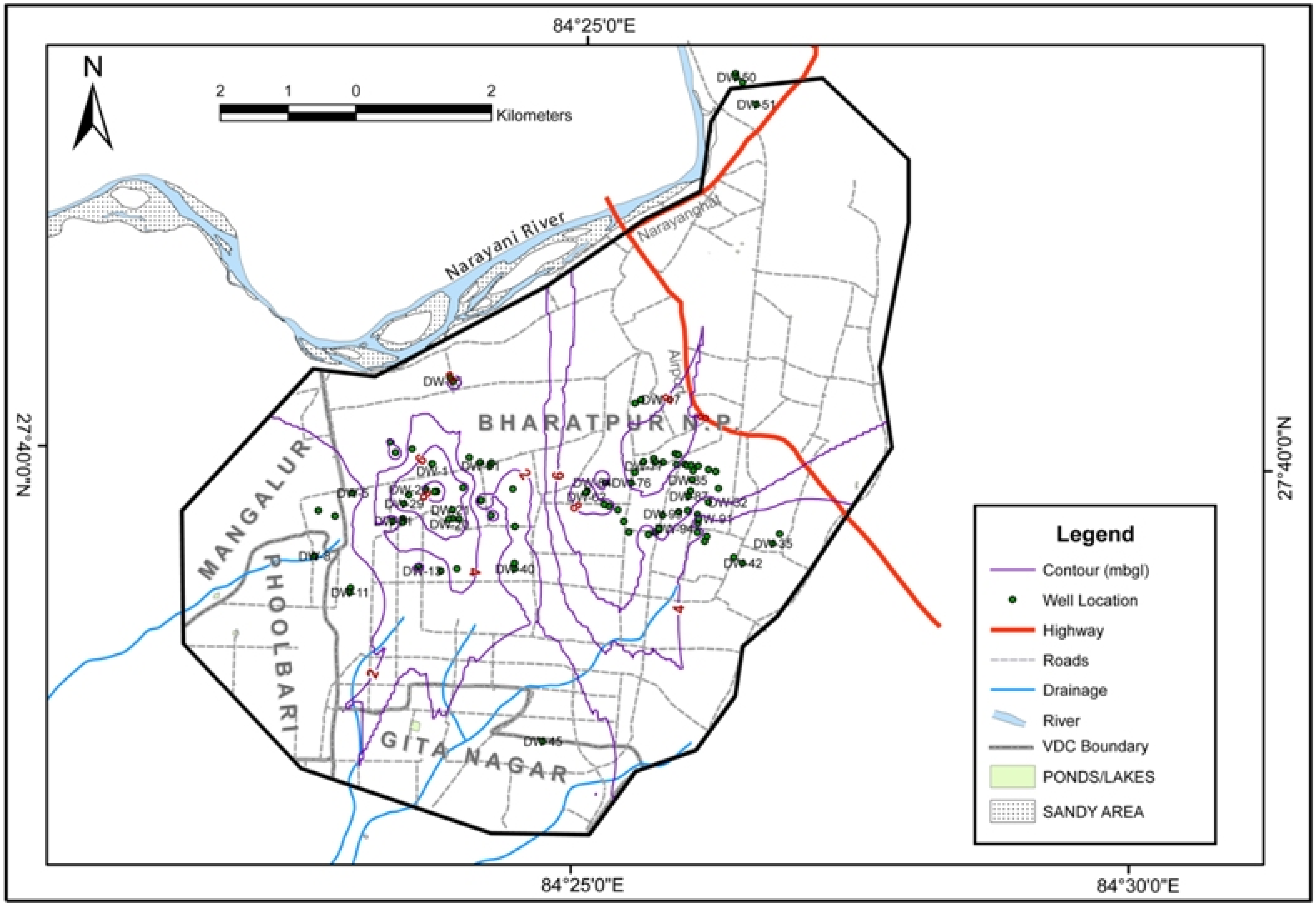


Fig: 6.5 Piezometric Contour Map of Dugwells (masl) in Post-Monsoon(August-September) ,2008

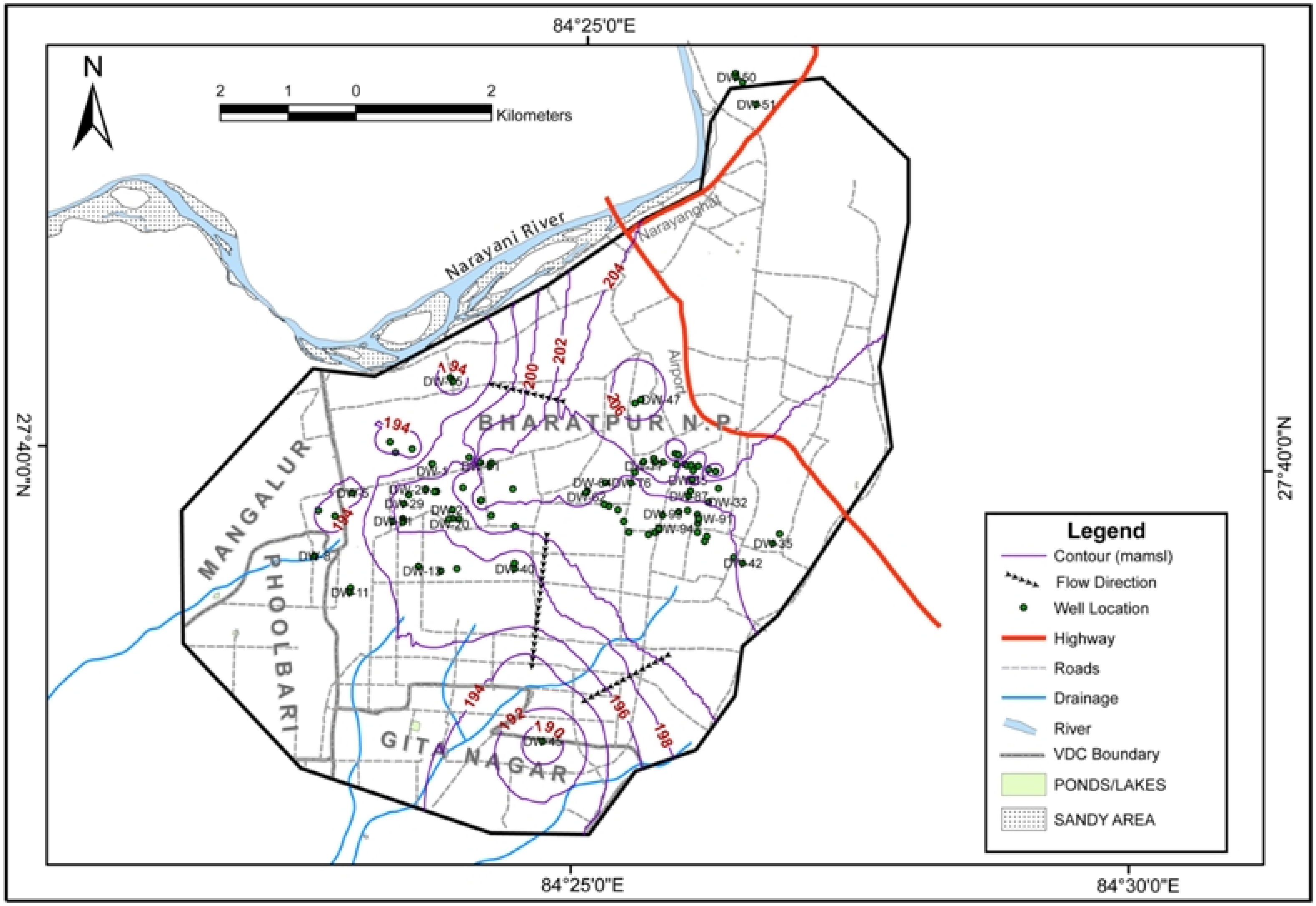


Fig: 6.6 Water Level Contour Map of Dugwells (mbgl) in Pre-Monsoon (April--May) 2008

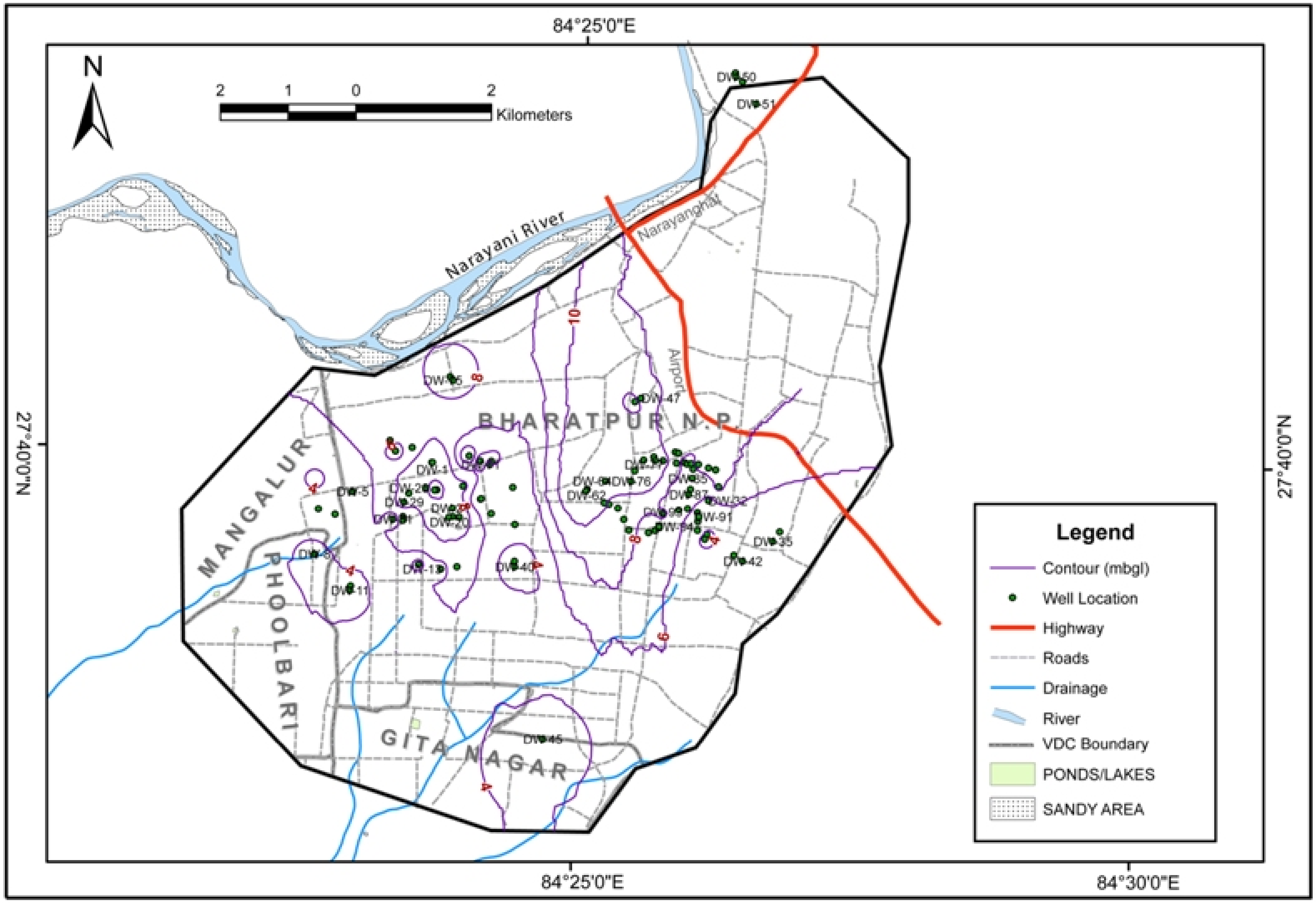


Fig 6.7 Piezometric Contour Map of Dugwells (masl) in Pre-Monsoon (April-May), 2008

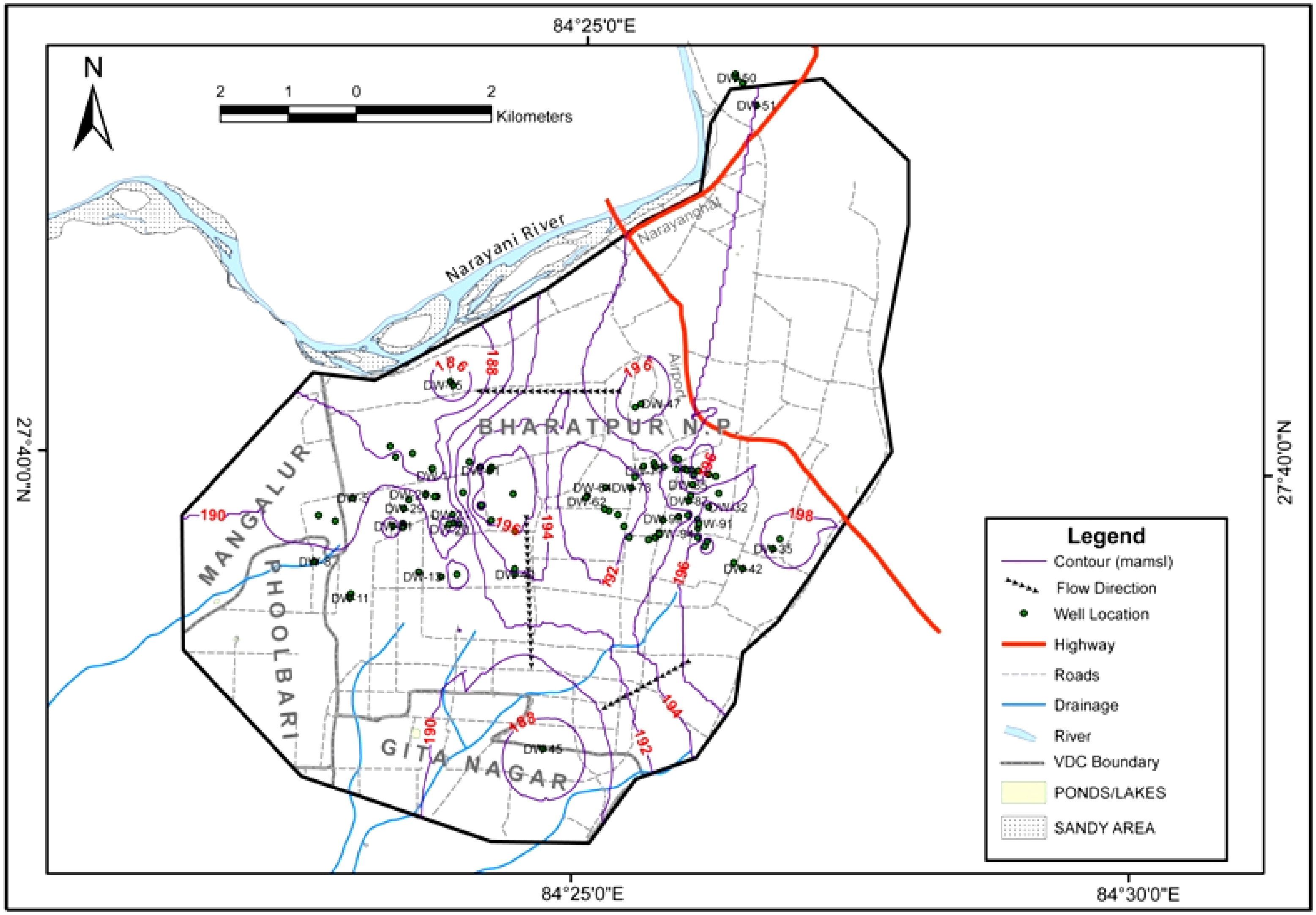


Table 6.2: Well Inventory of existing Dug wells

S. No.	Well ID	Well Location	Longitude	Latitude	Elevation mamsl	Depth (m)	Well Diameter (mm)	Piezometric Surface				Waterlevel Fluctuation (m)
								Post monsoon Aug 08		Premonsoon Mar 08		
								mbgl	mamsl	mbgl	mamsl	
1	DW-1	B.M.-13,Gulafbag.	84.395783	27.65703	200	15.86	914	8.35	191.65	10.9	189.1	2.55
2	DW-2	B.M.-14, Kalyanpur	84.395867	27.65705	193	13.54	1016	6.8	186.2	9.08	183.92	2.28
3	DW-3	B.M.-14, Kalyanpur	84.392817	27.65897	192	10	914	4.6	187.4	6.9	185.1	2.3
4	DW-4	B.M.-14, Rambag.	84.390317	27.65845	194	7.32	914	0.95	193.05	4.7	189.3	3.75
5	DW-5	B.M.-14, Rambag.	84.384	27.65293	193	8.7	914	1.4	191.6	3.95	189.05	2.55
6	DW-6	B.M.-14, Rambag.	84.379	27.65053	193.5	8.84	914	0.6	192.9	4.4	189.1	3.8
7	DW-7**	B.M.-13,Sripur	84.378483	27.65445	194	6.62	914	0	0	3.7	190.3	3.7
8	DW-8	B.M.-13,Gulafbag.	84.378517	27.64448	194		914	0.85	193.15	3.45	190.55	2.6
9	DW-9	B.M.-13,Rambag	84.3815	27.64985	193	6.71	914	0.95	192.05	5.4	187.6	4.45
10	DW-10	B.M.-13,Kailashnagar	84.38405	27.64033	194	9	762	0.75	193.25	3.75	190.25	3
11	DW-11	B.M.-14, Torikhet	84.383934	27.63973	195	7.3	914	0.5	194.5	3.2	191.8	2.7
12	DW-12	B.M.-14, Torikhet	84.3941	27.64338	196	10.38	1016	1.7	194.3	4.7	191.3	3
13	DW-13	B.M.-14, Torikhet	84.397467	27.64283	196		914	2.98	193.02	5.5	190.5	2.52
14	DW-14	B.M.-14, Torikhet	84.399867	27.64318	196	9.33	762	5.35	190.65	7.1	188.9	1.75
15	DW-15	B.M.-7, Krishnapur	84.40845	27.64407	197	4.6	914	0.9	196.1	2.6	194.4	1.7
16	DW-16	Prembasti high school.	84.408367	27.64895	200	9.03	914	1.7	198.3	3.9	196.1	2.2
17	DW-17	B.M.-14 Narayanpur	84.4048	27.65035	201	6.32	914	1.75	199.25	4.7	196.3	2.95
18	DW-18	B.M.-14 Narayanpur	84.400034	27.64978	198	12.81	914	6.22	191.78	9	189	2.78
19	DW-19	B.M.-14 Narayanpur	84.399034	27.64983	198	9.6	914	7.2	190.8	9.5	188.5	2.3
20	DW-20	B.M.-14 Narayanpur	84.3985	27.64977	198	14.45	914	6.8	191.2	9.5	188.5	2.7
21	DW-21	B.M.-14 Narayanpur	84.399017	27.65098	199	13.24	914	7.28	191.72	10	189	2.72
22	DW-22	B.M.-14 Narayanpur	84.400517	27.65398	202		914	6.7	195.3	8.45	193.55	1.75

