PART - III

NATURAL RESOURCES AND HAZARD APPRAISAL

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WATER REGIME

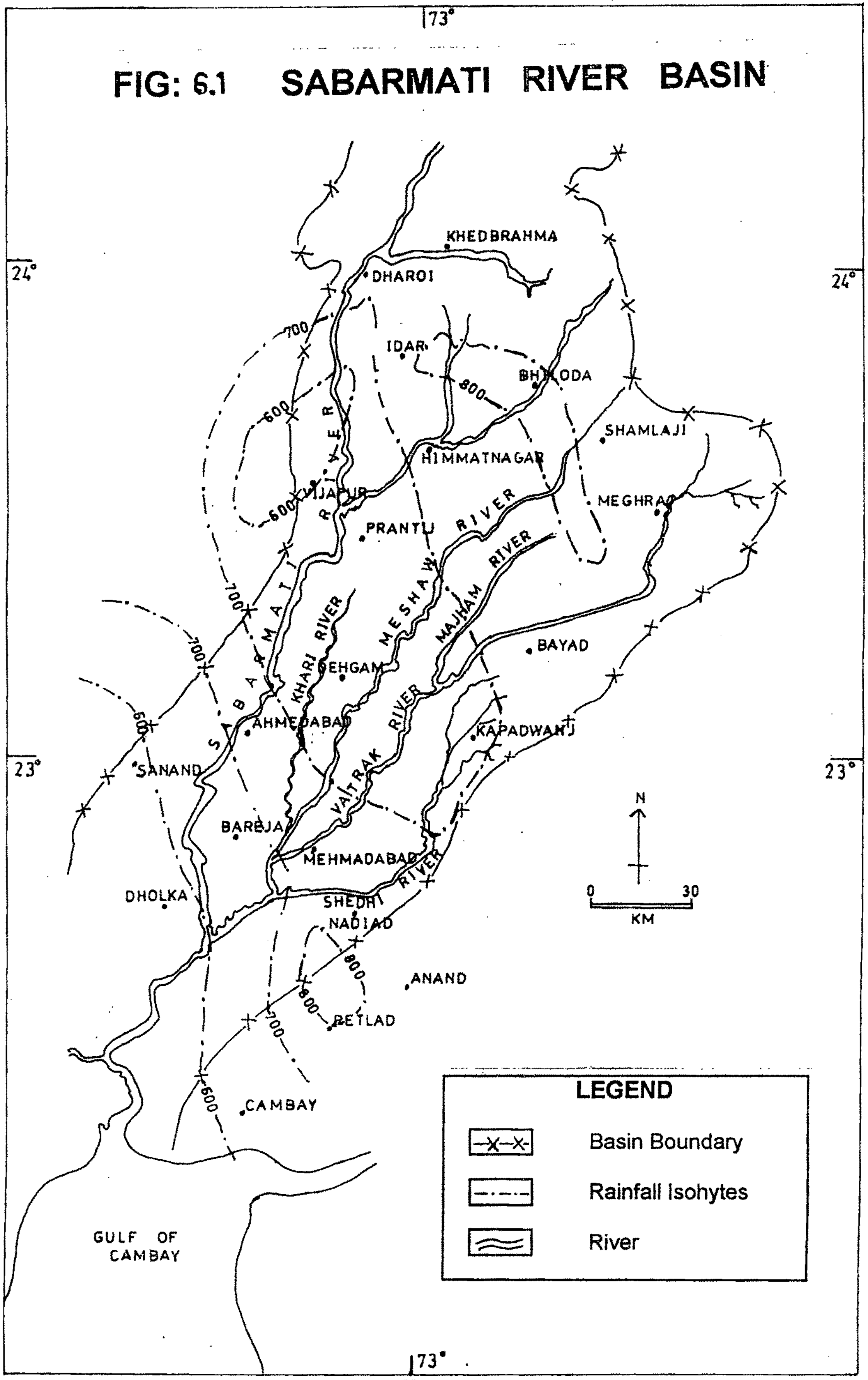
Water regime of the area constitutes an important facet of the geo-environment. It can be studied in both the ways viz. as a natural resource and as a natural hazard. To study the potentiality and availability of water in the study area, the water regime is divided into two divisions: (1) surface water and (2) under groundwater.

