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Hydrogeologic assessment and groundwater reserve evaluation in northwestern parts of Dun valley aquifers of Chitwan, inner Terai

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ABSTRACT

The Chitwan Valley is one of the largest Dun Valleys in the Himalayan foothills of Nepal. Dun gravels perhaps deposited in the late Pleistocene to very early Holocene about 22,000–7000 yr. B.P. Chitwan Dun Valley is underlain by Dun fan gravels or Dun gravels which form unconfined to semiconfined or leaky confined aquifers. The study area, situated in the NW part of the valley occupies an area of 70.8 km^2 .The hydrogeological situation in the study area is inferred from drilling data of Ground Water Resources Development Board (GWRDB), Agriculture Development Project Janakpur (ADPJ) and several private drilling companies .The Chitwan Dun Valley constitutes a closed groundwater system in the Siwalik Zone of Nepal Himalaya. The study area reveals the existence of two definite groundwater sub-basin each having its own hydraulic system and is a part of single large regional groundwater basin. Annual potential evapotranspiration (PET) calculated at Rampur (station no 0902) for five-year period (1990–1995) is 1.68 mm/day. Annual precipitation data recorded at Rampur is 2214 mm. Area of recharge is 70.8 km^2 and estimation of total groundwater storage(reserve) is 87.31 MCM per year, and dynamic reserve or annual potential recharge is estimated as 48.60 MCM per year.

INTRODUCTION

The study area lies in the Chitwan District, Narayani Zone, Central Development Region of Nepal between longitudes 83°54' 45''to 84°48'15'' E and latitudes 27°21'45'' to 27°52' 30''N. The district boundaries are marked by Nawalparasi District in the west along the Narayani River and the Makwanpur District in the east and the Parsa District and Bihar, India in the south. It has the Tanahun, Gorkha and Dhading Districts to the north (Fig. 1). It lies approximately 146 km SW from Kathmandu. The total area of the Chitwan is about 2,218 km^2.

The study area covers about 70.8 Km^2. The area includes ward nos. 2, 7,8,9,11,13 & 14 of Bharatpur municipality and parts of Mangalpur, Phulbari and Gitanagar VDCs. The study area includes the part of command area of the Narayani Lift Irrigation Project.

The climate of Chitwan is subtropical. Average maximum and minimum temperatures (1995 to 2006) recorded in the meteorological station at Rampur are 34.91°C in June and 8.08°C in January, respectively. The mean annual rainfall during 12 years from 1995 to 2006 at Rampur is 2214 mm. More than 80% of the total annual rainfall occurs during the monsoon season from June to September (DHM 2006).

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 m from mean sea level. The Narayani River is the biggest river in the Chitwan District, which forms the western border with the Nawalparasi District. The Rapti River, which

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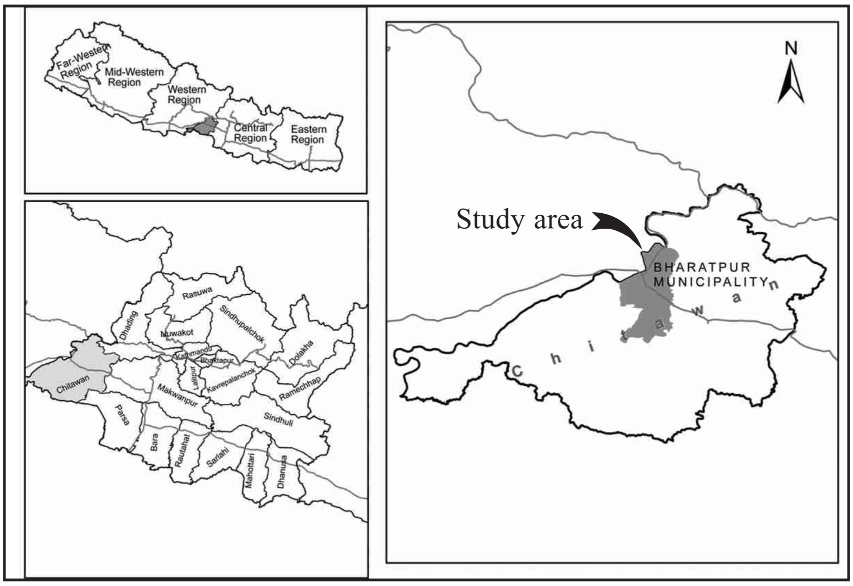

Fig. 1 Location Map of the Study Area

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. 2). Two major rivers the Narayani River in the west and the Rapti River in the south bound the study area. The Kerunga ghol is a drainage flowing from east to south west direction forming a tributary of the Rapti River. Many swamps, wetlands and depressions are present in this area.