23	DW-23	B.M.-14 Ganeshmandir	84.3966	27.6534	199	14.45	762	8.4	190.6	10.4	188.6	2
24	DW-24	B.M.-13,gulafbag.	84.396284	27.65337	199	14.45	914	8.75	190.25	10.4	188.6	1.65
25	DW-25	B.M.-13,gulafbag.	84.394967	27.65365	199		762	8.15	190.85	9.9	189.1	1.75
26	DW-26	B.M.-14,Narayanpur	84.39245	27.65287	199	15.09	914	7.41	191.59	7.8	191.2	0.39
27	DW-27	B.M.-14,Narayanpur	84.3917	27.6496	198	10.68	914	4.9	193.1	6.4	191.6	1.5
28	DW-28	B.M.-14,Narayanpur	84.391633	27.6497	198	12.04	762	4.6	193.4	7.4	190.6	2.8
29	DW-29	B.M.-14,Narayanpur	84.391733	27.65168	198		762	8.1	189.9	9.3	191.7	1.2
30	DW-30	B.M.-14,Narayanpur	84.391667	27.64922	198	12.04	914	4.05	193.95	5.75	192.25	1.7
31	DW-31	B.M.-14,Narayanpur	84.39015	27.64933	198		914	2.7	195.3	4.6	193.4	1.9
32	DW-32	B.M.-14,Narayanpur	84.4372	27.652717	202	9.6	371	5.3	196.7	5.6	196.4	0.3
33	DW-33	B.M.-8, Kalsikri	84.438667	27.65458	202		914	7.56	194.44	8.3	193.7	0.74
34	DW-34	B.M.-8, Kalsikri	84.44795	27.64872	203		914	3.2	199.8	4	199	0.8
35	DW-35	B.M.-8,Salyani	84.446934	27.64742	203		914	3.5	199.5	5	198	1.5
36	DW-36	B.M.-8,Salyani	84.441183	27.64547	202		914	2.55	199.45	4.2	197.8	1.65
37	DW-37	B.M.-8,Salyani	84.4247	27.55708	201	9.95	914	4	197	6.2	194.8	2.2
38	DW-38	B.M.-8, Parasnagar	84.49765	27.63656	190	9.03	1016	1.85	188.15	4.6	185.4	2.75
39	DW-39	B.M.-8, Parasnagar	84.410116	27.62897	193	7	914	0	193	4.1	188.9	4.1
40	DW-40	B.M.-7, Prembasti	84.40845	27.64333	197	6.02	914	1.3	195.7	3.4	193.6	2.1
41	DW-41	B.M.-8, Gauriganj	84.43565	27.6487	201		914	6.8	194.2	7.4	193.6	0.6
42	DW-42	B.M.-8, Salyani	84.442483	27.64472	202	11.44	914	2.95	199.05	4.45	197.55	1.5
43	DW-43	B.M.-8, Salyani	84.43705	27.64818	202	6.02	1016	1	201	3.5	198.5	2.5
44	DW-44	B.M.-8, Salyani	84.43675	27.64753	202	5.49	1676	0.75	201.25	3.05	198.95	2.3
45	DW-45	Gitanagar-6, Kesharbag	84.413167	27.62043	189	5.42	1016	0.8	188.2	2.95	186.05	2.15
46	DW-46	B.M.-7, Krishnapur	84.425917	27.66567	207	13.85	1828	6.45	200.55	9.45	197.55	3
47	DW-47	B.M.-7, Krishnapur	84.426833	27.66615	207		914	8.45	198.55	10.75	196.25	2.3
48	DW-48	B.M.-2, Anptari	84.441	27.70867	211	1.6	914	0		0.65	211	0.65
49	DW-49	B.M.-2, Anptari	84.439934	27.7098	211	2.74	1016	0.65		1.65	210.35	1
50	Dw-50	B.M.-2, Anptari	84.440017	27.7093	210	6.3	914	3.25		5.6	206.75	2.35
51	DW-51	B.M.-11, Ganeshthan	84.4431	27.70575	212	6.71	3302	4.5	205.1	6.9	207.5	2.4

52	DW-52	B.M.-9,Sharadpur	84.4321	27.65907	206		914	8.5	195.6	10.4	197.5	1.9
53	DW-53	B.M.-9, Sharadpur	84.43255	27.65897	207		914	8.75	198.25	10.55	196.45	1.8
54	DW-54	B.M.-8, Gauriganj	84.4323	27.65762	204		1016	8.15	195.85	10.15	193.85	2
55	DW-55	B.M.-8 Sharadpur,	84.433567	27.6577	204	6.62	914	6	198	6.2	197.8	0.2
56	DW-56	B.M.-8, Gauriganj	84.433934	27.65753	203	6.02	914	6.51	196.49	6.7	196.3	0.19
57	DW-57	B.M.-9, Sharadpur	84.434534	27.65758	203		914	7	196	7.15	195.85	0.15
58	DW-58	B.M.-8 Gauriganj,	84.4261	27.65647	203		914	8.8	194.2	11.8	191.2	3
59	DW-59	B.M.-7, Krishnapur	84.40795	27.65393	203		914	0.1	202.9	5.25	197.75	5.15
60	DW-60	B.M.-7, Krishnapur	84.403184	27.6523	202.5		914	0.95	201.55	2.65	199.85	1.7
61	DW-61	B.M.-7, Krishnapur	84.419083	27.6539	202.5	13.11	1016	9.25	193.25	11.9	190.6	2.65
62	DW-62	B.M.-7, Khaniyatole	84.418917	27.65367	203	13.72	914	9.4	193.6	11.8	191.2	2.4
63	DW-63**	B.M.-7 Krishnapur	84.4214	27.65513	202.5	14.64	914	0	0	11.5	191	11.5
64	DW-64	B.M.-8, Gauriganj	84.421767	27.65503	203	12.81	914	9.55	193.45	11.5	191.5	1.95
65	DW-65	B.M.14, Narayanpur	84.404733	27.40473	202	5.49	914	0.45	201.55	5.6	196.4	5.15
66	DW-66**	B.M.14, Narayanpur	84.405067	27.40507	202.5	5.49	914	0	0	4.6	197.9	4.6
67	DW-67	B.M.14, Narayanpur	84.403267	27.65233	202.5	7.23	914	1.7	200.8	5.2	197.3	3.5
68	DW-68	B.M.14, Narayanpur	84.652867	27.65287	202		914	1.35	200.65	4	198	2.65
69	DW-69	B.M.14, Narayanpur	84.40445	27.6569	203	13.54	914	1.75	201.25	5.4	197.6	3.65
70	DW-70	B.M.14, Narayanpur	84.404667	27.65735	203	7.2	914	2.35	200.65	6.5	196.5	4.15
71	DW-71	B.M.14, Narayanpur	84.403	27.65738	203.5	7.23	914	4.95	198.55	7.35	196.15	2.4
72	DW-72	B.M.-14,Narayanpur	84.389483	27.65983	193		1016	1.85	191.15	6.4	186.6	4.55
73	DW-73	B.M.-14,Narayanpur	84.401333	27.658	194		914	0.45	193.55	1	193	0.55
74	DW-74	B.M.-14,Narayanpur	84.398233	27.66853	194		914	2.05	191.95	8.5	185.5	6.45
75	DW-75	B.M.-14,Narayanpur	84.398667	27.66805	193	9.03	914	1.85	191.15	8.7	184.3	6.85
76	DW-76	B.M.-8, Gauriganj	84.425583	27.65508	200	13.55	1219	8.05	191.95	10.1	189.9	2.05
77	DW-77	B.M.-9, Sharadpur	84.4274	27.65793	206		914	8.8	197.2	11.3	194.7	2.5
78	DW-78	B.M.-9, Sharadpur	84.428917	27.65837	205		914	8.85	196.15	11.35	193.65	2.5
79	DW-79	B.M.-8, Gauriganj	84.429133	27.6579	203	15.05	914	8.9	194.1	11.3	191.7	2.4
80	DW-80	B.M.-9, Sharadpur	84.430283	27.65792	205	12.64	914	8.45	196.55	10.8	194.2	2.35

81	DW-81	B.M.-9, Sharadpur	84.4356	27.65752	202		1016	8.55	193.45	10.1	191.9	1.55
82	DW-82	B.M.-8, Gauriganj	84.4371	27.65707	206	7.83	914	7.75	198.25	8.05	197.95	0.3
83	DW-83	B.M.-9, Sharadpur	84.4382	27.65682	206		914	8.2	197.8	8.9	197.1	0.7
84	DW-84	B.M.-8, Gauriganj	84.434817	27.65687	203	9.03	914	6.5	196.5	7	196	0.5
85	DW-85	B.M.-8, Gauriganj	84.434717	27.65562	205		1016	7	198	7.1	197.9	0.1
86	DW-86	B.M.-8, Gauriganj	84.434483	27.65417	203		914	7.3	195.7	7.35	195.65	0.05
87	DW-87	B.M.-8, Gauriganj	84.4342	27.65347	203	9.03	914	7	196	7.3	195.7	0.3
88	DW-88	B.M.-8, Gauriganj	84.434117	27.65155	199		914	6.75	192.25	7	192	0.25
89	DW-89	B.M.-8, Gauriganj	84.435617	27.65105	201		914	4.4	196.6	5.4	195.6	1
90	DW-90	B.M.-8,Salyani	84.4357	27.64988	202.5	6.32	914	2.1	200.4	3.1	199.4	1
91	DW-91	B.M.-8,Salyani	84.435817	27.65052	202		914	3.1	198.9	3.3	198.9	0.2
92	DW-92	B.M.-8, Gauriganj	84.4328	27.65135	201		914	7.3	193.7	8.15	192.85	0.85
93	DW-93	B.M.-8, Polar star school	84.430367	27.65085	201		914	7.6	193.4	8.3	192.7	0.7
94	DW-94	B.M.-8, Gauriganj temple	84.4299	27.64907	201		914	6.8	194.2	8.55	192.45	1.75
95	DW-95	B.M.-8, Gauriganj	84.429333	27.64855	199		914	6.4	192.6	7.5	191.5	1.1
96	DW-96	B.M.-8, Gauriganj	84.428333	27.64825	201		914	3.7	197.3	5.55	195.45	1.85
97	DW-97	B.M.-8, Ashok chowk	84.425433	27.64852	201	12	914	6.3	194.7	8.85	192.15	2.55
98	DW-98	B.M.-8, Gauriganj	84.424617	27.64995	200.5		914	7.4	193.1	9	191.5	1.6
99	DW-99	B.M.-8, Gauriganj	84.423717	27.65143	201		914	7.45	193.55	7.9	193.1	0.45
100	DW-100	B.M.-8, Gauriganj	84.422367	27.65195	200	14.45	914	8.25	191.75	9.55	190.45	1.3
101	DW-101	B.M.-8, Gauriganj,public	84.42165	27.65213	199		914	8.6	190.4	10.75	188.25	2.15

DW** = SWL in post – monsoon could not be monitored because of mechanical problem.

Table 6.3: Well Inventory of Deep Tubewells:

Well ID	Well Location	Longi-tude	Lati-tude	Elevat-ion mamsl	Depth(m)	well Diameter (mm)	Piezometric Surface		Yield (Q) l/s	Transmissivity m^2/day	Hydraulic conductivity m/day	Specific capacity m^3/day/m	Screen Position m bgl
							mbgl	mamsl					
DTW-1	*Torikhet	84.40237	27.644	196	53.6	350/200	8.5	187.5	35	1105.6		355.76	20.1—50
DTW-2	*Parasnagar	84.4171	27.632	193	70	350/200	7	186	40	686.45		172.8	36—66
DTW-3	*Lanku	84.41348	27.675	197	73.5	350/200	22	175	40	1519.5		576	35-71
DTW-4	*Kalyanpur	84.39625	27.663	192	60	350/200	8	184	50	1114.3		360	24.5--36.5
DTW-5	Trichowk	84.42312	27.681	209		300/200	209						
DTW-6	DWSS off.	84.43905	27.69	210	120	300/200	18.40	191.6	30	887.16	13.92	254	34-40,59.5-70.5,73-84,89.5-95,100.5-106,110-114.5
DTW-7	Kataharchowk	84.42388	27.67	208	126	300/200		208					45-69, 75-81,97-115
DTW-8	BPKMCH—1	84.4155	27.663	204	105		6.2	197.8	43.4	763.22		203	50-62,68-80,86-92,96-102
DTW-9	BPKMCH—2	84.4171	27.667	204	70		10.5	193.5					
DTW-10	*Rambag	84.38392	27.652	194	75	350/200	10.5	183.5	35	686.45		172.8	42—72
DTW-	Municipal	84.42238	27.682	205		300/200		205					

11	complex												
DTW-12	Hotel Safari Narayani	84.4286	27.689	209	99	150	20.17	188.8	10.19	988.69		300	51---87
DTW-13	Hakim Chowk			208	115	300/200	15		40	197.77	3.29	288	49—83,86-112
DTW-14	Coca Cola Factory			207	40	300	1.45		1.5	85.68	5.36	24.90	18.5-36

* ADPJ Deep Tubewells drilled in 1993.

Table 6.4: Well Inventory of Shallow Tubewells :

S. No	Well ID	Well Location	Longitude	Latitude	Elevation mamsl	Depth(m)	well Diameter (mm)	Depth to water level		Yield (Q) l/s	Screen Position m
								mbgl	mamsl		
1	STW-1	Parasnagar -9	84.49765	27.637	193.5	12	100	1.95	191.6	15	8.5--11.6
2	STW-2	Parasnagar -8	84.41317	27.62	193	12	100	1.9	191.1	12	8.85--11.6
3	STW-3	Rambag	84.37288	27.65	194	25	100	3.96	190	12	18.5--24.5
4	UN-04	Shivanagar			186	7.85	100	2.8	183.2		5.10--7.85
5	UN—06	Geetanagar			189	7.85	100	2.79	186.2		5.10--5.85
6	UN—07	Narayanpur	84.39166	27.649	198	13.25	100	0	198		10.50---13.25
7	UN—08	Prembasti	84.40837	27.649	201	22	100	9.75	191.3		16.10--24.60
8	UN—09	Gondrang			206	12.42	100	2.65	203.4		9.67--12.42

VII. DATA ANALYSIS, INTERPRETATION & DISCUSSION

7.1 Groundwater Movement

The total energy per unit volume of a moving fluid tends to acquire the sum of three components—kinetic, gravitational and fluid - pressure energy. The potential energy has been termed the force potential is the driving impetus behind ground-water flow. Potential energy is the product of hydraulic head and the acceleration of gravity.

$\Phi = gh$, where Φ = force potential, h = hydraulic head, g = Accn. of gravity

Hydraulic head is energy per unit weight and force potential is energy per unit mass.

7.1.1 Static water Level

Plate 8: Water Level monitoring In Dugwel l at Kalyanpur

The depth to water level measured in a network of 98 dugwells uniformly spread over the study area during field survey in May and August, 2008 for the monitoring of piezometric level fluctuation (Pre Monsoon and Post Monsoon) respectively. (Table 6.2). Especially Pre monsoon and Post monsoon static water level data were taken and interpretated them.

Among these 98 dugwells the maximum depth to water level measured at DW—60, was 11.9 m, during Pre monsoon season. Similarly the maximum depth to water level observed in dugwells during Post monsoon period (early November) at DW—52 Sharadpur was 10.4 m (Fig 6.4 and Fig .6.6).

The minimum depth to water level measured in Pre-monsoon period (end of May to early June) at DW-73 was 1.0 m, (Fig 6.6). Position of Static and dynamic water level in pumping and non pumping wells is shown as in Fig.6.8.

Water table fluctuation ranges in the unconfined aquifers from about 0.1 m to 6.85 mbgl .with a mean water level of 2.21m. The minimum range has been observed in the Gauriganj (DW-41) area in the eastern part of the study area i.e water table at shallower depths in this area and deeper away towards north –central part. In addition, the maximum range has been noticed in Narayanpur (DW-65) the Central part of the study area.

Piezometric level in Pre-monsoon period ranges from 184.2 masl to 207.5 masl (Fig.6.7). The lowest piezometric level has been found at Narayanpur (DW-75 area. (Table 6.2) and highest at Ganeshthan (DW-45), the northern part of the study area. Similarly water level in Post-monsoon season in August—September ranges from 186.2 masl to 205.1 masl in the respective area (Fig. 6.5).High fluctuation may indicate loss of groundwater as subsurface outflow. Water level fluctuations have higher values towards northern part controlled by topography.

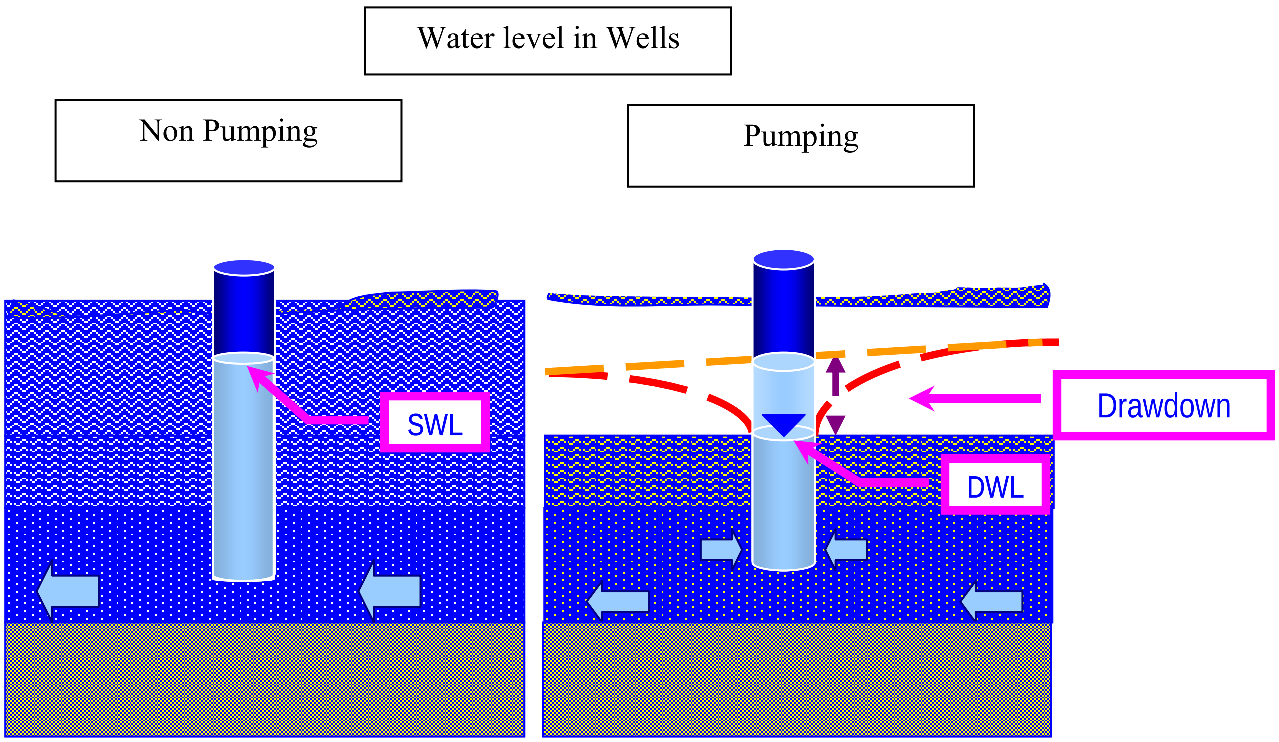


Fig 7.1 Water Level changes in pumping Wells

7.1.2 Flow Tendency:

Water table contour maps for different seasons have been prepared to predict flow tendency. The piezometric surface map shows that flow direction is mainly towards west to the Narayani River and south- east to the Kerungha ghol a depressed land in eastern part (Fig 6.3). Map imageries show several parallel depressions of Narayani could be part of of an abandoned channel. Remnant of past river course are observed at Gitanagar known as Gitanagar ghol. Another depression begins at Lonku Tandi and continues upto Sukranagar and Rapti River. All these abandoned channels show that these could serve as excellent aquifers.

In contour maps of groundwater levels, convex contours indicate regions of groundwater recharge, while concave contours are associated with groundwater discharge (Todd, 1980). For an area of uniform groundwater flow that areas with wide contour spacings (flat gradients) possess higher hydraulic conductivities than those with narrow spacings (steep gradients). Water level contour surfaces illustrate the development and deepening of cone of depression and drawdown due to pumping and seasonal decline.

In general, the water table follows the surface topography .Water level fluctuation in the study area is directly related to the rainfall or seasonal variation and return flow from irrigation, seepage from streams and canals. With maximum rainfall at four months of the year June –July-September - October water level rises and reaches maximum during July-October. In dry season with minimum rainfall water level gradually decreases and reaches minimum during April-May.

Contour map of static water level measured in post –monsoon 2008 has shown that there is a ground water discharge rareas in the south –eastern part around Baruwa (DW-35)-Salyani (DW-42)-Ghumti (DW-45)-Parasnagar(DW-39)-Kesharbag (DW-45) area. Groundwater flow is locally confined in the basin/ trench and the flow is eventually follows the south—west direction (Fig 6.5 and Fig 6.7). At the central part of the area, around Narayanpur (DW-45)-Rambag (DW-5) –Gulafbag (DW-1) - Kailashnagar (DW-10)--Krishnapur (DW-59) area water level contours are relatively closely spaced. Similarly in south east corner of the area shows widely spaced contours shows flatter area. In the rest of the area shows water level contours are more or less parallel and equally spaced shows moderate gradient throughout the year. In the flatter area contours revealed widely spaced together.