SURFACE WATER

Sabarmati, a major river, drains the area. It originates in the Aravalli hills in Rajasthan. Total length of the river is 370 km of which for 320 km it flows in the Gujarat state. The total drainage area of the river is 21674 sq km out of which 17550 sq km is in Gujarat (Irrigation commission, 1992). The river is out flowing in the Gulf of Cambay. The major tributaries joining Sabarmati at different places include Harnav, Hathmati and Watrak rivers. The Watrak has sub-tributaries like Khari, Meshwo, Shedi and Majham. The flow of the river is from NE and NNE to S and SSW. The river follows a meandering path when it enters in to the Ahmedabad city (Fig. 6.1).

The maximum discharge of Sabarmati as recorded at Ahmedabad was 11574 cumecs on Sept.19, 1950 and the minimum discharge recorded was 0.71 cumecs on April 24, 1952. Subsequent to the construction of Dharoi dam in 1978, the

FIG: 6.1 SABARMATI RIVER BASIN



water is released only when necessary and except for some periods during the monsoon, the river at Ahmedabad runs dry.

SABARMATI RIVER CHARACTERS

The present day river which is observed to have been superimposed over the older river channels, mainly follow numerous later date tectonic lineaments. This is also evident by the relicts of the earlier fluvial system in form of palaeochannels (Sridhar et al. 1994). However, the ancient fluvial system was responsible for the deposition of the main bulk of sediments, the present day drainage cuts across the older material deposited by older rivers.

Drainage

Mainly the Sabarmati and its tributaries constitute the drainage network in the study area. These rivers are ephemeral in nature and flow only in response to the rainfall. Sabarmati is a major river, which controls the drainage network of the hilly area of the Aravalli. The river maintains some flow because of regulated release of water from Dharoi dam for water supply to Ahmedabad city and thermal power projects at Ahmedabad and Gandhinagar. The river has broad and deep channel and its banks rise to heights of 20 to 30 m with badland features indicating active erosion. As a whole the drainage density is low.

Apart from the Sabarmati river, there are many small ponds scattered across the study area. These ponds owe their origin to the shifting river courses, which have left behind small depressions. During rainy season these depressions get filled with water and form ponds. They remain almost dry during the rest of the year. Nearby fields utilize this pond water for irrigation. These ponds have been re-excavated at many places to enhance their capacities.

Surface Water Resources

The area is deficient in respect to surface water resources. There are no perennial rivers flowing through the area and thus the water resources are dependent mainly on the surface run-off and river flow during monsoon period. In order to harness surface water resources, major and medium irrigation projects were planned and executed. Dharoi is a major irrigation project on the Sabarmati river and is in working condition. This dam has a major implication on the surface water flow in Sabarmati river and also on surface runoff – groundwater relationship in the study area. At the same time the area also falls within the command area of the Narmada canal. This canal is passing through the area between Ahmedabad and Gandhinagar. It will have a very important effect on the surface water, groundwater table and groundwater quality in future. On completion, the canal is likely to provide surface water irrigation facility in an area of nearly 3.40 lakh ha in the districts of Ahmedabad and Gandhinagar.

Dharoi Dam

Dharoi dam has been constructed across river Sabarmati near village Dharoi in Kheralu taluka of Mehsana district. The dam had started commissioning in the year 1978. Apart from the flood control and hydel power generation, the water storage in the reservoir is committed to provide water for fulfilling the need of water to Ahmedabad city (150 mgd), to Gandhinagar city (11 mgd) and to the thermal power stations at Ahmedabad and Gandhinagar (5 mgd each). Through the left and right bank canals, the structure is providing irrigation in Sabarkantha and Mehsana districts respectively. Dharoi reservoir has a capacity of 907.9 MCM of water and effective storage of 775.9 MCM. It has ultimate irrigation potential of 61085 ha. Till June 1994, 56136 ha of irrigation potential have been created.