GEOLOGICAL SETTING OF THE CHITWAN DUN VALLEY

The Dun Valleys are one of the ten natural divisions in Nepal Himalayas (Hagen 1969). These tectonic Dun Valleys are considered to be part of the Siwalik. The Chitwan Dun Valley is a NNW-SSE trending synclinal intermontane valley (about 140 km long and 60 km wide) formed within the Sub-Himalayas (Siwaliks) of Nepal Himalayas (Fig. 3). The Siwaliks consist mainly of conglomerates, sandstones and clays of Neogene period. The lenticular shaped longitudinal valley in the Siwaliks represents the active front of the Himalayan chain and represents tectonic or structural depression in the post Siwalik time. These youngest formations of the Himalayas, that were here caught up in final phases of folding and rising, so that they extend in a strike direction parallel to the Himalayas (Haffner 1979). The cross-section of geological map of the Chitwan Valley (Fig. 4) illustrates the geological condition of the valley.

The Lower and Middle Siwaliks occur continuously all along the Himalayas, 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 Siwaliks. The formations from the Lower Siwaliks predominate in the west (Hagen 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 tributaries emerging from the Mahabharat Range. In the west, the floor of the basin consists of alluvial deposits of the Narayani River (Haffner 1979). 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 the Middle Siwalik strata (Hagen 1969).