There occurs a crest area of water table in the Sharadpur (DW-53) area in eastern part below the East –west highway and groundwater flows to the east and finally south in this area. Similarly there occurs a ground water crest area of water table in the parallel alignment of the Narayani Canal in –Yangyapuri (DW-46) Narayanpur (DW-18)—Tiger Chowk (DW-81)—Gulafbag (DW-60) area. Water level contours shows that ground water movement follows topography from higher level to the level of lower topographic level. There occurs a ground water divide line(water table crest) in the center of the study area, from which ground water flows in the eastern and western direction or in opposite direction. This groundwater divide splits the study area into two groundwater flow systems. One flow system is associated with Narayani River and the other flow system is associated with watershed of the south-west corner or Kerunga stream. In both flow systems, groundwater initially moves from topographically high areas towards the valley axis.The lower reaches of Kerunga ghol is perennial due to base flow.

These crests and troughs represent the surface and subsurface topography of the area shows the groundwater exploitation and consequent recharge zones.These illustrate the groundwater discharge and recharge areas.In this area recharge areas are located in topographically high areas and discharge areas are located in topographically low areas.The Narayani River and Kerunga ghol are represented as the valley bottoms of concentrated groundwater discharge into streams, with the streamlines converge to them. There exist two recharge areas following by two topographic reliefs on either sides.Two kinds of local groundwater flow systems formed in the area.Because of the study area is smaller as compred to the Chitwan valley , these local flow systems are shallower of shallow basin, with short flow paths. If the basin depth –to-width increases the other flow systems local, intermediate and regional flow systems may also developed depending upon the drainage basin. .The Piezometric surface maps of Pre-monsoon and Post- monsoon in the area shows no ground water declining/ over exploitation trend in the area.

Narayani River is a perennial with increasing discharge towards south which shows the characeristic of a gaining or effluent river.

7.1.3 Hydraulic Gradient

Hydraulic gradient is the change in head per unit of distance in a given direction. The hydraulic gradient in pre-monsoon and post-monsoon season has been calculated from Piezometric contour map (Fig 6.5 & 6.7)

Pre-monsoon period (April/ May)

Piezometric contour map reveals that contour lines are closely spaced at Narayanpur (DW-31)—Rambag(DW-41)- Gulafbag(DW-81)- Kailashnagar(DW-10) –Krishnapur(DW-46)-Kalyanpur(DW-3) in the central and western part of the area. Similar closely spaced contour lines area reveals at the Sharadpur area (DW-53) where the ground water flow direction shows to the east. In the rest of the area shows water level contours are more or less parallel and equally spaced shows moderate gradient throughout the year. In the flatter area contours reveals widely spaced together.There is a groundwater ridge.

Hydraulic gradient has been calculated at different locations (Fig.6.7) such as DW-45/Kesharbag (5 m/km), DW-40/ Prembasti (1.58m/km), DW—47/ Krishnapur (1.67 m/km), DW-91/ Salyani (1 m/km), DW-29/ Narayanpur (1.5 m / km) DW-62/ Khaniya tol (2.14 m /km) .

Post-monsoon period (August/ September)

Piezometric Contour map in Post –monsoon August-September , 2008 has shown that there is a ground water basin in the south –eastern part around Baruwa(DW-35)—Salyani(DW-42)—Ghumti(DW-45)-Parasnagar(DW-39)—Kesharbag(DW-45) area. Groundwater flow is locally confined in the basin/ trench and the flow is eventually follows the south—west direction as baseflow.

Similarly the contour lines are closely spaced (Fig 6.5) at Sharadpur (DW-53), Narayanpur (DW-65)-Rambag(DW-5)-Gulafbag(DW-1)-Kailashnagar(DW-10)- Krishnapur(DW-59) Kalyanpur (DW-2) in the central area and Mangalpur, Laxmipur in the western part of the area.

By calculation, hydraulic gradient is found almost uniformly similar value at the whole study area. Hydraulic gradient found at different locations are as follows: at DW-45/ Kesharbag – 2.5 m / km, at Dw-40/ Prembasti—2.5 m/ km, at DW-47/ Krishnapur—2.3 m /km, at DW—95 , Gauriganj temple—3.0m / km respectively.

Hydraulic gradient changes in every meter of horizontal distance. The above calculated hydraulic gradient will provide tentative gradient value of the area.

7.1.4 Ground water Flow Rate

The rate of groundwater movement is governed by the hydraulic conductivity of an aquifer and the hydraulic gradient (Todd, 1980)

Hydraulic conductivity (Permeability) of shallow aquifer has been calculated by GWRDB/ UNDP in six wells. The trend of hydraulic conductivity can be estimated by Table 6.5 in the study area. The ground water flow rate is relatively higher at DTW-4 / Kalyanpur---50 l/s and BPKMCH /DTW-8 ---43.4l/s. whereas 35l/s discharge rate is found at Rambag (DTW-10).

7.2 Deep tubewells and piezometric surface:

Deep tubewells are used to exploit the groundwater from deep confined aquifer. The depth of the deep tubewells ranges from 40.0m at Coca Cola Factory to 120.0 m at DWSS office at Bhojad near East-West highway.

The static water level or Piezometric head of a confined aquifer recorded in these wells is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer. In the study area, the piezometric head ranges from 1.45m at Coca Cola Factory DTW—14 to 22 m at Lanku/ DTW-3. With reference to the mean sea level, piezometric surface varies from 153 m at Lanku / DTW-3 to 210 m at DWSS Office/Bhojad/ DTW—6. These tubewells tap variable thickness of granular zones (sand mixed with gravels), ranging from 18 to 42m (Average 30m) and occurring at different depths through slotted casings.

7.3 Aquifer Characteristics:

Aquifer parameters such as Yield (Q), Transmissivity (T), Hydraulic Conductivity (K), Storage coefficients (S) and specific capacity (C) are important parameters for the aquifer characteristics. Porosity, grain size, sorting and packing of aquifer materials influence them.

7.3.1 Yield:

Yield is the volume of the water per unit discharge from a well either by pumping or free flows. It is measured in Lit/sec or cubic meter per day (Driscoll, 1987). In the study area, yield of deep tubewells ranges from 35 l/s at Rambag and to 50l/s at Kalyanpur. The yield of the deep tubewells is highest at the Kalyanpur area and lowest at Coca Cola Factory-1.5l/s. ADPJ deep tube wells are mainly used for irrigation purpose. Some of them are used for municipal supply and domestic purpose.

7.3.2 Transmissivity.

Transmissivity is defined as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient (Todd, 1980). Transmissivity indicates how fast water will move through the formation i.e. ability of aquifer to transmit water is measured by transmissivity.

Transmissivity is calculated by Cooper- Jacob method.In the study area pumping test data in most of the deep tubewells were not available.

So the transmissivity values are presented in Table 6.3 ranges in DTW-14 is 85.68m^2/d. (Jacob-method) and in DTW-1 is 1105.6 m^2/d. (empirical method). Transmissivity in some ADPJ tubewells were calculated by the empirical formula developed by Srivastav et al in Deharadun valley as:

$$\log T=1.36+0.66\log (Q/s) \text{ or } T= 22.9(Q/s)^{0.66}$$

Where both T and Q/S are in m^2/d developed for the piedmont alluvial aquifer (Dun valley) system.

7.3.3 Hydraulic Conductivity.

A medium has a unit hydraulic conductivity if it will transmit in unit time a unit volume of groundwater at the prevailing kinematic viscosity through a cross section of unit area measured at right angles to the direction of flow, under a unit hydraulic gradient. Hydraulic conductivity of a soil or rock depends on a variety of physical factors including porosity, particle size and distribution, shape of particles, arrangement of particles and other factors. In general, for unconsolidated porous media hydraulic conductivity varies with particle size. Clayey materials exhibit low value of hydraulic conductivity while sand and gravel display high values (Todd, 1980)

Hydraulic conductivity is determined by pumping test of wells using Transmissivity and aquifer thickness.

In the study area Hydraulic conductivity of deep aquifer at DTW-14 (Coca Cola Factory) is 5.36m/d, DTW-6/Bhojad is 13.92m/d and DTW-13 (Hakim Chowk) is 3.29m/d respectively.

7.3.4 Specific Capacity.

Specific capacity of a well is its yield (discharge) per unit drawdown in the pumping well. Specific capacity generally varies with duration of the pumping, as pumping time increases specific capacity decreases (Driscoll, 1987). Specific capacity is a measure of productivity of a well clearly the larger the specific capacity betters the well (Todd, 1980).

In the study area, the specific capacity of deep tubewell ranges from 1519.54m^3/day/m at Kalyanpur/DTW-4 to 24.90m^3/day/m at Coca Cola Factory. Relatively greater specific capacity values are observed at ADPJ Tubewells.

Shallow Aquifers (Shallow Tubewells):

Kansakar and Amatya (1993) under GWRDB/UNDP has conducted pumping test in six wells in the Chitwan valley. The resulted parameters and well locations are given in Table 7.1

Table 7.1 Aquifer Properties of Pumping tested Shallow Wells in Chitwan

Location	Well No.	Transmissivity (m^2/day)	Saturated aquifer(m)	Hydraulic conductivity (m/day)	Aquifer lithology	Discharge	SWL(mbgl)
Dibyanagar	UN-2	1216	4	304	GB	6	2.8
Bhimnagar	UN-3	1127	8.3	135.8	GB	18.5	0.6
Tikauli	UN-10	4628	7.5	617.1	GB	5	2.6
Barchauli	UN-12	2312	7.9	292.7	GB	22	2.7
Kapiya	UN-14	767	10.7	71.7	GB	16	2.8
Piple	UN-17	6423	9.3	690.6	GB	22	4.1

GB = Gravel & Boulder *Source: GWRDB,1993*

7.4 Groundwater Potential

The groundwater potential zones in the study area are delineated on the basis of well yield, Transmissivity and specific capacity of deep tubewells.

7.5 Ground water Recharge.

There is active recharge through highly permeable superficial alluvium to the shallow aquifer recharge input is direct from rainfall and from riverbed infiltration.The infiltration rate gradually decreases towards south. The total recharge inflow in the study area can be conceptualized as having several sources: a) precipitation b) irrigation return flow and c) seepage beneath standing surface water bodies (lakes, ponds and losing reaches of streams) or inflow from rivers. During dry season, surface overflow is extremely low because available potential recharge is likely to infiltrate. However during the wet season, after a period when the aquifers become completely replenished (aquifer full conditions), any further potential recharge is rejected. This contributes to extensive flooding. The heavy rainfalls during the monsoon period together with snow melt from the Himalayas cause extensive flooding in the Terai.

The broad, ephemeral river/stream beds (composed of bare, highly porous and permeable sediments) form an important source of indirect recharge, especially during the monsoon. Direct recharge refers to diffuse or fairly uniform recharge over a large area from precipitationor irrigation, whereas indirect recharge refers to percolation to the water table through the beds of well defined surface-water courses.

During the high flow of water in Khageri and Narayani Lift Canal recharge is highly influenced by seepage losses through the canal. In the study area the recharge is mainly due to rainfall, (annual average rainfall in Rampur is 2214 mm) is the main source of direct groundwater recharge. Besides this the overland flow from the surrounding hills and mountains are the additional sources of direct and indirect recharge.The recharge zone is mostly along the northern side of the study area. Around Ramnagar and Devghat area, 10 to 15 m thick sediment of gravel facies is exposed. This older permeable formation acts as a recharge zone.

7.6 Hydrologic Balance of Groundwater Basins in Chitwan

Estimation about the recharge, storage and discharge of the groundwater system in Chitwan District has been calculated as follows:

Calculation of Total Groundwater storage in the study area:

i. Method 1 –Duba's Estimation

Annual precipitation recorded at Rampur station = 2214.31mm

Area of recharge in km^2 = 70.8 km^2

In the Chitwan Dun valley there is no Terai region and it is equivalent to Bhabar zone. Duba (1982) estimated 31 % of the rain that falls on Bhabar in the Narayani zone would percolate to the aquifer.

Therefore according to Duba,

Recharge in m^3/ year = Annual precipitation in metres* area of recharge in km^2 *% of rainfall to aquifer

= 2.214*70.8*1000*1000*.0.31=50604069m^3 = **48.592 MCM**

ii. **Method 2 –Conservative Estimate with 10% of rainfall**:

In this estimate recharge may be calculated by taking 10% of the average annual precipitation and assumed that it will recharge the aquifer.

Recharge = 2.21431*70.8*1000*1000*0.1 = **15.67 MCM/year**

iii. Method---3—Calculation considering effective porosity & fluctuation of water table

Assuming Storage coefficient or specific yield for saturated sand and gravel for unconfined condition (Raghunath, 1987) is 15% = 0.15

Average water table fluctuation in 98 dug wells over the study area ==2.21m

(But the value is 2.5 m According to Kansakar, 1993)

Recharge = 0.15*2.21m*70.8*1000*1000 = **23.47 MCM/year**

iv. Calculation of groundwater storage in the presence on both confined & unconfined aquifers condition:

The total groundwater storage of the confined aquifer, down to the depth, tapped by the existing tube wells, is estimated as follows:

Total groundwater storage = Area of the aquifer x Total average cumulative thickness of the aquifers x storage coefficients

Area of aquifer = Length x Breadth = 70.8 km^2

Average cumulative thickness of the aquifer = 30.0 m

Storage coefficient = 1×10^{-4} (assumed for confined aquifer) Therefore, total groundwater storage of the confined aquifer down to the depth tapped by the existing tubewells

= $70.8 * 10^{6} * 1 * 10^{-4} * 30$ = 0.2124 MCM

Again, for unconfined aquifer condition

Area of the aquifer = 70.8 km^2

Average cumulative thickness of the unconfined aquifer = 8.2 m

Specific Yield = 15 %, assuming saturated thickness for sand and gravel, (Raghunath, 1993)

Total groundwater storage of the unconfined aquifer

= $70.8*10^{6}*0.15*8.2\ m^3$

= 87.09 MCM

Therefore total ground water storage = (0.2124+87.09) MCM =0.2124+87.09=87.31 MCM

Table 7.2 Storage, recharge and discharge estimates of Groundwater in the study area:

Item	Storage	Recharge per year	Discharge per year
Volume of water (static reserve)	87.10MCM its 15% = 13.10MCM		
Recharge by 3 methods 1.Duba's estimate 2.Conservative estimate (with10% of rainfall) 3. Calculation considering effective porosity and fluctuation of W.T.		 48.6 MCM 15.67MCM 23.47MCM	
Evapotranspiration (Calculated PET value at Rampur Station is 1.68mm/day)			6.52MCM

Total Ground water draft:

The ground water draft in the study area is mainly through dug wells, and few shallow and deep tube wells. However, the data related to the amount of water needed per person per day in the area is not available. According to WHO standards the requirements for drinking and domestic need per person per day is 45litres (0.045 m^3).

The estimated population of the study area is 100000 on the basis of population census 2001.

Therefore, the total amount of ground water draft by this population

= Population × per capita demand of water

=100000 × 0.045

=4500 m^3/day

= 4500000 liters/ day.

for live stock ,the total draft of ground water can be estimated as 1/10th of the population demand (WHO), which is equal to 450 m^3/day.therefore the total amount of ground water draft = 4500+450 m^3/ day

=4950 m^3/day (=4950000 lit/day)

=1806750 m^3/year

=18.06×10^5 m^3 /year

7.7 Provenances of Dun Sediments:

Unlike the other discrete bounded inner Terai Valleys like Dang formed by fold structures and faulting within older, consolidated rocks, the Chitwan Valley is an extensive alluvial tract formed by the coalescence of the braided channels of the Rapti and Narayani Rivers as these enter the valleys. The area contains a shallow watertable and has thick, but locally cemented, alluvial deposits.

In process of deposition carrying sediments by the first and second grade rivers, these rivers have high energy and so the sediments are normally coarse grained. These rivers bring igneous, metamorphic and sedimentary sequences of pre-Himalayan ages are present. The second Grade Rivers have their origin in the Lesser Himalaya and bring sediment from both areas. The river Narayani is a best example of Transverse River. It has been suggested that many of the transverse river of the Himalayan region are of the antecedent type (Holmes 1965, pp595). Transverse Rivers are much smaller and carry coarser sediment loads. They may be alluvial fans. The Rapti River is an example of Consequent River. These river systems have a long geological history and follow very long established courses through their courses may be modified or even reversed by changes in plate-tectonic configuration. Sediment supply is primarily driven by tectonism (Mial, 1965).

All Dun Valleys including Chitwan originally were lake basins, which have distinct features based largely on the characteristics of the watershed draining into the prehistoric basins. They are structurally controlled valleys whose outlets at some time in the past were blocked by rapid tectonic uplift of the Siwalik range to the south. Conversely, the Chitwan Valley is affected by major river systems draining large portions of the country. The Narayani and Rapti rivers have markedly influenced the resulting soils in the Chitwan Valley, almost eliminating the original basin deposits.

7.8 Evapotranspiration Analysis:

For the comparative study of PET two locations were selected, one is the Narayani river at Devghat and another one is the crop land areas of Rampur (Fig 5.1). Similarly two sequences of calculations were carried out , one was with the actual data of the year 1990 and another one is on the basis of five years mean data of the years 1987—1991, comparative potential evapotranspiration value between the cropland area and at the river. The trend of PET has changed with the months of the year. The trends of change of PET values of the two areas are very similar. The value of PET is maximum in the month May with 6.7 mm of water/day at the crop land and 8.2 mm of water/day at the water surface. This is because during this period when the northern hemisphere of the earth leans towards the sun, mean temperature is high, sunshine hours per day is also high and no precipitation. Level of evaporable water surface is also very low during this period, so PET is maximum. The value of PET is minimum in the month of January with 1.84 mm of water/day at the cropland and 1.99 mm water /day at the water surface. This is because during this period the northern hemisphere of the earth leans away from the sun, mean temperature is very low. Relative humidity is highest, possible sunshine hours is also less so the PET value is least during this month.

7.9 Aquifer System:

7.9.1 Shallow Aquifer:

There is widespread occurrence, at about 9 to 10 m of a hard, cemented conglomerate which cannot be penetrated by manual methods. There are many caisson lined, shallow dug wells have been constructed in the layer above 10 m. In some case, penetration into the saturated zone is insufficient to maintain production discharge in May—June. Locally, fine sands in the shallow section may impede drilling and well digging.

There are 8 shallow tubewells studied in the area. Among them 5 are the UN- shallow tubewells and rest 3 are the private one. Most of these STWs are manually drilled; they were necessarily very shallow, of average depth only 12m. The wells proved that 70% of the section consisted of screenable material. The yields of these wells vary 5-20l/s. These area indicate a widespread zone of high transmissivities in the range of 500-1500m^2/day. By the analysis of lithological logs it is indicated that a very typical profile is 2-3 m clay upon gravels; boulders in this sequence usually terminate drilling, particularly by manual methods, at 8 to 10 m. Average percentage of the aquifer materials is 70 % in the area for shallow tubewells.

Aquifer occurrence in the Chitwan area has been controlled by alluvial sedimentation from the Rapti and Narayani Rivers. The shallow alluvial section commonly contains 70 % of coarse sand -gravel which supports a highly transmissive aquifer (some permeabilities exceed 200m/d) which is exploited by dug wells. However, there is widespread occurrence, at about 9 to 10 m, of hard, cemented boulder conglomerate, while locally, fine sands occur in shallow section. Both lithologies cause drilling difficulty. The watertable in Chitwan is shallow and generally lies at less than 5 m below ground level. Similar aquifer conditions are anticipated in deep zones, where 70 % of the lithological section to be screenable. Pump tested wells indicate a widespread zone of high transmissivities in the range 767 to 6423 m^2/d.

It is considered a credible but conservative value for planning purposes. It would for example allow development level in the shallow aquifer of 32 STWs/km^2 (13 l/s discharge, 300h/y operation.), a level quite unlikely to be practically realized. If irrigation losses are considered available for pumping, the STW density could reach 50/km^2.