Khari – Cut Canal

The Khari – Cut Canal is passing through the eastern Ahmedabad city. It starts from Raipur village of Dehgam taluka about 19 km away in NE direction of Ahmedabad city. A small weir was constructed on the Khari river – a tributary of the Sabarmati river between 1880 and 1884. It is a 61.88 m long pick up weir with a 83 km long canal. Dehgam and Dascroi talukas of the Ahmedabad district are getting benefit of this canal. About 10200 ha of area was irrigated from this canal. Later on Hathmati and Indrasi dams were constructed on the upstream of the Khari river on the Hathmati and Bokh rivers respectively. Now the water is released from these dams during Kharif season only. As the water is not available during most part of the year, the Khari – Cut canal remains almost dry. Toxic and polluted industrial effluents released by the surrounding industrial areas of Naroda, Narol, Odhav and Vatva make this canal highly polluted (Plate 6.1). At places the canal is blocked by construction of houses etc. This results in to inundation during monsoon. Fig. 6.2 shows the command area of the Khari – Cut canal.

Plate 6.1: Narmada Canal near Koba.

Plate 6.2: Polluted Khari Cut Canal near Odhav.

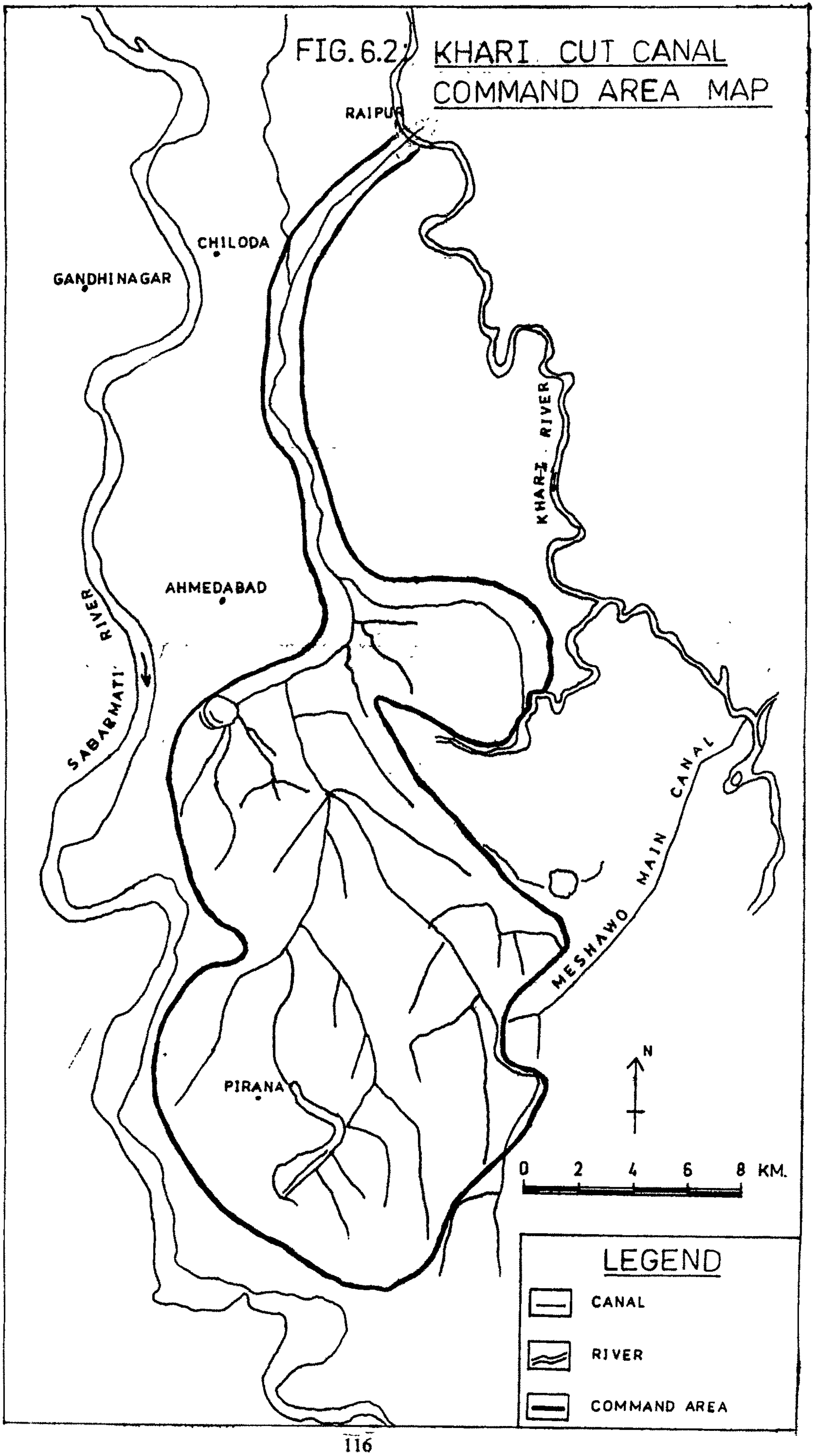


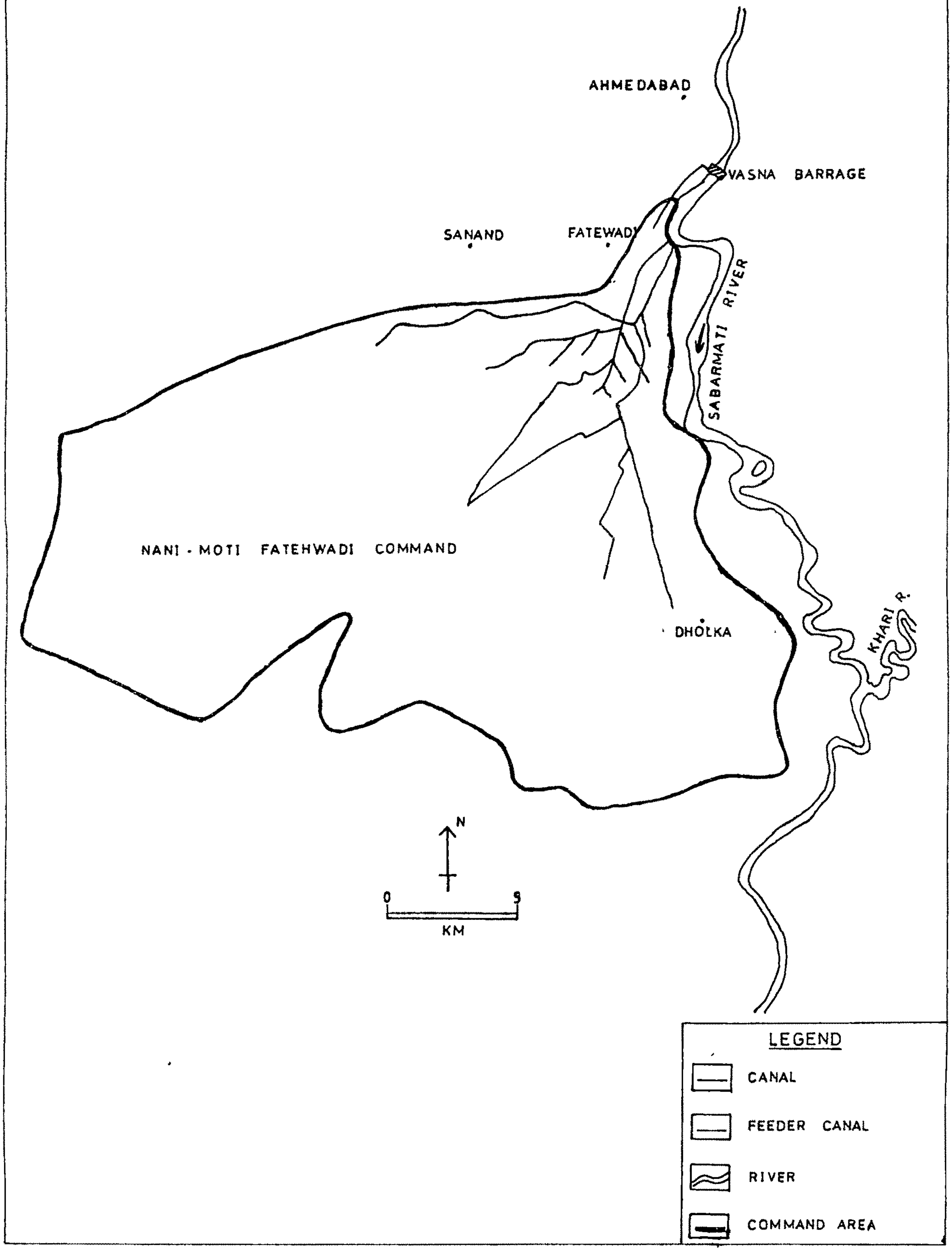
FIG. 6.2: KHARI CUT CANAL COMMAND AREA MAP
RAIPUR
CHILODA
GANDHINAGAR
KHARI RIVER
AHMEDABAD
SABARMATI RIVER
MESHAWO MAIN CANAL
PIRANA
N
0 2 4 6 8 KM.
LEGEND
CANAL
RIVER
COMMAND AREA