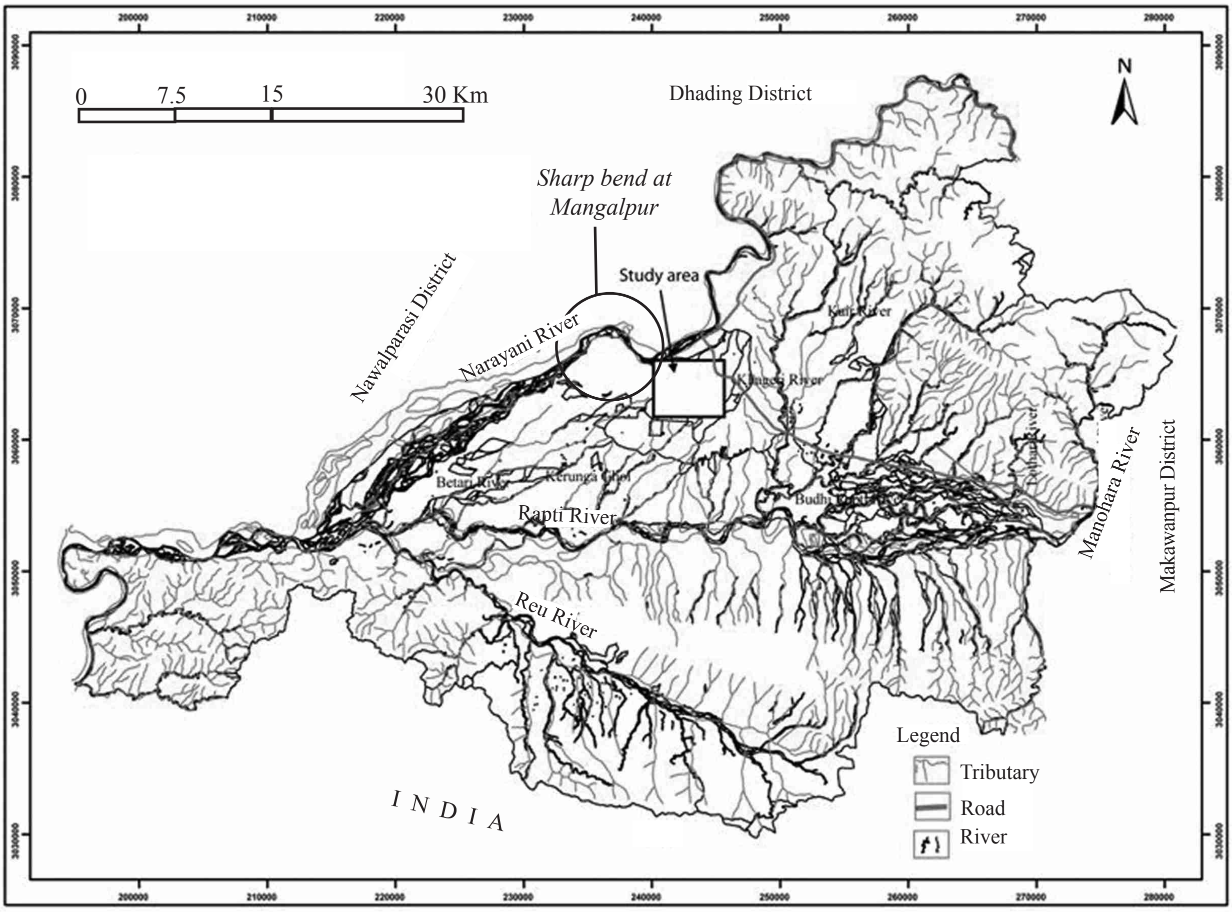

Fig. 2 Drainage system of the Chitwan Dun Valley

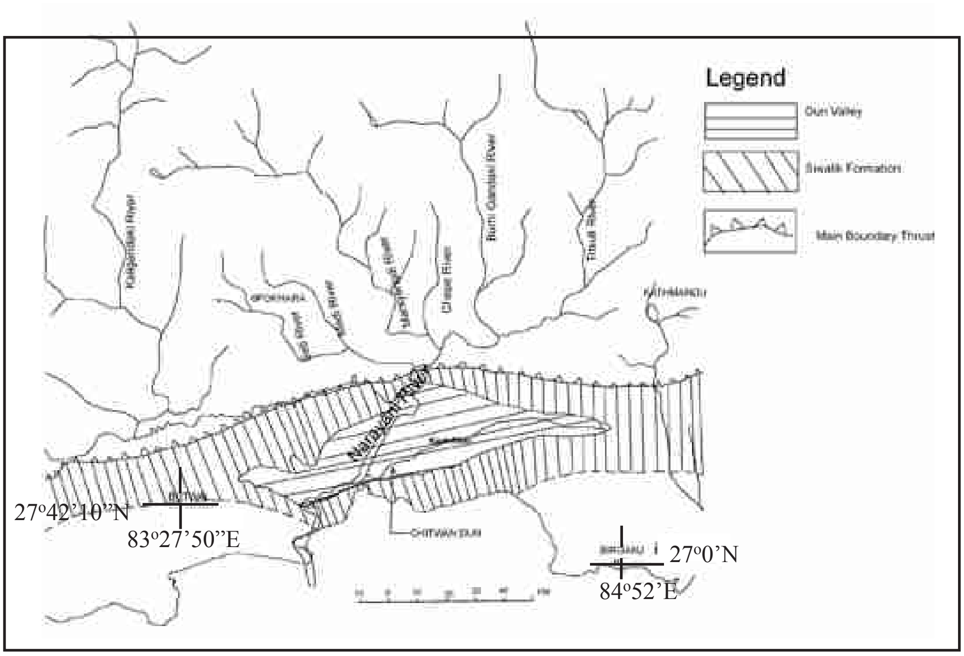

Fig. 3 Location of Chitwan Dun in Siwalik (Sub-Himalaya) of Nepal

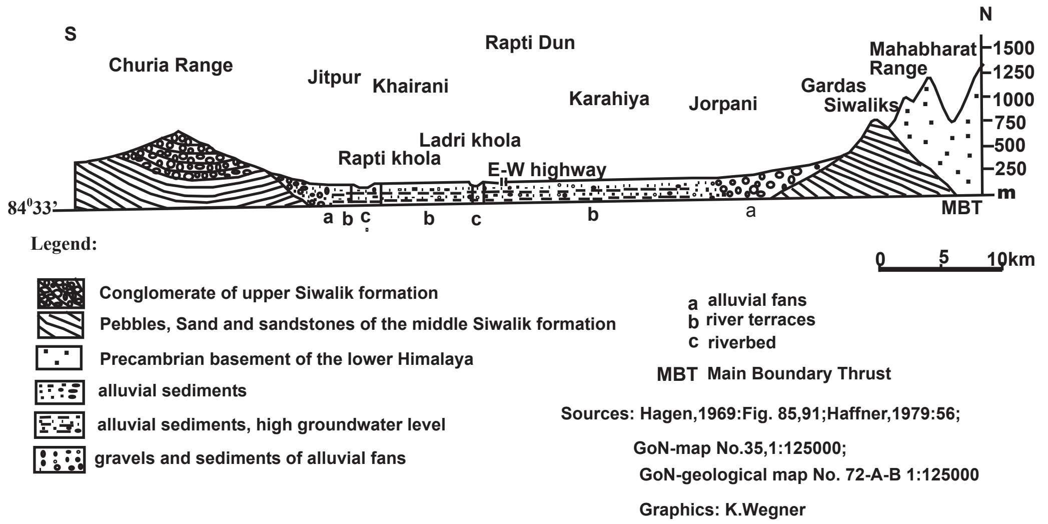

Fig.4 Geological cross-section of Chitwan dun Valley (After Hagen 1969; Haffner 1979)

HYDROLOGY AND HYDROGEOLOGY

The Narayani River Basin

The area of the Narayani River Basin is of about 31,100 km^2 in central Nepal behind the confluence of the two major rivers, the Kaligandaki River and the Trisuliganga River. The main stream is the Kaligandaki River that flows from Mustang. The catchment of 90% area lies in the Nepalese territories. Major tributaries are the Trisuli, Marsyandgdi, Seti, Budhi Gandaki, Madi, Daraudi and Kali gandaki etc.