Thickness of the alluvial fill is not known. In the inner valleys such as Chitwan there are considerable variations in rainfall, soil and topography, and it is anticipitated that recharge conditions will differ from those in the main Terai.

7.9.2 Deep Aquifer:

It is revealed that sedimentation by the Rapti and Narayani Rivers has accumulated a sediment pile containing permeable materials in deep sections. GDC(1993) has classified the aquifers in Chitwan as follows (appendix A-7a &7b):

Acoording to the classification by GDC the study area falls on the category as S3/ D4.

Table 7.3 Aquifer Development Classification:-

Shallow Tubewells			Deep Tubewells		
Class	**Lithology**	**Water table**	**Class**	**Lithology**	**Piezometry**
S1	Good	<5m	D1+ D1	Good Good	Artesian <10m
S2	Marginal	<5m	D2+ D2	Fair Fair	Artesian <10m
S3	Good	>5m	D3	Marginal Good	<10m >10m
S4	Marginal	>5m	D4	Marginal	>10m
S0	Marginal Any	Any North of 5m limit (drilling difficulty)	D0	Poor	Any

Source: GDC, 1993

For STWs," Good "stands for the values of T= 600—800m^2 and Q= 15l/s with s= 2m of max . drawdown. STW classification takes a water level of 5 m bgl, as this is thought to reflect a practical limit for operation of suction pumps within STWs. The DTW cut off point has been set at a SWL of 10 mbgl .

For DTWs, "Good "stands for areas between proven expanses of DTW lithology,"Fair "for which there are few or no data.

----"good" lithology/ deep water level: used as class D3 and

-----"fair" lithology/ deep water level: used as class D4.

-----impossible to construct STW: S0

-----impossible to construct DTW: D0

UNDP (1993) presents a groundwater balance for the Chitwan Dun which allows that about 31% of rainfall (average rainfall 1995-2006 is 2214mm in Rampur) i.e. recharge value exceeds over 600mm. While GDC (1993) also adopted this value in Bhabar zone which is to include 460mm rainfall recharge and 140 mm leakance from the deep aquifer to the shallow aquifer

VIII. CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions:

A comprehensive hydrogeological study is carried out in the north-western part of the Chitwan Valley as a partial fulfillment of the requirement for the master's degree in Geology. In the course of this study systematic data collection, field work and table works were accomplished results the following concluding remarks.

Chitwan Valley is a Dun valley, which comprises alluvial fans, talus, alluvium, deposited or reworked by water, wind or ice including river terrace. The grain size of the alluvium gradually decreased from north to south. The lithological cross-section indicates that the aquifers are multi layered interconnected lenses of sand, gravel and pebble alternating with silt and clay. Aquifer materials for unconfined and semi-confined aquifers are generally sand, gravel, pebble and even cobble and boulder. Antecedent Narayani River cut across the fold – thrust belt of Siwaliks. At synclinal and anticlinal axes, aggredation and degradation occurs. By anticlinal upliftment, braided rivers were adjusted to degradation pattern and terraces were formed.

By neotectonic movement in the last 1.6 m.y., the stream impoundment filled up in the lakes forming intermontane Duns. Dun gravels perhaps deposited in the late Pleistocene to very early Holocene about 22,000- 7000 yr. B.P.Higher and highest terraces in Chitwan dun related to during Pre-last interglacial time.

Piezometric surface of deep aquifers ranges from 188.83 masl at Hotel Safari Narayani to around 210 masl at Bhojad/Bharatpur and Yield of deep tubewells ranges from 1.5 l/s at DTW-14(Coca Cola Factory) to 50l/s at Kalyanpur (DTW—4). Similarly specific capacity ranges from 24.9 m^3/day/m at DTW-14 to 576 m^3/day/m at DTW-3, Lanku. In the study area Transmissivity value ranges from 85.68m^2/d to 1519.5 m^2/d. The highest value of Transmissivity, 1519.5 m^2/d is found at DTW-3, Lanku. The minimum value of Transmissivity 85.68 m^2/d is found in tube well of Coca Cola Factory.

The aquifers in Chitwan are recharged primarily by infiltration of local precipitation and by irrigation return flow from Narayani Lift Irrigation. Average annual precipitation recorded at Rampur is 2214mm (1996-2006).

Estimation of total groundwater storage in the area on both confined and unconfined condition is 87.31 MCM per year and potential recharge calculated by applying Duba's estimation is 48.60MCM per year. As annual recharge by precipitation exceeds rate of evapotranspiration in the valley area there could be ample scope for groundwater utilization.

The water level monitoring network progressed from Dug wells in 2008 hydrologic year at two seasons. The one is the Premonsoon, April-May and the other season is August—September reveals that the wells have the deepest water levels just prior to the monsoon and the shallowest water levels just after the monsoon.

Based on flow lines, the ground water flow direction is mainly towards Narayani River and SE corner / Kerunga ghol area both in pre monsoon an post monsoon season. Contour lines are closely spaced at central part of the study area Narayanpur---gulafbag--Krishnapur and SE part Baruwa—Kesharbag area representing higher Hydraulic gradient and widely spaced at rest of the part indicating relatively lower hydraulic gradient.The study reveals that the study area is good potential for both shallow and deep aquifer. But shallow aquifers are confined to the south eastern part i.e Gauriganj-Kesharbag- Parasnagar area.

According to Koeppen's classification of climate, the study area falls under" Bwh" category i.e. hot wet summer and winter dry season , with at least 10 times as much precipitation in wet month of Summer. Summer is the season with most rain.

PET in water surface is higher than (2.37mm/day) PET in cropland (1.68mm/day) but trend of change of PET in both places are very similar. The value of PET is maximum in May and minimum in January.

Bliney-Criddle Formula has been used for calculation of crop water requirement for different crops. The results shows that during the crop growth period, PET of rice is maximum with 105.80 cm-and wheat has minimum PET value with 37.4 cm nearly 3 times difference. It may be useful for estimation of crop water requirement

The bank of Narayani River is situated at the Ist terrace and the studied area lies in the IInd and IIIrd terraces of land system. Deep aquifers are recharged by inflow of Narayani River and shallow aquifers may be recharged in the lower reaches of the valley.it maynot be possible to recharge the terraces of study area because present bed level of Narayani is 179m amsl but these terraces are in higher elevationi.e.210mams than bed level of Narayani. The movement of groundwater towards the Narayani River lowers the salinity. Hence the observed and calculated resistivities are of higher values.

The minimum observed resistivity value for the aquifer i.e. sandy gravel is 50 ohm-m and the maximum is 1000 ohm-m. but most of the resistivity values for aquifer ranges from 200—800 ohm-m. Two layer sequences of geoelectric sections reveal that the upper layer has high resistivity values and lower layer has low resistivity values. The lower layer is composed of sand, gravel, and boulders and has comparatively low resistivity due to water content. The upper layer is thick in NE part of the area than in the SE part. Thickness ranges from 2m to 25 m. while in the middle part of the area the upper layer is very thin. i.e.2 m.

Water table fluctuation ranges from 0.1 m to 6.85 m. The minimum range has been observed in Gaurigang/DW-41 in the eastern part of the study area. In addition, the maximum range has been noticed in Narayanpur/Dw-65, the Central part of the study area.

8.2 Recommendations:

Conjunctive use of surface and Groundwater sources should be given high priority for the year round irrigation in such area as Narayani Lift irrigation command area where large part of land is dependable. As aquifers are rechargeable by direct, indirect and induced recharges, both shallow and deep aquifers are highly productive in the area. Different sizes of boreholes could be drilled by applying appropriate drilling technology. Manual Shallow Tubewells could be drilled at a depth of 10-15 m while machine drilled Deep tubewells could be drilled at a depth of 60- 130 m.

The thickness of alluvial fill in Chitwan valley is not known yet. So detailed geophysical survey including gravity survey, Ground penetrating Radar Survey and several other surveys should be carried out in this valley. No specific recharge studies have been carried out, and it is anticipated that the recharge conditions will differ from those in the main Terai.

The evolution of surface water and groundwater and past climatic changes should be studied and analysed by Radiocarbon analysis.

Groundwater of both shallow and deep aquifers and recharge climatic condition as well as paleohydrology in the Dun Valley should be studied by Radiocarbon dating. Evolution of Paleohydrology is related to the evolution of Dun valley. So research on evolution of Paleohydrology as well as Dun valley should be studied simultaneously.

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Appendix: A-i

Field Format for the Well Inventory Survey

1. Date: ………/…. /
2. Location: a. V.D.C./Municipal b. Village c. Ward No.
3. Survey Period : a. Pre-monsoon b. Post-monsoon
4. GPS Value: a. Longitude b. Latitude c. Altitude
5. Well Type: a. Dug well b. Shallow Tube well c. Deep Tube Well
6. Well Depth:
7. Water Level: a. Pre-monsoon b. Post-monsoon
8. Date of Construction:
9. Condition in Jestha (Dry month): a. Dry b. Not Dry
10. Purpose: a. Drinking b. Irrigation c. Industry d. Other
11. Contact Person: a. Owner of well b. Neighbor c. Others
12. Lithology:
13. Field Visited by:

Cost Estimate
F.Y. 2065/66

Name of Project: Shallow Tubewell Irrigation Project
Name of Work: Shallow Tubewell Construction (25m deep)
Location: Baniniya-6, Dhanusha

A. Tube Well Construction (One Shallow Tube Well)						
SN	Description	Unit	Quantity	Rate	Amount (NRs.)	Remarks
1	**Transportation of drilling Tools**	**LS**			**1000**	
2	**Pilot hole drilling (down to 25 m. 2" dia.)**					
2.1	**Skilled driller**	**Md**	**2**	**250**	**500**	
2.2	**Semi skilled driller**	**Md**	**2**	**160**	**320**	
2.3	**Helper**	**md**	**6**	**125**	**750**	
			Sub-total		1570	
	Per meter drilling cost = Rs. 62.80					
3.	**Plant Installation and reaming work , 7" dia.**					
3.1	**Skilled driller**	**Md**	**3**	**250**	**750**	
3.2	**Semi skilled driller**	**Md**	**3**	**160**	**480**	
3.3	**Helper**	**Md**	**15**	**125**	**1875**	
			Sub-total		**3105**	
	Per meter plant installation and reaming work= Rs. 124.20					
4	**Well Development work**					
4.1	**Skilled Labour**	**Md**	**1**	**250**	**250**	
4.2	**Helper**	**Md**	**2**	**125**	**250**	
4.3	**Pump set on hire**	**Hrs**	**11**	**150**	**1650**	
			Sub-total		**2150**	
	Per hour rate of Well Development = Rs. 195.4545					
5	**Pumping test Work**					
5.1	**Skilled Driller**	**Md**	**1**	**250**	**250**	
5.2	**Helper**	**Md**	**3**	**125**	**375**	
5.3	**Pump set on hire**	**Hrs**	**4**	**150**	**600**	
			Sub-total		**1225**	
	Per hour rate of pumping test =Rs. 306.25					
6.	**Gravel**	**M^3**	**0.84**	**1850**	**1554**	
			Sub-total		**1554**	
			Total of A		10604	
B.	**Material Cost**					
1	**PVC Pipe 4", 4.5mm thick**	**M**	**15**	**660**	**9900**	
2	**PVC Screen**	**M**	**6**	**560**	**3360**	
3	**Sand Trap**	**M**	**2**	**585**	**1170**	
4	**Cone 4"**	**Nos**	**1**	**75**	**75**	
5	**4" MS pipe 4.5mm thick**	**M**	**2**	**445**	**890**	
6	**4" MS cap**	**Nos**	**1**	**500**	**500**	
7	**Top concrete seal (30cm*30cm & 10cm)**	**Nos**	**1**			
	Total of B				15895	
	VAT @13% of B				2066.35	
	Total of A &B				26499	
	Contingencies 5% of A+B				1324.95	
	Grand Total(A+B+VATof B+Contingencies)				29890.3	
	Cost of Centrifugal Pump including 13% VAT				40000.0	

	Total capital cost for operation of shallow Tubewell	69890.3	

In words Rs. Sixty nine thousand eight hundred ninty and paisa thirty only.
Assuming the command area for one shallow tubewell = 3ha**.**
Then cost per ha. = Rs. 23296.76

ABSTRACT OF COST for DEEP TUBEWELL
F.Y.2065/66

Name of Project: Production deep Tubewell (10”/6”) (APP)
Name of Work: Construction of deep tubewell upto the depth of 130m
Location : Laxminiya, Mahottari

SN	Details of work	Unit	Quantity	Rate	Amount (NRs.)	Remarks
1	Site Preparation					
	Semi Skilled worker	**m-day**	**3**	**200**	**600**	
	Unskilled worker	**m-day**	**20**	**150**	**3000**	
2	Drilling of pilot hole by 9.88”dia. bit					
2.1	Upto 100m					
	Skilled worker	**m-day**	**6.625**	**300**	**1987.5**	
	Semi skilled worker	**m-day**	**86.125**	**200**	**17225**	
	Unskilled worker	**m-day**	**126.25**	**150**	**18937.5**	
	Construction materials	**Set**	**1**	**147645**	**147645**	
	Machinery	**Set**	**1**	**76748.99**	**76748.99**	
	VAT of construction materials and machinery				**29171.2187**	
2.2	Beyond 100m					
	Skilled worker	**m-day**	**2.08**	**300**	**624**	
	Semi skilled worker	**m-day**	**27.04**	**200**	**5408**	
	Unskilled worker	**m-day**	**39.44**	**150**	**5916**	
	Construction materials	**Set**	**1**	**46046.6**	**46046.6**	
	Machinery	**Set**	**1**	**24493.88**	**24493.88**	
	VAT of construction materials and machinery				**9170.2624**	
3	Logging as per instruction					
	Skilled worker	**m-day**	**2**	**300**	**600**	
	Semi skilled worker	**m-day**	**4**	**200**	**800**	
	Unskilled worker	**m-day**	**8**	**150**	**1200**	
	Logging	**Job**	**1**	**3000**	**3000**	
4	Reaming of pilot hole by 13.75” dia.bit					
4.1	Upto 100m					
	Skilled worker	**m-day**	**3.3125**	**300**	**993.75**	
	Semi skilled worker	**m-day**	**43.063**	**200**	**8612.6**	
	Unskilled worker	**m-day**	**59.625**	**150**	**8943.75**	
	Construction materials	**Set**	**1**	**80768.75**	**80768.75**	
	Machinery	**Set**	**1**	**30842.1579**	**30842.1579**	
	VAT of construction materials and machinery				**14509.418**	
4.2	Beyond 100m					
	Skilled worker	**m-day**	**1.04**	**300**	**312**	

	Semi skilled worker	**m-day**	**13.48**	**200**	**2698**	
	Unskilled worker	**m-day**	**18.72**	**150**	**2808**	
	Construction materials	**Set**	**1**	**25251.9**	**25251.9**	
	Machinery	**Set**	**1**	**14441.56**	**14441.56**	
	VAT of construction materials and machinery				**5160.1498**	
5.	Reaming of pilot hole by 17.6” Φ bit					
	Skilled worker	**m-day**	**1.625**	**300**	**487.5**	
	Semi skilled worker	**m-day**	**21.125**	**200**	**4225**	
	Unskilled worker	**m-day**	**29.25**	**150**	**4387.5**	
	Construction materials	**Set**	**1**	**25684**	**25684**	
	Machinery	**Set**	**1**	**15130**	**16130**	
	VAT of construction materials and machinery				**5305.82**	
6	Reconditioning of borehole					
	Semi skilled worker	**m-day**	**9.75**	**200**	**1950**	
	Unskilled worker	**m-day**	**17.55**	**150**	**2632.5**	
	Construction materials	**Set**	**1**	**17550**	**17550**	
	Machinery	**Set**	**1**	**12492.87**	**12492.87**	
	VAT of construction materials and machinery				**3905.5731**	
7	Lowering of Assenbly					
	Skilled worker	**m-day**	**1.95**	**300**	**585**	
	Semi skilled worker	**m-day**	**10.4**	**200**	**2080**	
	Unskilled worker	**m-day**	**17.55**	**150**	**2632.5**	
	Machinery	**Set**	**1**	**32613.96**	**32613.96**	
	VAT of construction materials and machinery				**4239.8148**	
8.	Gravel Packing	M^3	18	1580	28440	
9.	Well development by rig machine					
	(Back washing and inner washing)					
	Skilled worker	**m-day**	**1**	**300**	**300**	
	Semi skilled worker	**m-day**	**5**	**200**	**1000**	
	Unskilled worker	**m-day**	**9**	**150**	**1350**	
	Construction materials	**Set**	**1**	**26037.5**	**26037.5**	
	Machinery	**Set**	**1**	**14314.45**	**14314.45**	
	VAT of construction materials and machinery				**5245.7535**	
10.	Well development by compressor					
	Skilled worker	**m-day**	**7**	**300**	**2100**	
	Semi skilled worker	**m-day**	**27**	**200**	**5400**	
	Unskilled worker	**m-day**	**36**	**150**	**5400**	
	Machinery	**Set**	**1**	**63110.44**	**63110.44**	
	VAT of construction materials and machinery				**8204.3572**	
11	Well development by pump					
	Skilled worker	**m-day**	**5**	**300**	**1500**	
	Semi skilled worker	**m-day**	**14**	**200**	**2800**	
	Unskilled worker	**m-day**	**35**	**150**	**5250**	
	Machinery	**Set**	**1**	**30454.6**	**30454.6**	
	VAT of construction materials and machinery				**3959.098**	

12.	Pumping test					
12.1	Drawdown test					
	Skilled worker	**m-day**	**2**	**300**	**600**	
	Semi skilled worker	**m-day**	**4**	**200**	**800**	
	Unskilled worker	**m-day**	**29**	**150**	**4350**	
	Machinery	**Set**	**1**	**18273**	**18273**	
	VAT of construction materials and machinery				**2375.49**	
12.2	Recovery test					
	Skilled worker	**m-day**	**2**	**300**	**600**	
	Semi skilled worker	**m-day**	**4**	**200**	**800**	
	Unskilled worker	**m-day**	**18**	**150**	**2700**	
	Total				959180.713	
	Contingencies @5%				42943.2507	
	Grand Total				1002123.98	

In words Rs. Ten lakhs Two thousand Twenty three and Paia Ninety six only.

Appendix A - 1
Mean Monthly Air Temperatures in Degrees Celsius, at Rampur

Index No: 0902 — Elevation: 0256 masl
Station: Rampur — Latitude: $27^{0}37'$ N
District: Chitwan — Longitude: $84^{0}25'$ E

Year	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	14.35	17.80	22.05	26.80	31.45	29.75	29.65	29.80	28.75	26.60	21.50	17.25
1996	15.60	18.10	23.50	26.75	29.95	29.25	29.30	29.40	28.95	25.20	21.45	16.70
1997	14.55	16.05	22.15	25.10	28.45	30.30	30.00	29.60	28.75	24.45	21.10	16.15
1998	14.40	18.15	20.90	26.25	30.20	31.50	29.15	29.30	29.60	28.00	23.05	18.80
1999	15.35	19.50	22.70	29.00	28.80	29.30	29.20	29.10	29.15	26.40	21.55	17.65
2000	15.15	16.35	21.70	26.90	28.70	29.60	29.50	29.40	28.50	26.85	22.35	16.70
2001	15.10	18.55	22.65	27.40	28.80	29.55	29.75	29.85	28.55	26.60	21.80	16.75
2002	16.00	19.15	23.25	26.95	28.40	29.95	29.25	29.80	28.40	25.85	21.75	17.15
2003	14.20	18.25	21.90	27.20	28.35	29.25	29.55	29.75	29.00	26.85	22.05	16.95
2004	15.15	18.35	24.50	26.80	28.75	29.50	29.15	30.20	28.85	25.15	20.55	17.20
2005	16.15	18.45	23.85	26.80	28.75	30.75	29.30	29.25	29.80	25.70	20.60	16.90
2006	15.50	21.25	22.60	26.65	29.15	29.65	30.25	30.10	28.70	26.40	21.55	17.40

Source --- Department of Hydrology & Meteorology

Appendix A - 2

Precipitation Records at Rampur Station

Year	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	0.00	15.00	6.00	184.00	74.00	646.00	381.00	410.00	304.00	130.00	43.00	10.00	2203.00
1972	0.00	36.00	30.00	14.00	64.00	297.00	557.00	303.00	291.00	52.00	4.00	0.00	1648.00
1973	61.00	24.00	2.00	13.00	175.00	648.00	310.00	361.00	502.00	244.00	0.00	0.00	2340.00
1974	28.00	1.00	71.00	12.00	110.00	396.00	678.00	653.00	500.00	78.00	0.00	6.00	2533.00
1975	28.00	14.00	7.00	21.00	132.00	256.00	792.00	350.00	612.00	102.00	0.00	0.00	2314.00
1976	21.00	35.00	0.00	77.00	113.00	486.00	553.00	390.00	129.00	20.00	0.00	0.00	1824.00
1977	20.00	7.00	0.00	87.00	185.00	113.00	520.00	461.00	97.00	154.00	30.00	40.00	1714.00
1978	5.00	26.00	34.00	36.00	267.00	451.00	705.00	294.00	426.00	29.00	5.00	9.00	2287.00
1979	4.00	15.00	1.00	24.00	8.00	303.00	558.00	453.00	285.00	90.00	29.00	54.00	1824.00
1980	0.00	0.00	27.00	7.00	168.00	322.00	374.00	376.00	255.00	52.00	0.00	3.00	1584.00
1981	52.00	0.00	56.00	136.00	220.00	272.00	678.00	446.00	474.00	0.00	25.00	0.00	2359.00
1982	19.00	8.00	52.00	79.00	21.00	538.00	492.00	455.00	310.00	8.00	10.00	4.00	1996.00
1983	15.00	0.00	6.00	29.00	169.00	92.00	74.00	322.00	165.00	121.00	0.00	15.00	1008.00
1984	39.00	11.00	5.00	17.00	287.00	386.00	658.00	300.00	388.00	49.00	0.00	13.00	2153.00
1985	11.00	11.00	0.00	11.00	196.00	202.00	713.00	319.00	422.00	181.00	2.00	65.00	2133.00
1986	0.00	20.00	0.00	45.00	85.00	291.00	390.00	443.00	201.00	112.00	1.00	54.00	1642.00
1987	0.50	11.30	26.60	47.40	100.90	246.20	836.70	360.70	161.00	193.00	0.00	11.30	1995.90
1988	0.00	2.70	38.20	92.20	220.40	205.60	491.10	524.40	150.50	14.90	4.80	32.50	1777.30
1989	47.60	1.10	26.30	0.10	162.80	394.50	667.70	192.10	290.00	40.50	0.30	1.40	1824.40
1990	0.00	29.80	34.40	26.50	131.80	285.00	478.10	298.80	272.00	85.00	0.00	1.80	1643.20
1991	17.20	8.40	23.70	21.00	113.90	322.40	523.80	441.20	331.60	0.00	0.00	57.30	1860.50
1992	6.40	9.50	0.00	29.40	62.20	194.70	530.20	429.40	187.50	139.10	7.70	0.70	1596.80
1993	3.90	9.10	49.40	82.50	190.50	258.30	309.10	615.10	246.70	99.90	0.60	0.00	1865.10
1994	39.90	32.60	9.30	24.80	123.40	406.30	419.70	400.30	483.50	3.60	0.00	4.20	1947.60
1995	1.50	22.90	5.90	36.00	152.90	507.40	479.40	454.60	196.40	42.50	58.90	3.50	1961.90
1996	55.70	40.40	0.00	6.00	113.60	364.20	482.70	341.80	261.60	117.80	0.00	0.00	1783.80
1997	13.40	1.50	2.90	144.60	83.40	321.70	583.20	481.30	290.90	64.40	7.90	146.00	2141.20
1998	4.40	13.20	87.20	88.30	150.10	332.30	573.70	1046.50	253.60	92.50	3.10	0.00	2644.90
1999	0.40	0.00	0.00	10.10	334.20	384.50	611.40	686.60	312.40	202.10	0.20	0.00	2541.90
2000	0.80	9.80	24.90	73.00	315.80	520.80	558.30	333.20	206.90	6.40	0.00	0.00	2049.90
2001	1.60	18.60	0.80	67.40	246.90	386.30	644.80	548.20	376.80	28.30	20.40	0.00	2340.10
2002	31.90	28.30	45.60	57.70	391.90	600.90	853.30	303.30	263.70	22.70	44.60	0.00	2643.90
2003	35.10	59.40	62.00	101.00	99.90	473.20	930.00	548.90	292.20	81.10	0.00	10.70	2693.50
2004	62.70	0.00	0.00	180.20	111.40	472.50	495.50	214.30	417.70	75.70	12.00	0.00	2042.00
2005	32.10	6.40	38.90	28.80	133.50	139.90	349.20	671.10	148.60	183.50	0.00	0.00	1732.00
2006	0.00	0.10	3.00	125.90	279.70	387.10	352.30	405.40	362.00	60.60	2.10	19.00	1997.20

Average	18.281	14.67	21.56	56.53	160.92	358.41	544.53	434.26	301.85	82.66	8.66	15.59	2017.92
Monsoon wetness index							1574.30						

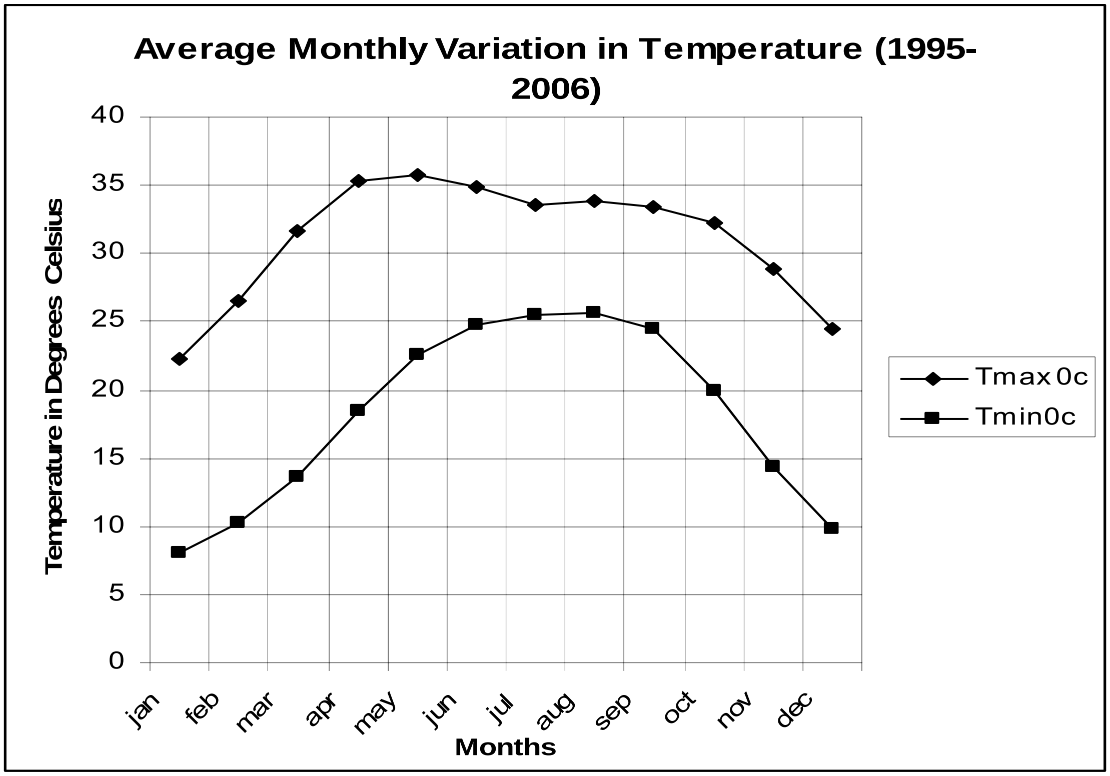
Source --- Department of Hydrology & Meteorology

Precipitation Records at Rampur (1995-2006)
Appendix A - 3

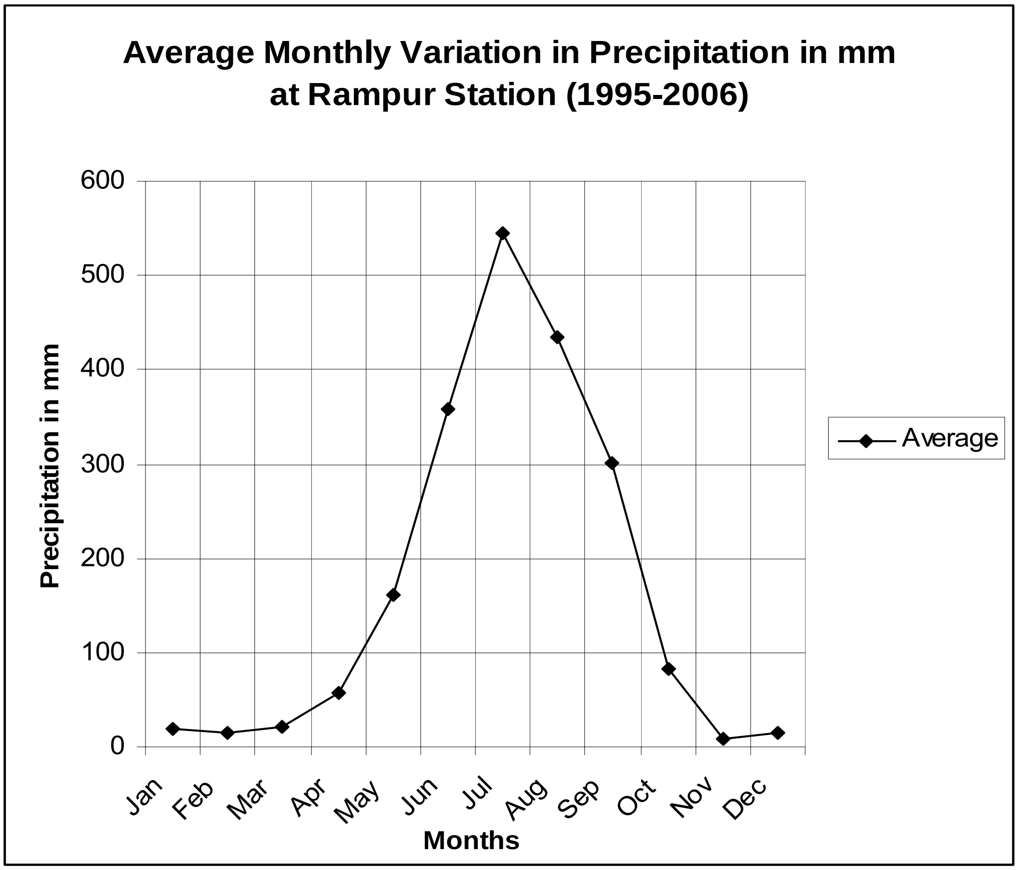
Years	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	1.50	22.90	5.90	36.00	152.90	507.40	479.40	454.60	196.40	42.50	58.90	3.50	1961.90
1996	55.70	40.40	0.00	6.00	113.60	364.20	482.70	341.80	261.60	117.80	0.00	0.00	1783.80
1997	13.40	1.50	2.90	144.60	83.40	321.70	583.20	481.30	290.90	64.40	7.90	146.00	2141.20
1998	4.40	13.20	87.20	88.30	150.10	332.30	573.70	1046.50	253.60	92.50	3.10	0.00	2644.90
1999	0.40	0.00	0.00	10.10	334.20	384.50	611.40	686.60	312.40	202.10	0.20	0.00	2541.90
2000	0.80	9.80	24.90	73.00	315.80	520.80	558.30	333.20	206.90	6.40	0.00	0.00	2049.90
2001	1.60	18.60	0.80	67.40	246.90	386.30	644.80	548.20	376.80	28.30	20.40	0.00	2340.10
2002	31.90	28.30	45.60	57.70	391.90	600.90	853.30	303.30	263.70	22.70	44.60	0.00	2643.90
2003	35.10	59.40	62.00	101.00	99.90	473.20	930.00	548.90	292.20	81.10	0.00	10.70	2693.50
2004	62.70	0.00	0.00	180.20	111.40	472.50	495.50	214.30	417.70	75.70	12.00	0.00	2042.00
2005	32.10	6.40	38.90	28.80	133.50	139.90	349.20	671.10	148.60	183.50	0.00	0.00	1732.00
2006	0.00	0.10	3.00	125.90	279.70	387.10	352.30	405.40	362.00	60.60	2.10	19.00	1997.20
Average	19.97	16.72	22.60	76.58	201.11	407.57	576.15	502.93	281.90	81.47	12.43	14.93	2214.36
Monsoon wetness index							1574.30						

Source --- Department of Hydrology & Meteorology

Total Annual Precipitation in the watershed area



Average Monthly Variation in Temperature (1995-2006)



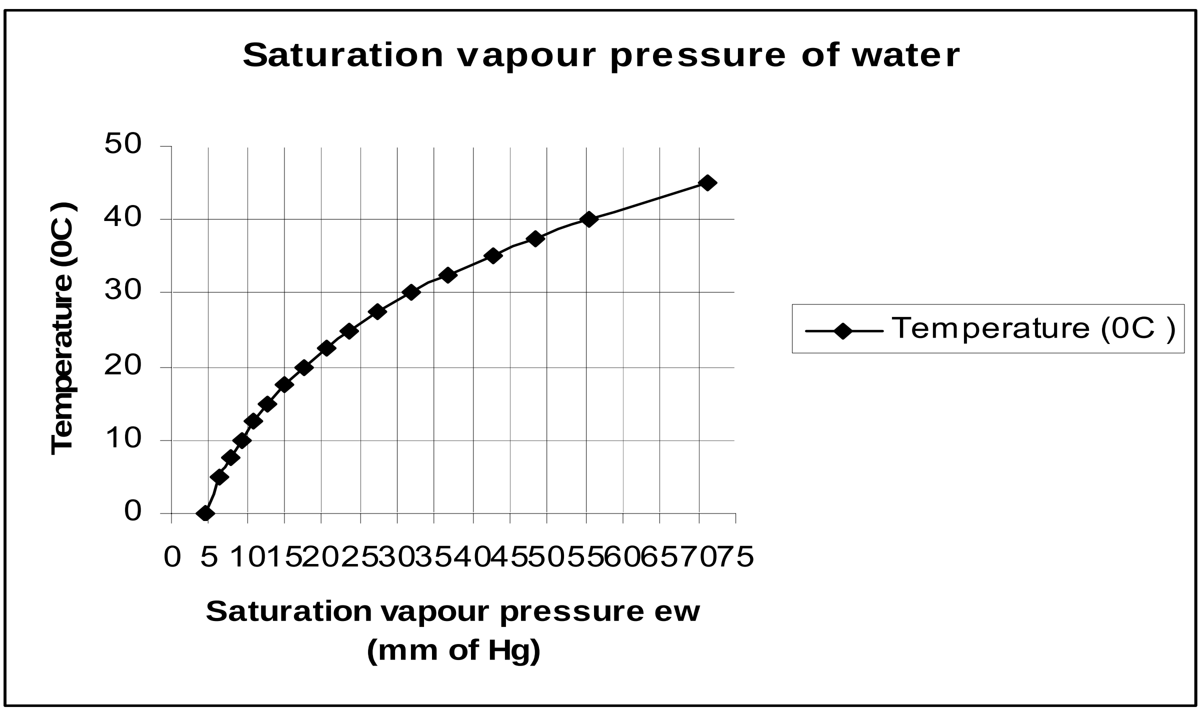
Appendix A–4(Evapotranspiration analysis)

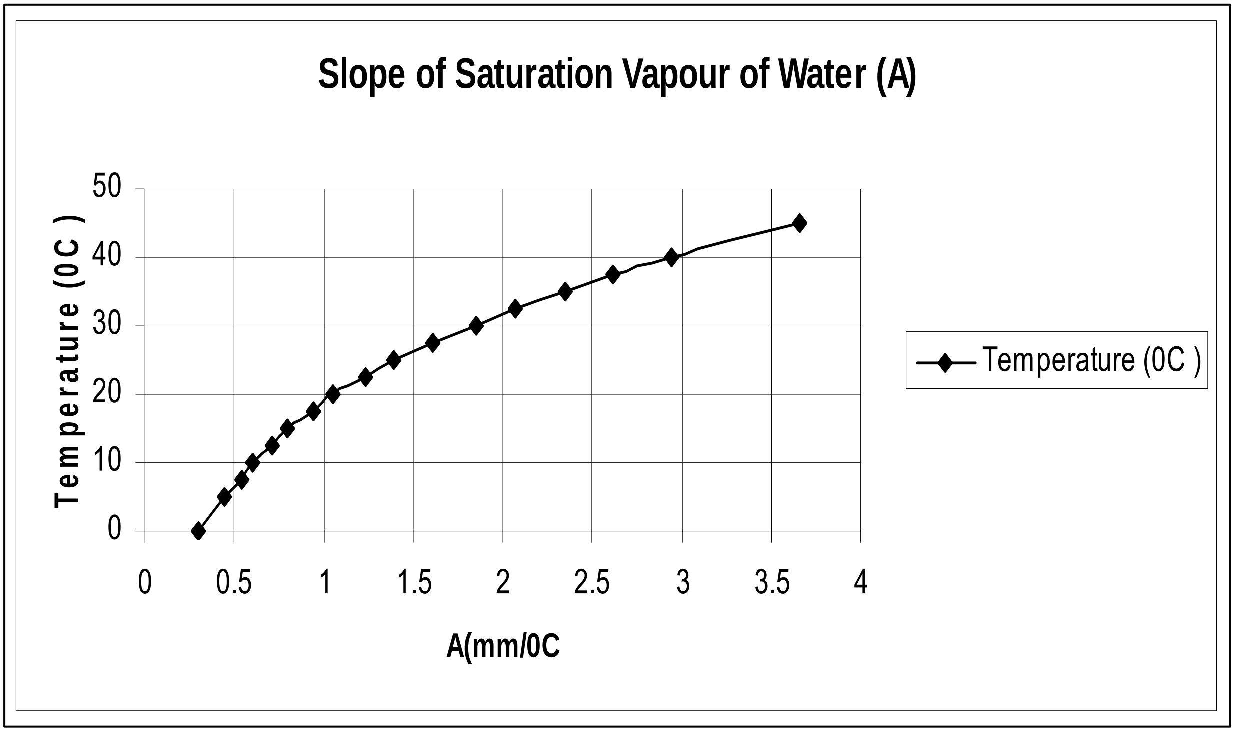
Reflection coefficient (r)

Surface	Range of r Values
Close ground crops	0.15--0.25
Bare lands	0.05--0.45
Water surface	0.05
Snow	0.45--0.95

Saturation Vapour pressure of Water

Temperature (^0C)	Saturation vapour pressure ew (mm of Hg)	A(mm/^0C)
0.00	4.58	0.30
5.00	6.54	0.45
7.50	7.78	0.54
10.00	9.21	0.60
12.50	10.87	0.71
15.00	12.79	0.80
17.50	15.00	0.95
20.00	17.54	1.05
22.50	20.44	1.24
25.00	23.76	1.40
27.50	27.54	1.61
30.00	31.82	1.85
32.50	36.68	2.07
35.00	42.81	2.35
37.50	48.36	2.62
40.00	55.32	2.95
45.00	71.20	3.66





Mean Monthly Solar Radiation at top of Atmosphere, Ha in mm of Evaporable Water / day

N-Latitude(degrees)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	14.50	15.00	15.20	14.70	13.90	13.40	13.50	14.20	14.90	15.00	14.60	14.30
10	12.80	13.90	14.80	15.20	15.00	14.80	14.80	15.00	14.90	14.10	13.10	12.40
20	10.80	12.30	13.90	15.20	15.70	15.80	15.70	15.30	14.40	12.90	11.20	10.30
30	8.50	10.50	12.70	14.80	16.00	16.50	16.20	15.30	13.50	11.30	9.10	7.90
40	6.00	8.30	11.00	13.90	15.90	16.70	16.30	14.80	12.20	9.30	6.70	5.40
50	3.60	5.90	9.10	12.70	15.40	16.70	16.10	13.90	10.50	7.10	4.30	3.00