Recent shifting trend of Narayani River

Just after crossing the Mahabharat Range, the Trisuli and the Kaligandaki Rivers confluence at Devghat, and gives way to the Narayani River. The River takes an eastward course from Devghat. While reaching Narayanghat, the river follows in the southward trend (Fig. 5). There is a sharp bend at Mangalpur. The river then flows in the westward direction. The bend displays a contrasting sharpness.

The areal distance from the first eastern depression to the present river channel is over 32 km. Present river also has various braided channels, and the latter 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 (Dangol and Paudel 2004).

SUB-SURFACE GEOLOGY OF THE STUDY AREA

The sediment distribution in the area is relatively uniform and homogeneous (Fig. 6). The depth of these deep wells ranges from 40 m to 126 m respectively. Generally, effects of local rivers influence sediment distribution. All the deep wells are situated at the elevations between 184 m and 210 m above mean sea level. In general, the most permeable portions of the Dun sediments, 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 predominates at Bharatpur. In most of the areas predominance of sand and boulders constituting more than 80% of total sediments, which form thick layers in most of the places.

The subsurface lithology is composed of boulder, cobble, pebble, gravel, and sand with intercalation of clays as well as detritus of quaternary age. There is relatively uniform distribution of sediments in the

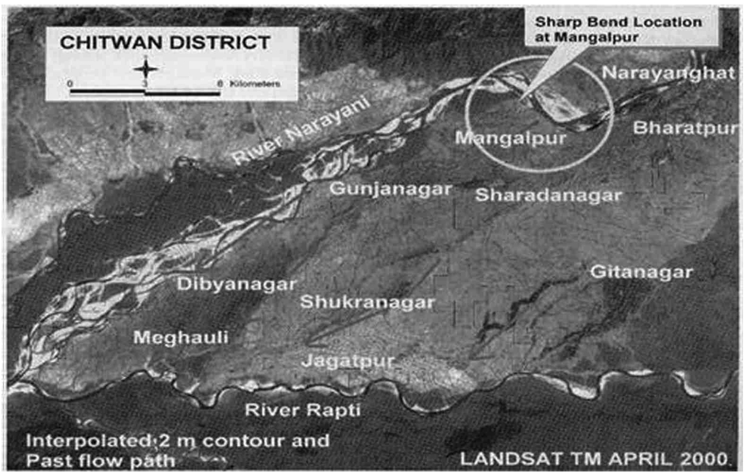

Fig. 5 Parallel alignment of depressions in west Chitwan (After Dangol and Paudel 2004)

underlying alluvial deposits and the sequence shows a little areal change in lithology.

GROUND WATER CONDITIONS

The main Dun valley aquifer is chiefly filled with highly porous and permeable unconsolidated to poorly consolidated pedimont alluvium or fan deposits (late Pleistocene to Holocene), 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 forming the main aquifer system is homogeneous as evident in the tubewell logs and by their hydraulic properties. River fans and ancient river terraces are found mainly in the valley. The Bhabar Zone area in the Chitwan Ddistrict is estimated as 280 km^2 (Sharma 1995) while area of the Dun valley is estimated as 800 km^2. The Chitwan Dun lies at a slightly higher elevation than the Terai Plain.

The porous and permeable pedimont 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 types in shallow aquifers and under semi-confined or leaky confined conditions in deeper aquifers. Perched water table conditions also present in places. The deeper aquifers are productive and have been tapped through hundreds of tube wells. Well inventory of deep wells are presented in Table 1.

Static Water Level

The depth to water level is measured in a network of 98 dugwells uniformly spread over the study area Pre-Monsoon and Post-Monsoon season. Among these 98 dugwells the maximum depth to water level was 11.9 m measured at Krishnapur, in Pre-monsoon season. Similarly, the maximum depth to water level observed in dugwells during Post-monsoon period (early November) at Sharadpur was 10.4 m.

The minimum depth to water level was 1.0 m measured in Narayanpur in Pre-monsoon (end of May to early June). Water table fluctuation ranges in the unconfined aquifers from about 0.1 m to 6.85 m b.g.l. (below ground level) with a mean water level of 2.21 m. The minimum range has been observed in the Gauriganj area in the eastern part of the study area i.e, water table at shallower depths in this area and deeper away towards northcentral part. In addition, the maximum range has been noticed in Narayanpur, i.e. 6.85 m in the Central part of the study area.