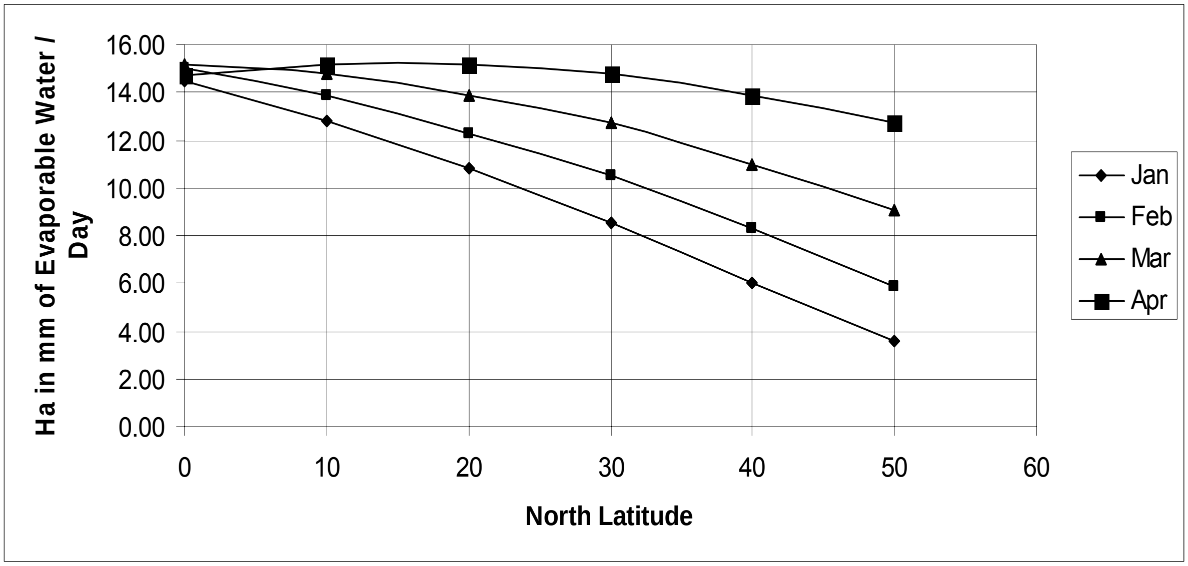


Fig. 6.3 a

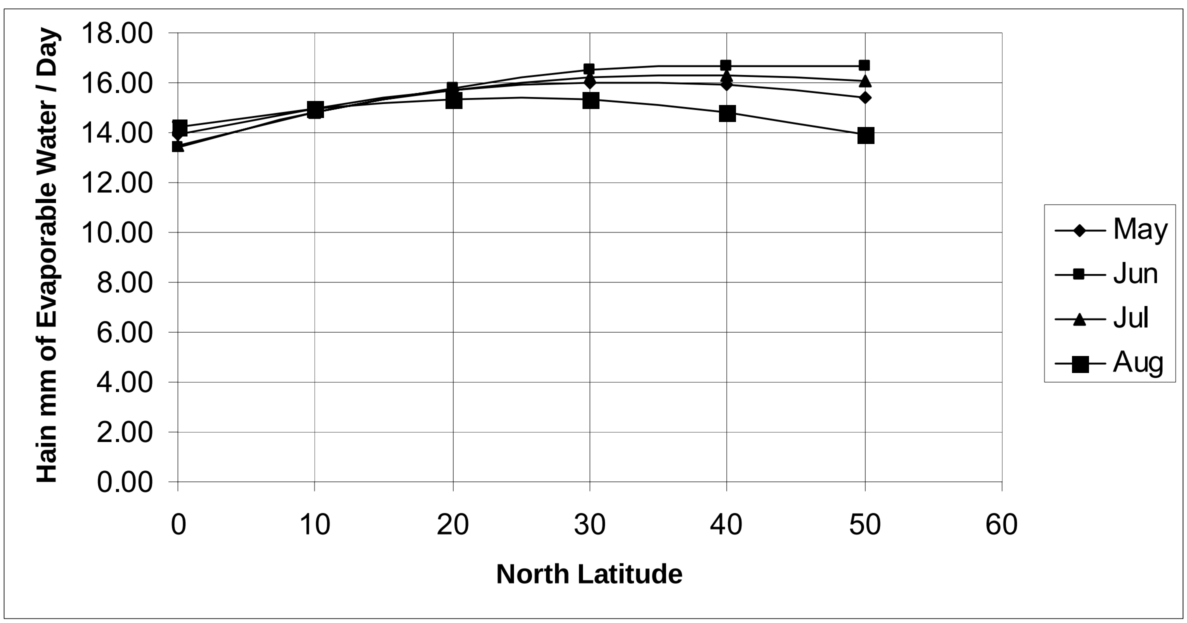


Fig. 6.3 b

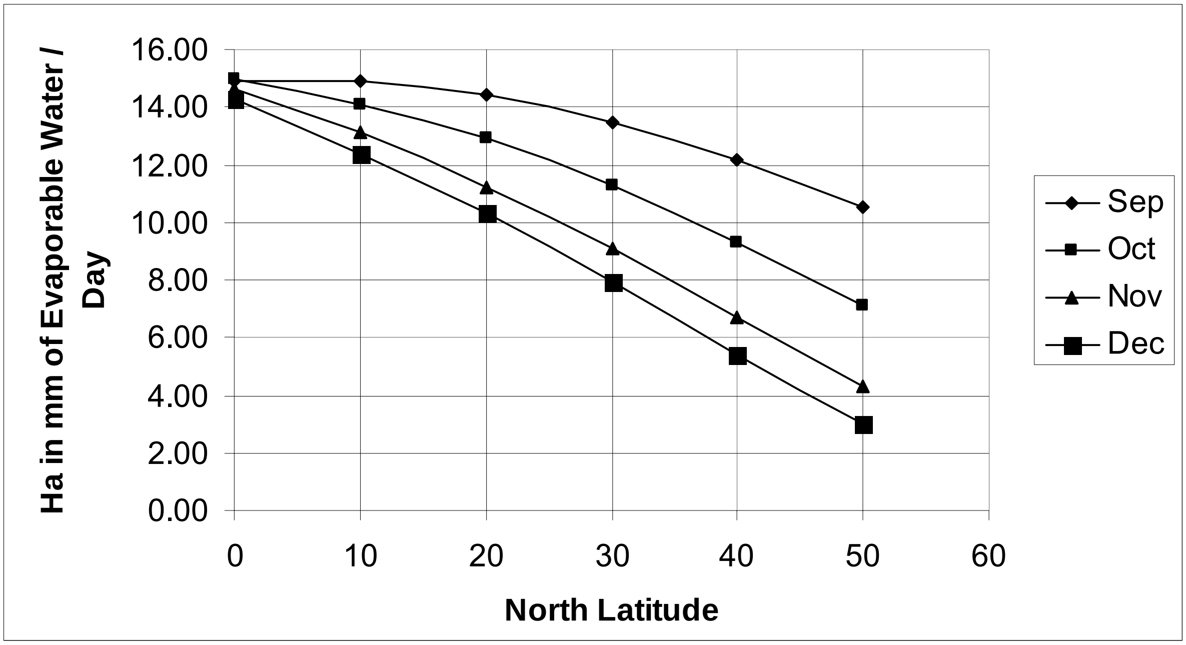


Fig 6.3 c

Fig 6.3 Mean Monthly Solar Radiation at top of atmosphere, Ha in mm of evaporable water / Day a) from Jan to Apr, b) from May to Aug and c) from sep to Dec.

Mean Monthly Values of Possible Sunshine Hours, N

N-Latitude(degrees)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
10	11.6	11.8	12.1	12.4	12.6	12.7	12.6	12.4	12.9	11.9	11.7	11.5
20	11.1	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
30	10.4	11.1	12.0	12.9	13.7	14.1	13.9	13.2	12.4	11.5	10.6	10.2
40	9.6	10.7	11.9	13.2	14.4	15.0	14.7	13.8	12.5	11.2	10.0	9.4
50	8.6	10.1	11.8	13.8	15.4	16.4	16.0	14.5	12.7	10.8	9.1	8.1

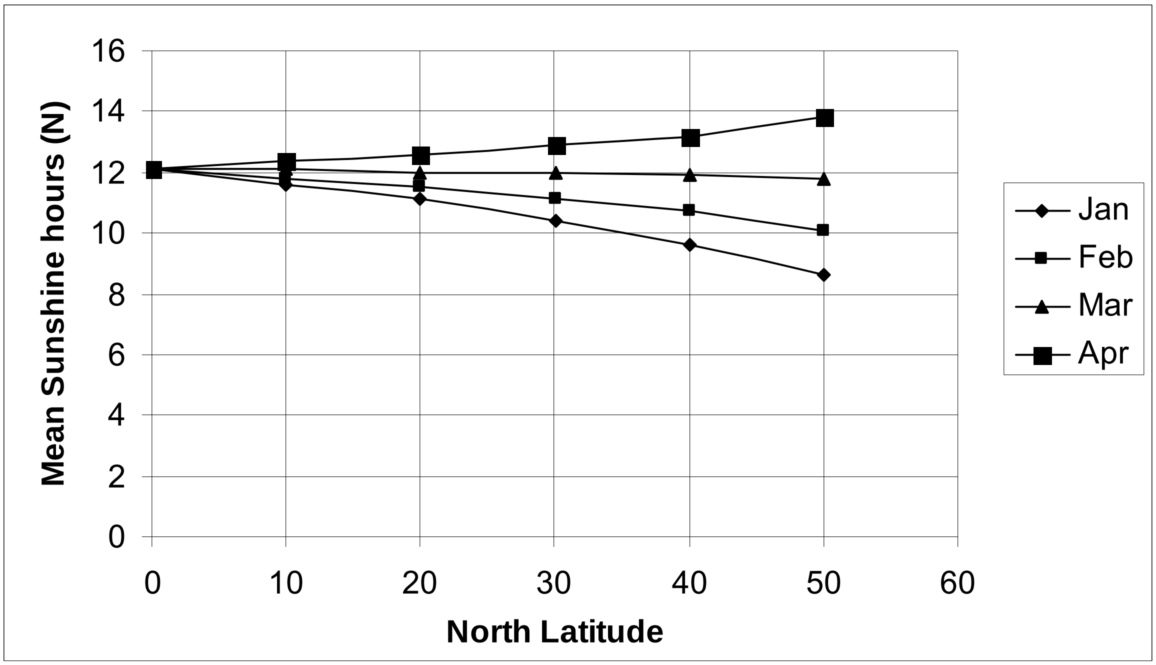

16
14
12
10
8
6
4
2
0
Mean Sunshine hours (N)
0
10
20
30
40
50
60
North Latitude
Jan
Feb
Mar
Apr

Fig 6.4a

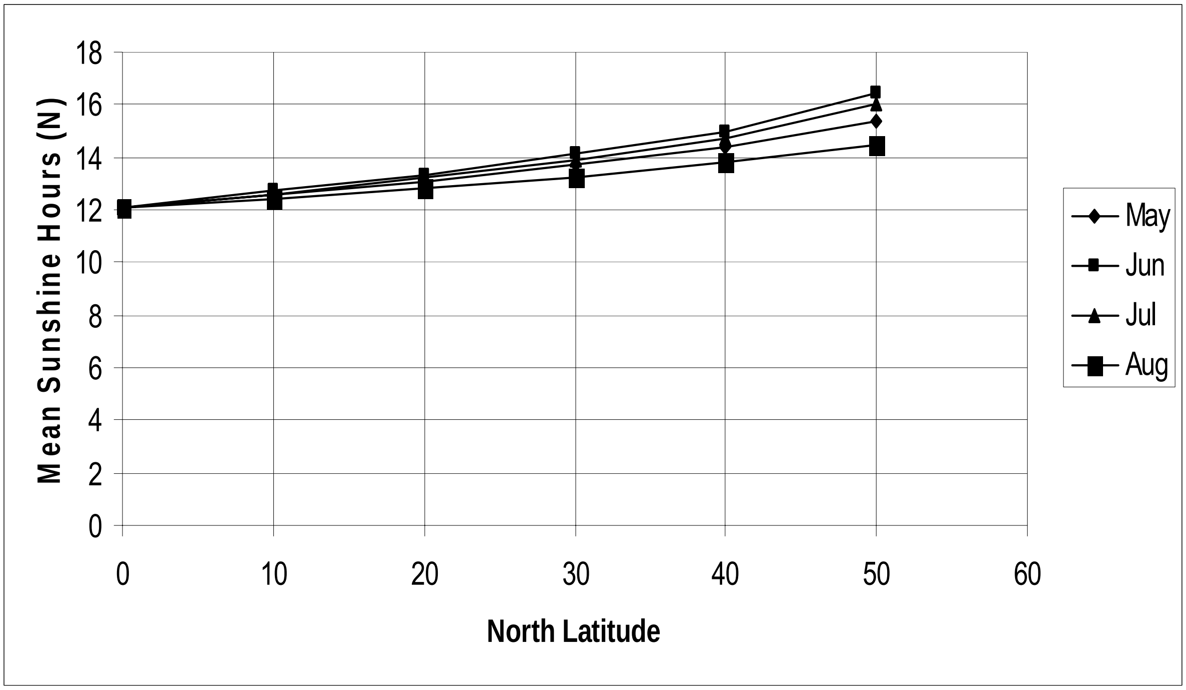


Fig 6.4 b

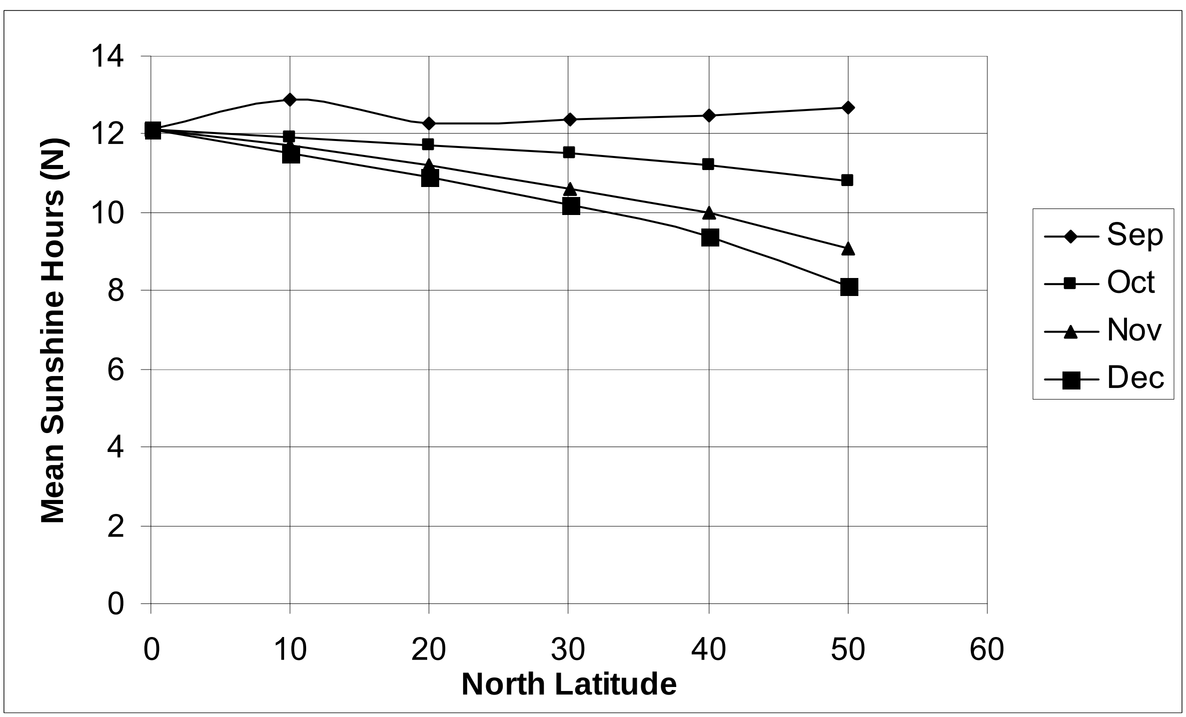


Fig 6.4 c

Fig 6.4 : Mean Monthly Values of Possible Sunshine Hours, N, a) from Jan to Apr, b) from May to Aug and c) from sep to Dec.

Monthly Daytime Hours Percentages, P_h, For use in Blaney- Criddle Formula

N-Latitude(degrees)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	8.5	7.66	8.49	8.21	8.5	8.22	8.5	8.49	8.21	8.5	8.22	8.5
10	8.13	7.47	8.45	8.37	8.81	8.6	8.86	8.71	8.25	8.34	7.91	8.1
15	7.94	7.36	8.43	8.44	8.98	8.8	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9	9.25	8.96	8.3	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.4	7.42
30	7.3	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
35	7.05	6.88	8.35	8.83	9.76	9.77	9.93	9.37	8.36	7.87	6.97	6.86
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52

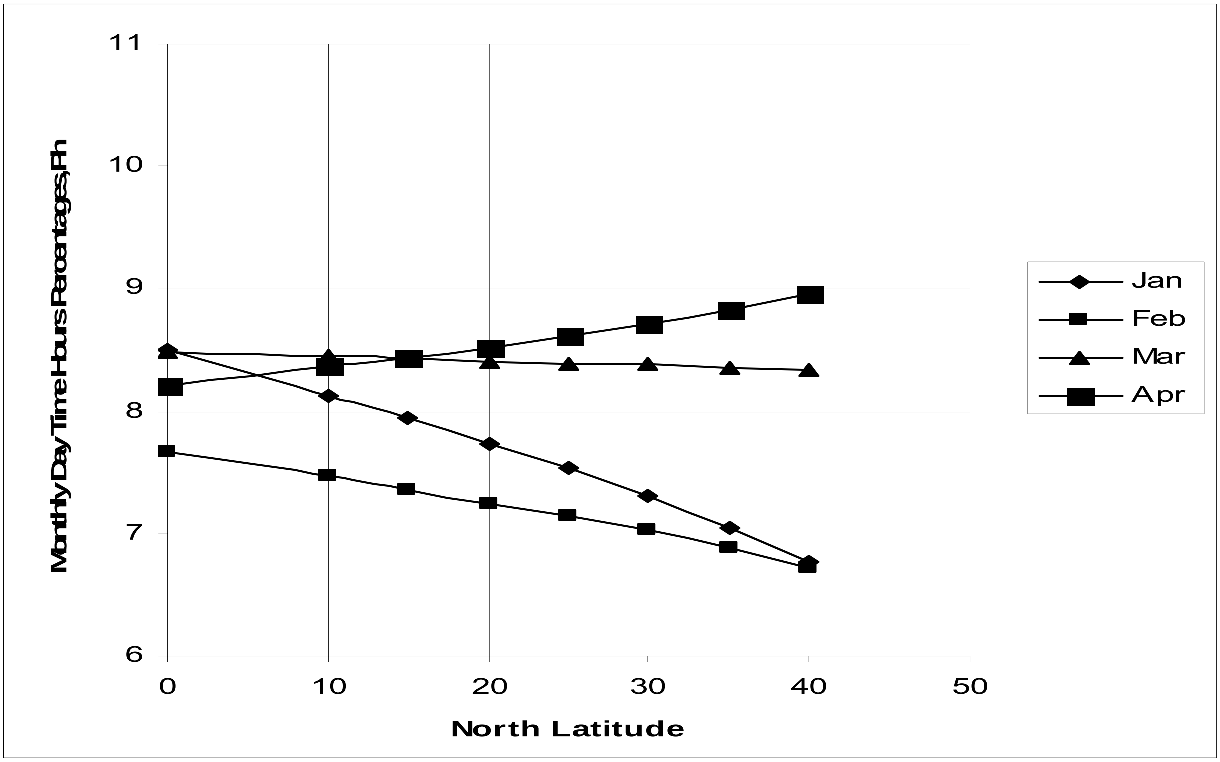


Fig: 6.6 a

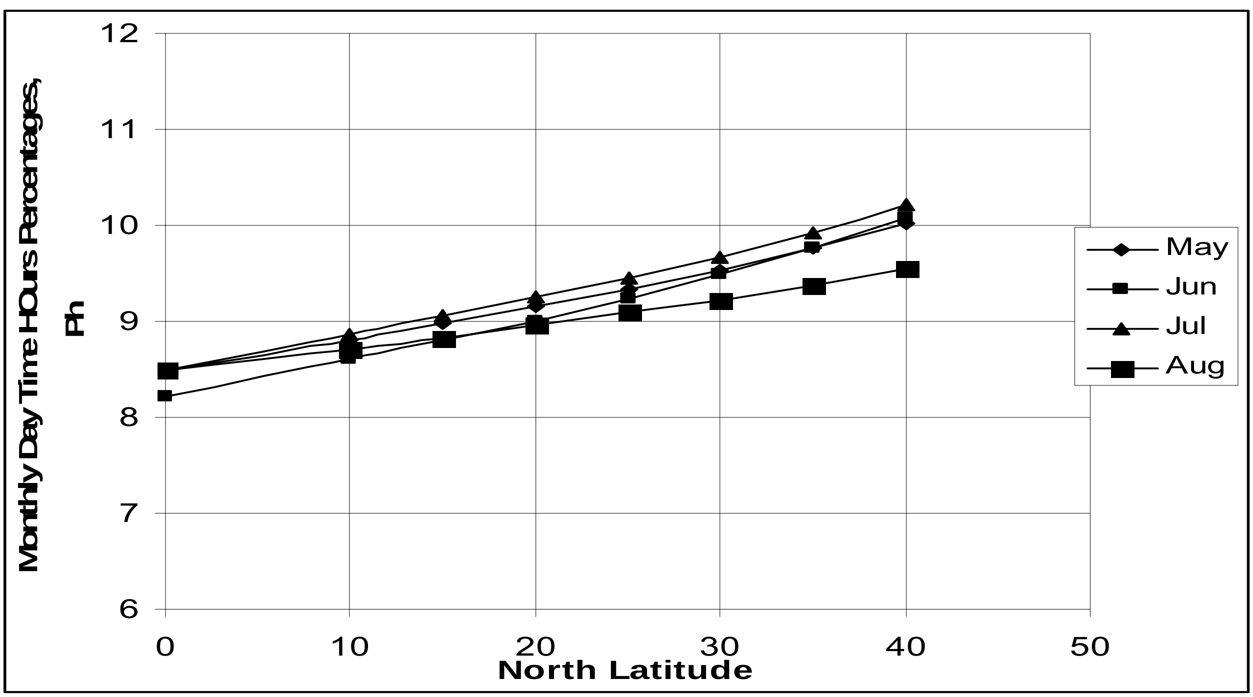


Fig: 6.6 b

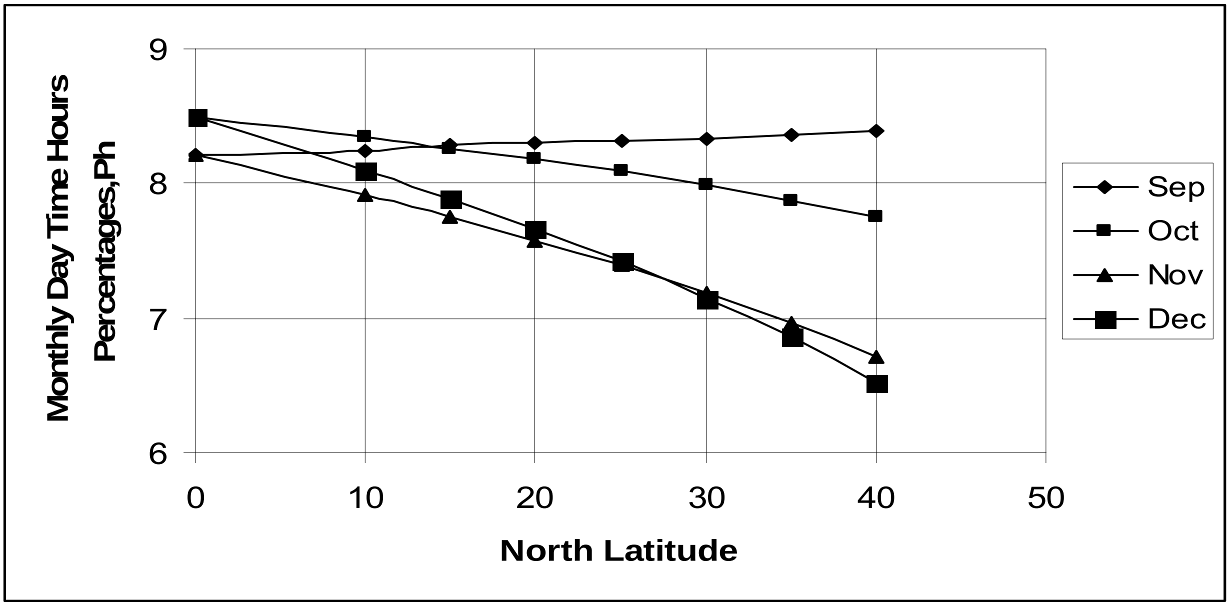


Fig : 6.6 c

Fig: 6.6 : Monthly Day time %, Ph vs. north latitude a) from Jan to Apr, b) from May to Aug and c) from sep to Dec.

Adjustment Factor La for use in Thornthwaite Formula

N-Latitude(degrees)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.9	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
30	0.9	0.87	1.03	1.08	1.18	1.17	1.2	1.14	1.03	0.98	0.89	0.88
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81

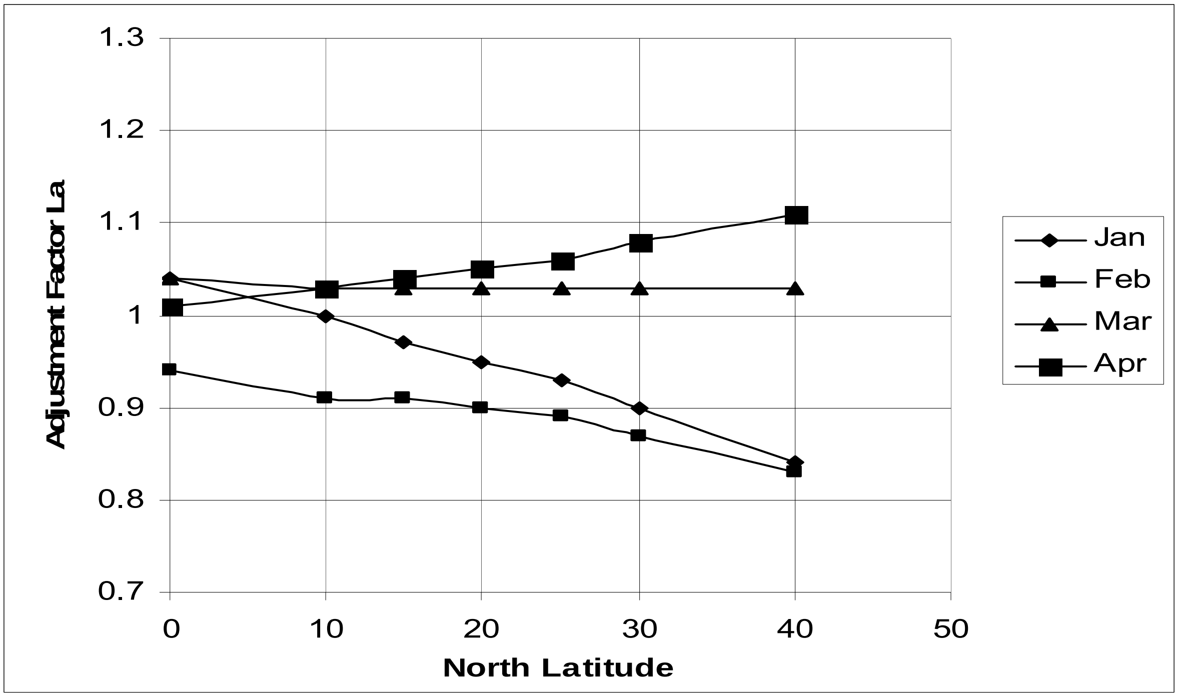


Fig: 6.7 a

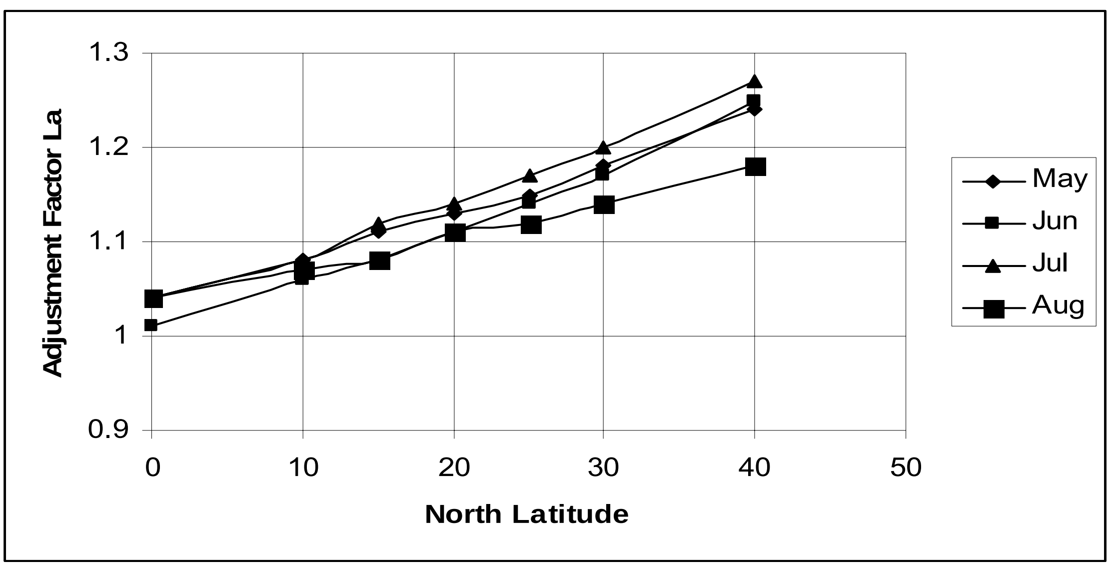


Fig 6.7 b

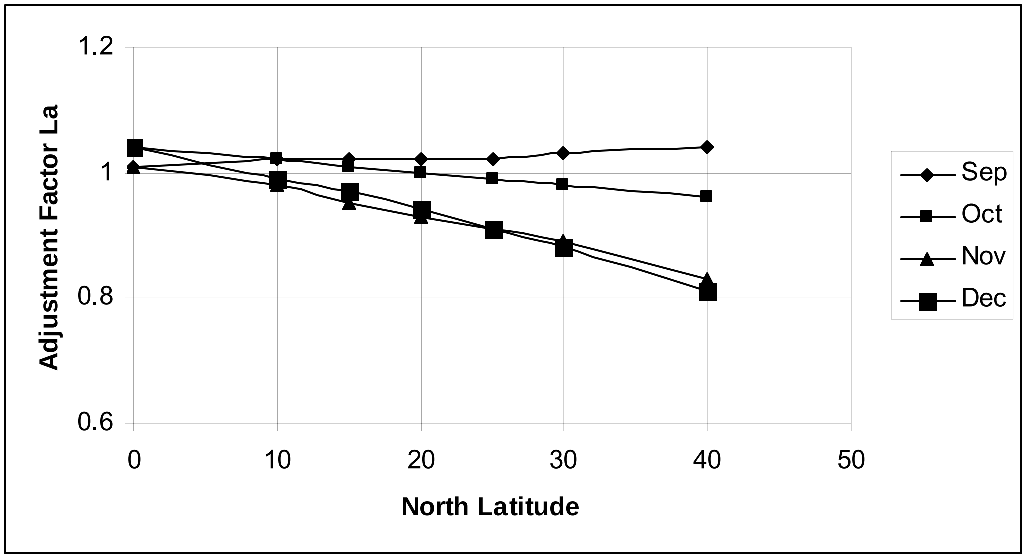


Fig 6.7 c

Fig 6.7: Adjustment factor La for using in Thornthwaite formula a) from Jan to Apr, b) from May to Aug and c) from sep to Dec.

Table: Sunshine hours in hrs / day at Rampur station

Year	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	6.2	7.7	8.2	7.7	10.4	6.8	2.5	4.9	4.7	7.1	7.6	6.3
1988	6.8	7.3	8.5	8.4	8.6	6.1	3.5	3.6	6.7	8.8	8.8	6.2
1989	6.1	7.7	8.1	9.8	8.4	7.1	3.5	5.6	5.0	8.7	7.8	6.6
1990	5.7	5.9	8.5	9.7	8.2	6.9	3.4	5.9	5.7	8.3	8.6	6.1
1991	5.8	7.4	8.6	8.8	8.1	5.1	4.4	3.8	5.6	8.5	7.6	5.9
Average	6.1	7.2	8.4	8.9	8.7	6.4	3.5	4.8	5.5	8.3	8.1	6.2

Source: Department of Hydrology and Meteorology

Table: Wind Speed in Km / hr at Rampur station

Year	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1987	0.8	1.6	2.2	3.1	3.0	3.3	2.6	2.4	1.7	1.1	0.6	0.4	1.9
1988	0.7	1.4	1.9	2.6	2.9	2.4	2.4	2.5	1.7	0.7	0.6	1.2	1.8

1989	1.1	1.4	2.1	2.8	3.3	2.8	2.4	2.1	1.9	0.9	0.7	0.7	1.9
1990	0.8	1.3	2.5	3.0	3.2	2.8	1.8	2.2	1.7	1.2	0.8	0.0	0.0
1991	1.0	1.6	2.3	2.8	3.2	2.7	1.9	2.4	1.6	1.0	0.8	0.9	1.9
Average	0.9	1.5	2.2	2.9	3.1	2.8	2.2	2.3	1.7	1.0	0.7	0.6	1.5

Source: Department of Hydrology and Meteorology

Table: Relative Humidity in Percentage at Rampur station

Year/Month	Year									
	1987		1988		1989		1990		1991	
	8:45	17:45	8:45	17:45	8:45	17:45	8:45	17:45	8:45	17:45
Jan	97.0	79.0	97.0	83.0	98.0	82.0	98.0	82.0	99.0	77.0
Feb	88.0	67.0	88.0	69.0	87.0	62.0	87.0	62.0	88.0	59.0
Mar	72.0	54.0	74.0	57.0	73.0	49.0	73.0	49.0	74.0	50.0
Apr	56.0	39.0	65.0	54.0	48.0	28.0	48.0	28.0	57.0	37.0
May	59.0	47.0	73.0	62.0	65.0	50.0	65.0	50.0	64.0	54.0
Jun	78.0	70.0	80.0	73.0	80.0	67.0	80.0	67.0	81.0	72.0
Jul	89.0	83.0	86.0	82.0	89.0	81.0	89.0	81.0	84.0	77.0
Aug	86.0	80.0	88.0	86.0	86.0	79.0	86.0	79.0	84.0	83.0
Sep	85.0	84.0	85.0	82.0	87.0	85.0	87.0	85.0	86.0	83.0
Oct	87.0	85.0	83.0	82.0	87.0	84.0	87.0	84.0	88.0	80.0
Nov	91.0	85.0	88.0	81.0	91.0	83.0	91.0	83.0	95.0	78.0
Dec	96.0	88.0	97.0	87.0	97.0	87.0	97.0	87.0	99.0	80.0
Year	82.0	72.0	84.0	75.0	82.0	70.0	82.0	70.0	83.0	69.0

Source: Department of Hydrology and Meteorology

Table:

Mean Monthly Air Temperature in Degrees Celsius at Rampur, Chitwan

Year/Month	Months														
	1987			1988			1989			1990			1991		
	Max	Min	Daily	Max	Min	Daily	Max	Min	Daily	Max	Min	Daily	Max	Min	Daily
Jan	24.2	6.8	15.5	24.5	8.2	16.4	22.0	6.8	14.4	22.0	6.8	14.4	22.5	7.4	15.0
Feb	27.1	9.5	18.3	28.0	10.6	19.3	25.3	7.1	16.2	25.3	7.1	16.2	28.0	9.6	18.8
Mar	30.5	12.6	21.6	31.5	12.8	22.2	31.3	12.9	22.1	31.3	12.9	22.1	32.7	14.2	23.5
Apr	35.9	15.9	25.9	36.0	17.5	26.8	37.0	15.3	26.2	37.0	15.3	26.2	36.0	17.7	26.9
May	36.5	18.0	27.3	35.9	22.1	29.0	36.8	22.2	29.5	36.8	22.2	29.5	36.5	23.0	29.8
Jun	35.4	24.5	30.0	34.2	24.4	29.3	34.4	25.1	29.8	34.4	25.1	29.8	34.1	25.2	29.7
Jul	31.5	24.6	28.1	32.9	24.7	28.8	31.9	25.0	28.5	31.9	25.0	28.5	33.5	25.8	29.7
Aug	32.2	24.4	28.3	32.8	0.0	0.0	33.7	25.3	29.5	33.7	25.3	29.5	33.3	25.4	29.3
Sep	32.8	24.6	28.7	33.4	23.1	28.3	32.3	24.7	28.5	32.3	24.7	28.5	33.0	24.6	28.8
Oct	31.0	20.2	25.6	32.8	18.8	25.8	32.4	19.9	26.2	32.4	19.9	26.2	32.2	19.2	25.7
Nov	28.9	13.7	21.3	29.6	10.8	20.2	27.7	12.4	20.0	27.7	12.4	20.0	27.9	11.2	19.5
Dec	25.0	10.1	17.5	25.5	10.0	17.8	23.7	7.9	15.8	23.7	7.9	15.8	24.1	8.0	16.0
Year	30.9	17.1	24.0	31.4	0.0	0.0	30.7	17.1	23.9	30.7	17.1	23.9	31.1	17.6	24.4

Source: Department of Hydrology and Meteorology

Table: Values of K for selected crops for use in Eq. 6.4

Crop	Period of growth	Value of K	Average Water Depth (cm)	Range of Monthly Values
Rice	July - Nov.	1.1	125 - 150	0.85 - 1.30
Wheat	Octo - April	0.65	38	0.50 - 0.75
Maize	June - Sept	0.65	45	0.50 - 0.80
Sugarcane	Feb.- Dec.	0.9	90	0.78 - 1.00
Cotton	June - Jan.	0.65	25 - 40	0.50 - 0.90
Potatoes	Oct. - Feb.	0.7	60 - 902	0.65 - 0.75
Natural Vegetation				
a. very dense		1.3		
b. dense		1.2		
c. Medium		1		
d. Light		0.8		

Table: Estimation of PET for different crop at Rampur (Narayani Lift Irrigation Project Command area)

Month's	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean T.(^{0}C)	23	26.7	31.5	36.4	36.5	34.5	32.3	33.1	32.8	32.2	28.4	24.1
Mean T (^{0}F).	73.4	80.06	88.7	97.52	97.7	94.1	90.14	91.58	61.04	89.96	83.12	75.38

Crops Paddy, Transplanted Rice, Latitude 27.6^0 N

Table: PET for Paddy & Potato

Crops: Paddy ,Transplanted Rice , K = 1.10				Crops : Potatoes K = 0.70			
Periods of Growth : July - Nov.				Peroids of Growth : Oct. - Feb.			
Months	$\bar{T}$ f	Ph	$\bar{T}$ f x Ph/100	Months	$\bar{T}$ f	Ph	$\bar{T}$ f x Ph/100
July	90.14	9.56	8.62	Oct.	89.96	8.03	7.22
Aug.	91.58	9.15	8.38	Nov.	83.12	7.29	6.06
Sept.	91.04	8.33	7.59	Dec	75.38	7.27	5.49
Oct.	89.96	8.03	7.23	Jan	73.4	7.41	5.44
Nov.	83.12	7.29	6.06	Feb	80.06	7.08	5.67
			37.87				29.88
		F=$\sum \bar{T}$ f×Ph/100=37.87				F=$\sum \bar{T}$ f×Ph/100=29.88	
		∴ Et=105.80 cm				∴ Et=52.99 cm	