Piezometric level in Pre-monsoon period ranges from 184.2 m a.m.s.l. (above mean seal level) to 207.5 m a.m.s.l. The lowest piezometric level has been found at Narayanpur area, i.e., 184.2 m and highest at Ganeshthan i.e., 207.5 m the northern part of the study area. Similarly, piezometric level in Post-

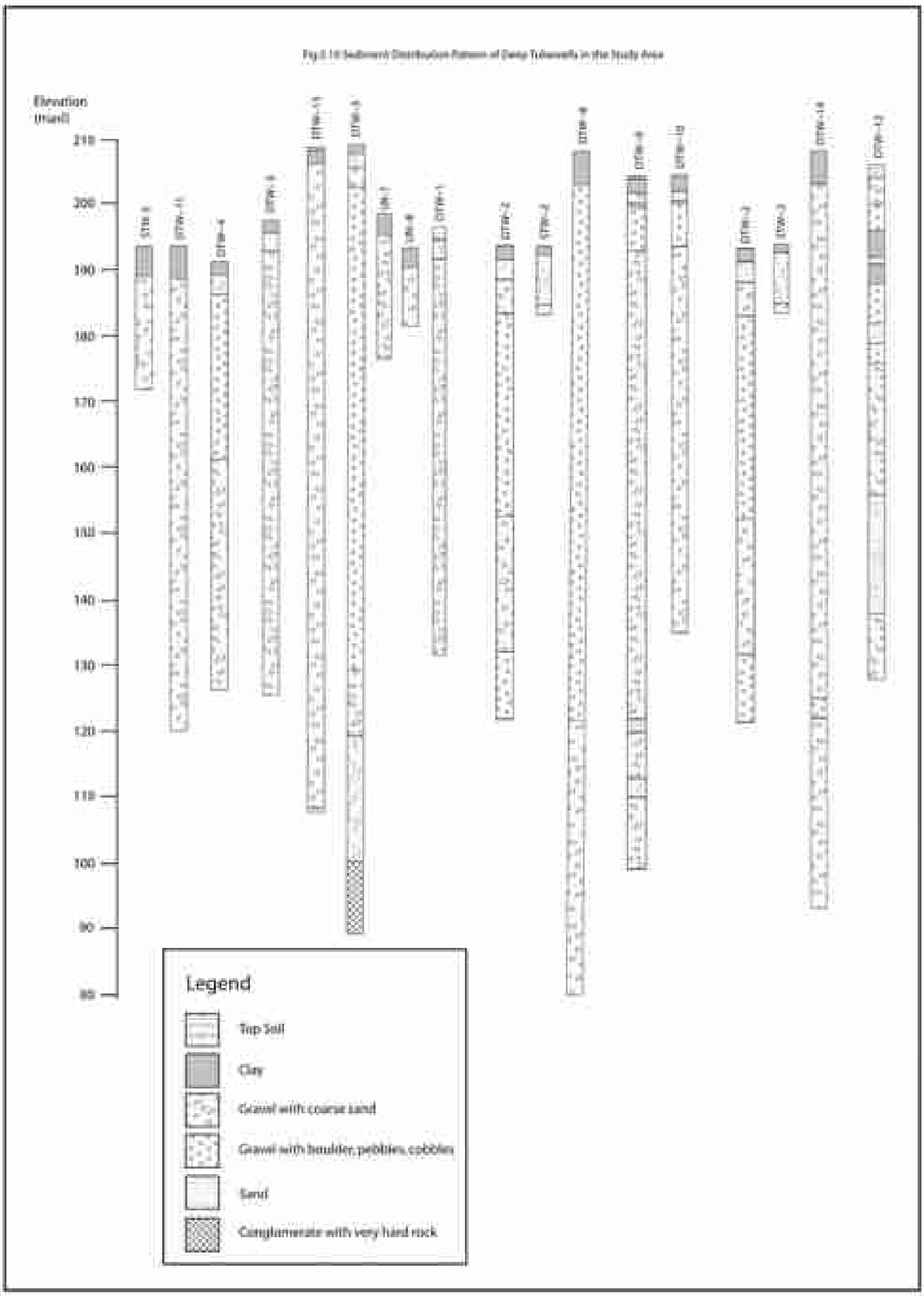

Fig. 6 Sediment distribution pattern in the study area

Table 1: Well inventory of deep tubewells

Well ID	Well Location	Longitude	Latitude	Elevation m (a.m.s.l)	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 (b.g.l.)
							m (b.g.l.)	m (a.m.s.l.)					
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	18.4	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-11	Municipal complex	84.42238	27.682	205		300/200		205					
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	24.9	18.5-36

monsoon season in August–September ranges from 191.15 m a.m.s.l. to 205.1 m a.m.s.l. in the respective area. High fluctuation may indicate loss of groundwater as subsurface outflow. Water level fluctuations have higher values towards northern part controlled by topography.

Hydraulic gradient

Hydraulic gradient is the change in head per unit of distance in a given direction. Hydraulic gradient during pre-monsoon period (April/May) has been calculated at different locations such as Kesharbag (5 m/km), Prembasti (1.58m/km), Krishnapur (1.67 m/km), Salyani (1 m/km), Narayanpur (1.5 m / km) and Khaniya tol (2.14 m /km) .

Hydraulic gradient during Post-monsoon period (August/September) found at different locations are as follows: at Kesharbag-2.5 m/km, at Prembasti-2.5 m/km, at Krishnapur-2.3 m/km, at Gauriganj temple-3.0m/km, respectively. By calculation, hydraulic gradient is found almost uniformly similar at the whole study area. Hydraulic gradient changes in every meter of horizontal distance.

Ground water flow rate

The rate of groundwater movement is governed by the hydraulic conductivity of an aquifer and the hydraulic gradient (Todd 2001). Hydraulic conductivity (Permeability) of shallow aquifer has been calculated by GWRDB/UNDP in six wells. The trend of hydraulic conductivity can be estimated from Table 1 in the study area. The ground water flow rate is relatively higher at DTW-4/Kalyanpur-50 l/s and BPKMCH/DTW-8 -43.4 l/s, whereas 35 l/s discharge rate is found at Rambag (DTW-10).

Deep tubewells and piezometric surface

Deep wells are used to exploit the groundwater from deep confined aquifer. The depth of the deep tubewells ranges from 40 m at Gondrang area to 120 m at DWSS office at Bhojad near East-West highway. In the study area, the piezometric head ranges from 1.45 m at Gondrang area/DTW-14 to 22 m at Lanku/DTW-3. With reference to the mean sea level, piezometric surface varies from 153 m at to 210 m at These tubeless tap variable thickness of granular zones (sand mixed with gravels), ranging from 18 to 42 m (Average 30 m) and occurring at different depths through slotted casings.

Aquifer Characteristics

Yield (Q)

In the study area, the yield of the deep tubeless is highest at the area (50 l/s) and lowest at Cocoa Cola Factory, i.e., 1.5 l/s. ADAPT deep tube wells are mainly used for irrigation purpose. Some of the deep wells are used for municipal supply and domestic purpose.

Transmissibility

The transmissibility values are presented in Table 1 ranges in Dwell is 85.68 mad. (Jacked-method) and in Two is 1105.6 mad. (empirical method). Transmissibility in some ADAPT tubeless were calculated by the empirical method developed by (2007) in Deriding valley as:

$$\log To = 1.36 + 0.66 \log (Q/S)$$

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

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

Hydraulic Conductivity.

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

Specific Capacity

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

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. Map imageries show several parallel depressions of the Narayani River could be part of of an abandoned channel. Remnants of the past river courses are observed at Gitanagar known as Gitanagar ghol. Another depression begins at Lonku Tandi and continues upto Sukranagar and the Rapti River. There is a distinct depression close to the western end of the Barandabhar forest. All these abandoned channels show that these could serve as excellent aquifers.

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 to 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 has shown that there is a ground water discharge areas in the southeastern part of the study area. Groundwater flow is locally confined in the basin/ trench and the flow eventually follows southwest (Fig. 7 and Fig. 8). At the central part of the area, around Narayanpur-Krishnapur area water level contours are relatively closely spaced. Similarly southeast corner of the area shows widely spaced contours revealing flatter area. The rest of the area shows water level contours, which are more or less