Table : PET for Wheat & Maize

Crops : Wheat K = 0.65				**Crops : Maize K = 0.65**			
Periods of Growth : Nov. - Feb.				Perod of Growth : June - Sept.			
Months	$\bar{T}$ f	Ph	$\bar{T}$ f x Ph/100	Months	$\bar{T}$ f	Ph	$\bar{T}$ f x Ph/100
Nov	83.12	7.29	6.06	June	94.10	9.36	8.81
Dec	75.38	7.27	5.48	July	90.14	9.56	8.62
Jan	73.40	7.41	5.44	Aug	91.58	9.15	8.38
Feb	80.06	7.08	5.67	Sepr	91.04	8.33	7.58
			22.65				33.39
		$F=\sum \bar{T}$ f×Ph/100=22.65				$F=\sum \bar{T}$ f×Ph/100=33.39	
		∴ Et=37.40 cm				∴ Et=55.13 cm	

Table: PET for Sugarcane & Cotton

Crops: Sugarcane K = 0.90				**Crops: Cotton K = 0.65**			
Periods of Growth: Feb. - Dec.				Perod of Growth :June - Jan.			
Months	$\bar{T}$ f	Ph	$\bar{T}$ f xPh/100	Months	$\bar{T}$ f	Ph	$\bar{T}$ f xPh/100
Feb.	80.06	7.08	5.67	Jun.	94.10	9.36	8.81
Mar	88.70	8.38	7.43	Jul	90.14	9.56	8.62
Apr	97.52	8.66	8.45	Aug	91.58	9.15	8.38
May	97.70	9.43	9.21	Sep	91.04	8.33	7.58
Jun	94.10	9.36	8.81	Oct	89.96	8.03	7.22
Jul	90.14	9.56	8.62	Nov	83.12	7.29	6.06
Aug	91.58	9.15	8.38	Dec	75.38	7.27	5.48
Sep	91.04	8.33	7.58	Jan	73.40	7.41	5.44
Oct	89.96	8.03	7.22				57.59
Nov	83.12	7.29	6.06			$F=\sum \bar{T}$ f×Ph/100=88.35	
Dec	75.38	7.27	5.48			∴ Et= 95.09 cm	
		$F=\sum \bar{T}$ f×Ph/100=88.35					
		∴ Et= 201.96 cm					

Table: Annual E_t of Natural Vegetation

Months	$\bar{T}$ f	Ph	$\bar{T}$ f×Ph/100	Natural Vegetation	K	Et = 2.54*K*F
Jan	73.4	7.41	5.44	Very Dense	1.3	291.74
Feb	80.06	7.08	5.67	Dense	1.2	269.29
Mar	88.7	8.38	7.43	Medium	1	224.41
Apr	97.52	8.66	8.45	Light	0.8	179.53
May	97.7	9.43	9.21			
Jun	94.1	9.36	8.81			
Jul	90.14	9.56	8.62			
Aug	91.58	9.15	8.38			
Sep	91.04	8.33	7.58			
Oct	89.96	8.03	7.22			
Nov	83.12	7.29	6.06			
Dec	75.38	7.27	5.48			
			88.35			
		F=$\sum \bar{T}$ f×Ph/100=88.35				

Appendix: A-5

Vertical Electrical Sounding (VES) Lithologs

VES Station No. : 29 **Location: Sharadanagar—1, North**

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	3064	1	Top soil
2.	2109	8	Boulders
3.	83	30	Coarse sand
4.	1787	64	Pebbles/ Cobbles
5.	293	-------	Gravel

VES Station No.: 30 Location: Sharadanagar—1, South

VES Station No.: 32 Location: Rampurbazar

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	755	1	Top Soil
2.	224	6	Coarse sand
3.	348	31	Coarse sand
4.	493	52	Gravel
5.	326		Coarse sand

VES Station No : 27 Location: Lanku

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	7177	2	Top Soil
2.	483	11	Gravel
3.	1054	81	Pebbles/ Cobbles
4.	232	-----	Coarse sand

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	8322	2	Top Soil
2.	2802	17	Boulder
3.	503	-----	Gravel

VES Station No: 27 Location: Kalyanpur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1190	2	Top Soil
2.	6874	4	Boulders (dry)
3.	170	7	Coarse sand
4.	542	55	Gravel
5.	475	----	Coarse sand

VES Station No: 41 Location: Gitanagar

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	2110	3	Top Soil
2.	668	75	Gravel
3.	102	112	Sand fine
4.	599	---	Gravel

VES Station No: 43 Location: Shivanagar

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1440	2	Top Soil
2.	491	16	Gravel
3.	371	90	Coarse sand
4.	285	---	Sand fine

VES Station No: 44 Location: Kiranganj

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	124	1	Top Soil
2.	28	2	Silt
3.	89	16	Fine sand
4.	345	------	Coarse sand

VES Station No: 45 Locations: Sripur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	3457	4	Top Soil
2.	173	34	Coarse sand
3.	741	108	Gravel
4.	88	------	Silt

VES Station No: 46   Location: Narayanpur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	3064	1	Top Soil
2.	2109	8	Pebbles/cobbles
3.	83	30	Sand Coarse
4.	1787	64	Pebbles/ Cobbles
5.	293	-------	Gravel

VES Station No: 47   Location: Laxmipur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1094	5	Top Soil
2.	3315	14	Boulders
3.	451	---	Gravel

VES Station No: 51   Location: Baseni

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1822	2	Top Soil
2.	968	9	Gravel
3.	274	36	Coarse sand
4.	1240	54	Pebbles/cobbles
5.	249	-----	Coarse sand

VES Station No: 54   Location: Sharadpur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1200	2	Top Soil
2.	2537	13	Boulder
3.	183	22	Sand coarse
4.	2018	39	Pebbles/Cobbles
5.	375	---	Sand Coarse

VES Station No: 75   Location: Bhojad

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1060	3	Top Soil
2.	454	12	Gravel
3.	14	20	Silt
4.	202	186	Sand Coarse
5.	1337	----	Pebbles/ Cobbles

VES Station No: 54   Location: Sharadpur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1200	2	Top Soil
2.	2537	13	Boulder
3.	183	22	Sand coarse
4.	2018	39	Pebbles/Cobbles
5.	375		Sand Coarse

VES Station No: 59   Location: Baruwa

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1089	2	Top Soil
2.	244	9	Gravel
3.	68	44	Fine sand
4.	482		Coarse sand

VES Station No: 48   Location: Dhaddaghari

Layer No.	Resistivity	Depth (m)	Expected Lithology

	Ω-m		
1.	346	1	Top Soil
2.	96	3	Silt
3.	9650	7	Boulders (dry)
4.	133	----	Fine sand

VES Station No : 110   Location: Mohanpur

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	1515	2	Top Soil
2.	4305	6	Boulders
3.	468	129	Gravel
4.	274	----	Coarse sand

VES Station No : 72   Location: Gondrang --II West

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	137	2	Top Soil
2.	29	13	Silt
3.	109	70	Sand fine
4.	409	---	Sand Coarse

VES Station No : 73   Location: Gondrang --III

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	2910	1	Top Soil
2.	725	3	Gravel
3.	74	30	Sand fine
4.	271	---	Sand Coarse

VES Station No : 71   Location: Gondrang --I , East

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	54	1	Top Soil
2.	143	8	Sand Coarse
3.	74	37	Sand fine
4.	251	----	Sand Coarse

VES Station No : 26   Location: Gunjanagar

Layer No.	Resistivity Ω-m	Depth (m)	Expected Lithology
1.	306	1	Top Soil
2.	642	5	Gravel
3.	263	10	Pebbles/ Cobbles
4.	1503	34	Gravel
5.	321	----	

Appendix A-6

Driller's Borehole Lithologic Sample Logging

1. Well ID: Torikhet—14, Chitwan
   Well Type: Deep for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0	2.0	Top soil	2.00	
2	2.00	5.00	Sand	3.00	
3	5.00	65.00	Gravel	60.00	

2 Well ID: Kalyanpur –14, Chitwan
   Well Type: Deep for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.0	2.0	Clay	2.0	
2	2.0	5.0	Sand , gravel	3.0	
3	5.0	30.0	Boulders &gravel	25.0	
4	30.0	65.0	Gravel	35.0	

3 Well ID: Gitanagar—8, Parasnagar Chitwan
   Well Type: Deep for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	2.00	Top soil with clay	2.00	
2	2.00	5.00	Sand	3.00	
3	5.00	10.00	Gravel with sand	5.00	
4	10.00	40.00	Gravel with boulders, pebbles & cobbles	30.00	
5	40.00	60.00	Gravel with sand	20.00	
6	60.00	70.00	Gravel with boulders, pebbles & cobbles	10.00	

4 Well ID: Ramnagar, Bharatpur Municipality
Well Type: Deep for Drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	28.00	Clay	28.0	
2	28.0	31.0	White clay with siltstone cuttings	3.0	
3	31.0	40.0	Mudstone	9.0	
4	40.0	58.0	Clay	18.0	
5	58.0	64.0	Gravel with sand	6.0	
6	64.0	79.0	Clay	15.0	
7	79.0	90.0	Mudstone	11.0	
8	90.0	100.0	Clay	10.0	
9	100.0	104.0	Mudstone	4.0	
10	104.0	110.0	Cobbles, pebbles with clay	7.0	
11	110.0	150.0	Clay, white and grey	40.0	

5 Well ID: Rambag—13, Chitwan
Well Type: Deep for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	5.00	Top soil		
2	5.00	75.00	Gravel coarse with pebbles and cobbles		

6 Well ID: Lanku- , Chitwan
Well Type: Deep for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	2.00	Top soil	2.00	
2	2.00	5.00	Sand	3.00	
3	5.00	75.00	Gravel	70.00	

7 Well ID: Hotel Safari Narayani, Bharatpur,Chitwan
Well Type: Deep for drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	0.5	Top soil	0.5	
2	0.5	2.00	Black clay	1.5	
3	2.00	98.5	Medium sand to coarse sand with gravel and few boulder	96.5	
4	98.5	99.0	Very hard rock	0.5	

8 Well ID: Cancer Hospital (BPKMCH) –Krishnapur, Bharatpur—7
Well No--1
Well Type: Deep for drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	0.5	Top soil	0.5	
2	0.5	2.5	Black clay	2.00	
3	2.5	4.0	Sand with gravels	1.50	
4	4.0	4.5	Black clay	0.5	
5	4.5	11.0	Sand and gravels with boulders	6.5	
6	11.00	82.0	Coarse sand and gravels	71.0	
7	82.0	84.00	Sandy clay	2.0	
8	84.00	91.00	Coarse sand and gravels	7.0	
9	91.00	94.00	Coarse to fine sand	3.0	
10	94.00	105.00	Coarse sand gravels	11.0	

9 Well ID: Cancer Hospital (BPKMCH) –Krishnapur, Bharatpur—7
Well No--2
Well Type: Deep for drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	0.5	Top soil	0.5	
2	0.5	2.5	Black clay	2.00	
3	2.5	4.0	Sand with gravels	1.50	
4	4.0	4.5	Black clay	0.5	
5	4.5	11.0	Sand and gravels with boulders	6.5	
6	11.00	70.0	Coarse sand and gravels	59.0	

10 Well ID: Katahar chowk, Krishnapur , Bharatpur--7
Well Type: Deep for Drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.0	5.0	Top soil	5.0	
2	5.0	85.0	Boulders, gravels ,pebbles	80.0	
3	85.0	126.0	Gravels	41.0	

11 Well ID: UNSTW-06
Well Type: Shallow for investigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	2.4	Clay sandy	2.4	
2	2.4	7.85	Gravel with boulders	5.45	

12 Well ID: UNSTW-09,Gondrang, Bharatpur
Well Type: Shallow tubewell for investigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	3.7	Clay sandy	2.4	
2	3.7	12.42	Gravel sandy with boulders	8.72	

13 Well ID: Gitanagar—8, Janaki Tole, Parasnagar
Well Type: private shallow tubewell for irrigation

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	1.22	Top soil	1.22	
2	1.22	8.85	Sand fine grey, red	7.63	
3.	8.85	12.2	Gravel boulders, pebbles, cobbles	3.35	

14 Well ID: UNSTW-08, Prembasti

Well Type: Exploratory shallow tubewell

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	3.2	Clay sandy	3.2	
2	3.2	22.0	Gravel sandy with boulders	18.8	

15 Well ID: UNSTW-07, Narayanpur
Well Type: Exploratory shallow tubewell

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	3.2	Clay sandy	3.2	
2	3.2	13.25	Gravel with boulders	10.05	

16 Well ID: Bharatpur municipality -10, Hakimchowk, Bharatpur
Well Type: Deep for Drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.0	5.0	Clayey sand	5.0	
2	5.00	83.00	Boulders	78.0	
3	83.0	86.0	Boulders , quartzite	3.0	
4	86.0	115.0	Boulders	29.0	

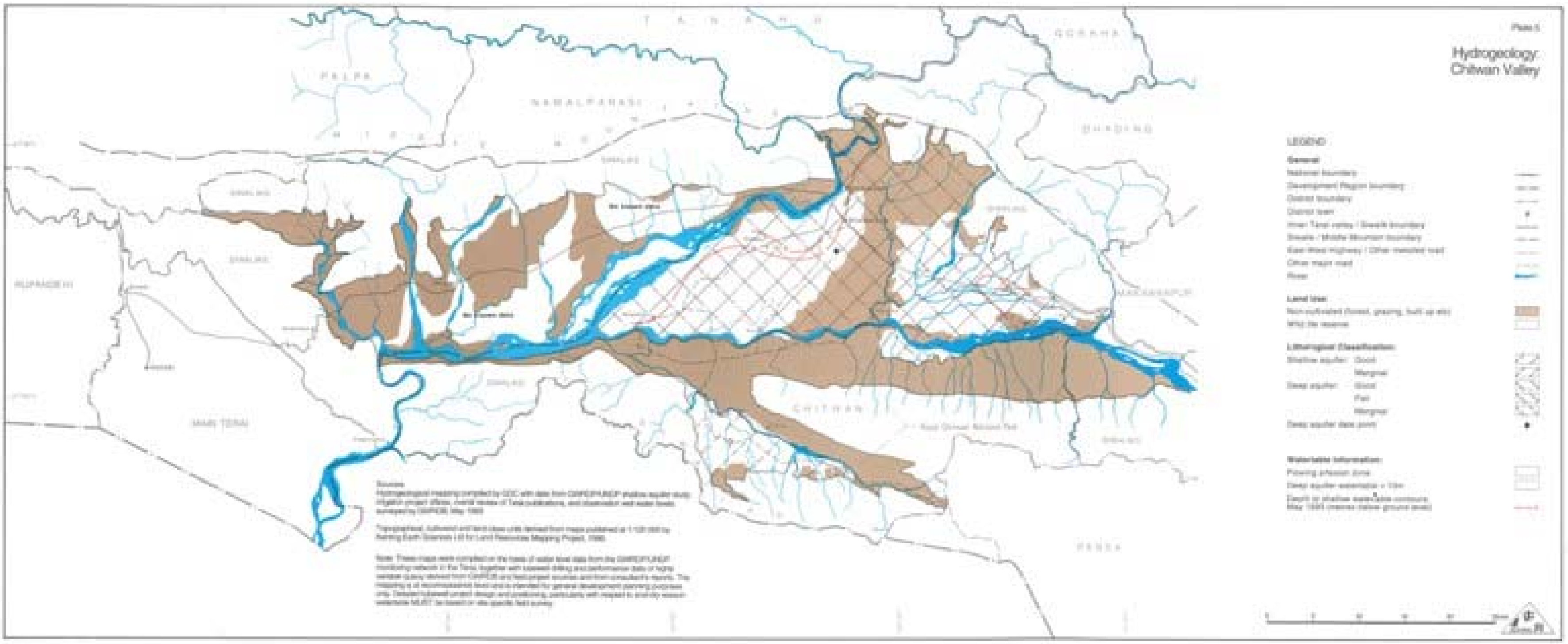
17 Well ID: IAAS Campus- Rampur, Chitwan

Well Type: Deep for Drinking water

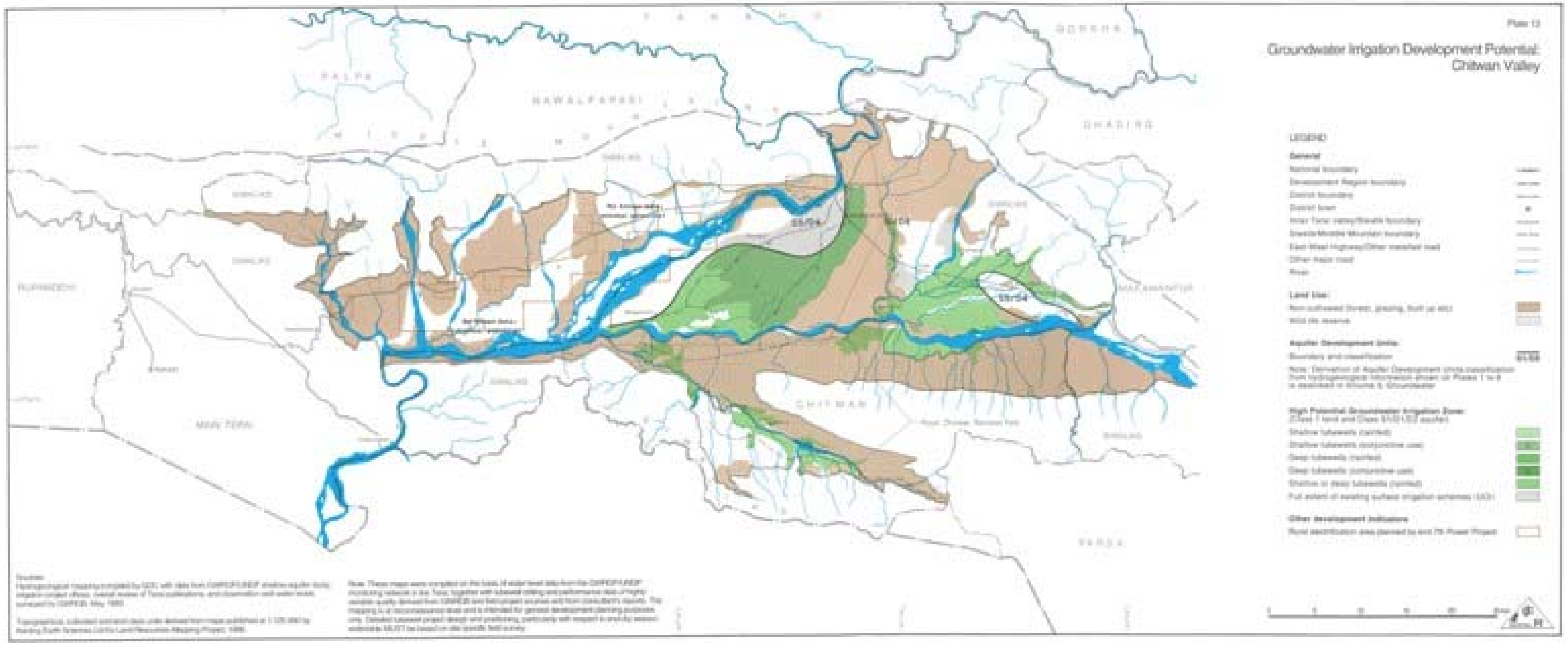
S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.0	6.0	Fine sand	6.0	
2	6.0	12.0	Boulders & gravels	12.0	
3	12.0	15.0	Gravels & coarse sand	3.0	
4	15.0	16.0	Coarse sand	1.0	
5	16.0	40.0	Gravels & coarse sand	24.0	

18 Well ID: Coca cola factory , Gondrang, Bharatpur
Well Type: Deep for Drinking water

S.No.	Depth in Metre		Lithologic Description	Thickness in metre	Remarks
	From	To			
1	0.00	2.00	Soil		
2	2.00	6.00	Gravel		
3	6.00	10.00	Cobble & boulders		
4	10.00	14.00	Clay		
5	14.00	15.00	Sand		
6	15.00	18.00	Clay		
7	18.00	24.00	Cobble & boulders		
8	24.00	27.00	Sand		
9	27.00	30.00	Cobble & boulders		
10	30.00	50.0	Gravel		
11	50.00	68.00	sand		
12	68.00	78.00	Gravels with sand		



Appendix-7 (a & b)


Groundwater Irrigation Development Potential:
Chitwan Valley