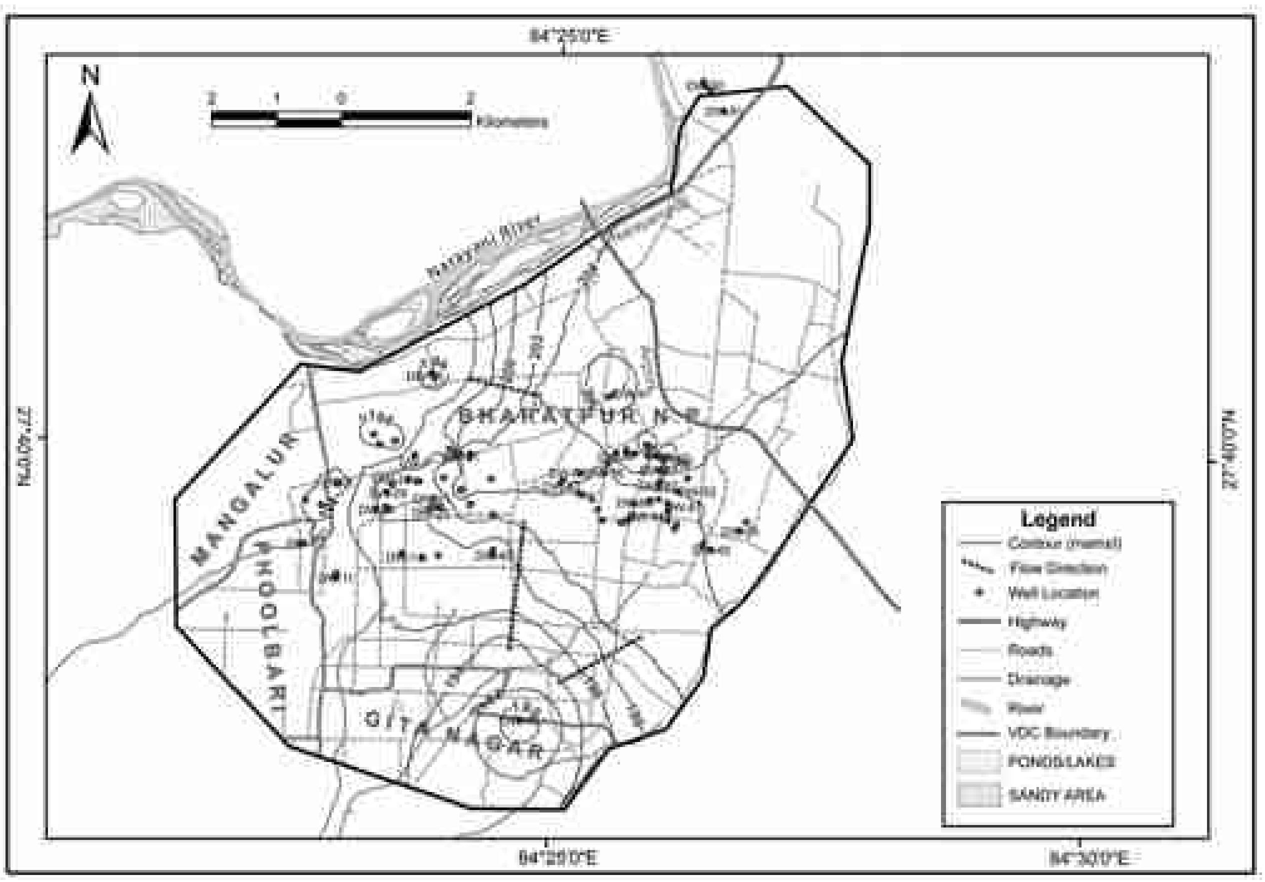

Fig. 7 Water Level Contour Map of Dugwells (m b.g.l.) in Pre-Monsoon (April–May) 2008

parallel and equally spaced showing moderate gradient throughout the year.

There occurs a groundwater mound in the Sharadpur area in eastern part below the East-west highway and groundwater flows to the east and finally south in this area. Similarly, a ground water mound of water table occurs in the parallel alignment of the Narayani Canal in Yangyapuri-Narayanpur-Tiger Chowk-Gulafbag area. Water level contours show that ground water movement follows topography from higher level to the lower level. A ground water mound in the center of the study area, from which ground water flows in the eastern and western directions or in opposite direction, also occur. This groundwater divide splits the study area into two groundwater flow systems. One flow-system is associated with the Narayani River and the other flow-system is associated with watershed of the southwest corner or the Kerunga River. In both flow-systems, groundwater initially moves from topographically high areas towards the valley axis. The lower reaches of Kerunga ghol are perennial due to base flow.

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 converging to them. Two recharge areas exist following two topographic relieves on either sides. The Piezometric surface maps of Pre-monsoon and Post-monsoon in the area show

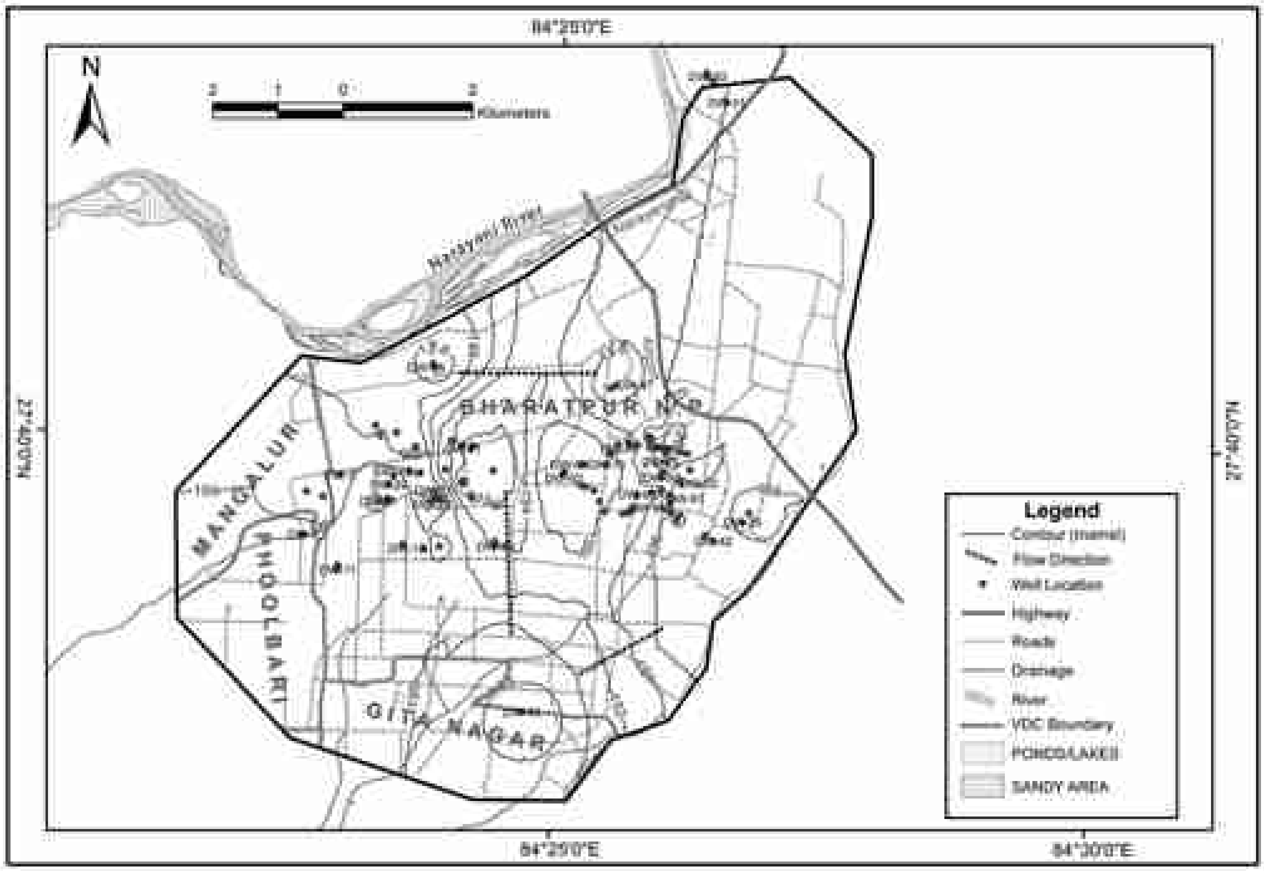

Fig. 8 Piezometric Contour Map of Dugwells (m a.m.s.l.) in Post-Monsoon (August-September), 2008

Table 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)	87.10 MCM its 15% = 13.10 MCM		
Recharge by 3 methods			
1. Duba's estimate		48.6 MCM	
2. Conservative estimate(with 10% of rainfall)		15.67 MCM	
3. Calculation considering effective porosity and fluctuation of water table		23.47 MCM	
Evapotranspiration (Calculated PET value at Rampur Station is 1.68 mm/day)			6.52 MCM

no ground water declining/over exploitation trend in the area. The flow of the Narayani River is perennial with increasing discharge towards south.

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 conceptualised 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. 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. Heavy rainfalls during the monsoon period together with snow melt from the Himalayas cause extensive flooding in the area.

The groundwater recharge is mainly due to rainfall and is the main source. Besides this, the overland flow from the surrounding hills and mountains are the additional sources of direct and indirect recharge. The recharge zone lies mostly along the northern side of the study area. Around Ramnagar and Devghat area, 10 to 15 m thick gravel deposit is exposed. This older permeable formation acts as a recharge zone.

CONCLUSIONS

The grain size of the alluvium gradually decreased from north to south. 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.

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 48.60 MCM per year. As annual recharge by precipitation exceeds rate of evapotranspiration in the valley area there could be ample scope for groundwater utilization.

Based on flow lines, the ground water flows mainly towards the Narayani River and southeast area both in pre-monsoon an post-monsoon seasons. The study area has good potential for both shallow and deep aquifers. But shallow aquifers are confined to the southeastern part.

Deep aquifers are recharged by inflow of the Narayani River and shallow aquifers may be recharged in the lower reaches of the valley. It may not be possible to recharge the terraces of study area because present bed level of the Narayani River is 179 m a.m.s.l., whereas these terraces are in higher elevation, i.e., 210 m a.m.s.l..

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