Vasna Barrage

Vasna barrage is constructed across Sabarmati river at Vasna of City taluka just south of the Ahmedabad city. The length of the barrage is 611 m and having a storage capacity of 5.35 MCM. The total area of the catchment is 10620 sq km. It was completed in the year 1976. The Fatehwadi canal system is getting benefit of the water from the barrage. The total length of the canal is 6.9 km. The irrigated command area is about 35000 ha. The maximum height to which water level is raised in the reservoir is 135 feet. During monsoon the reservoir gets filled with water (Plate 6.2). The benefits of the barrage include irrigation as well as water in the reservoir is also available for the recharge of underground aquifers. Thus it is also helpful for solving water supply problem of the Ahmedabad city. Fig. 6.3 shows the command area of the Fatehwadi canal.

In the background of limitations of the surface water resource, its availability largely affected by erratic and poor rainfall, the dependence on groundwater has increased. Growing irrigation water demands have accelerated groundwater exploitation. This has ultimately created the over exploitation of groundwater resource. Therefore, the need of conserving surface water resource for induced groundwater recharge in overexploited areas is a foregone conclusion.

FIG. 6.3: FATEHWADI CANAL COMMAND AREA MAP.



The surface water resource of the Sabarmati river basin is given in the table 6.1.

Table 6.1: Sabarmati river basin water resource

BASIN	CATCHMENT AREA sq km	TOTAL WATER RESOURCE MCM (@ 50 % dep.)
Sabarmati	19819	1694.70

At present nine major and medium irrigation projects have been completed in the Sabarmati river basin. While six such projects are in progress. Similarly 428 minor irrigation projects have been completed and 73 schemes are in progress. Details of these irrigation schemes are given in table 6.2.

Table 6.2: Statement showing water resources and irrigation potential of major, medium and minor irrigation projects in the Sabarmati basin.

	Existing Schemes			
Irrigation projects	No. of schemes	Catchment sq km	Gross utilization* MCM	Irrigation potential ha.
Major and medium irrigation schemes	9	1344	440.75	76707
Minor irrigation schemes	428	502	81.38	16166
	Ongoing schemes			
Major and medium irrigation schemes	6	5105	581.47	89373
Minor irrigation schemes	73	20	21.81	4652
Total				
Major and medium	15	6449	1022.22	166080
Minor	501	522	103.19	21818

*Water supply storage of 330 MCM for Ahmedabad, Gandhinagar and Power Plants is excluded.

RIVER WATER RUNOFF – GROUNDWATER INTERACTION

The flow of the Sabarmati river is dwindled down rapidly with increase in the groundwater drawal in the city. The river discharge varies considerably in response to the rainfall fluctuations in the catchment area. However, the most striking feature is that the river discharge has drastically decreased in response to the sharp increase in groundwater withdrawal. Even during the prominent high rainfall years 1970 and 1973, the discharge was not more. The river discharge peaks of 1957 and 1960 are associated with two high rainfall years, having about 120 cm annual rainfall each. The same magnitude of rainfall peak of 1973 does not result in a significant recharge of the river flow. Thus the role of heavy groundwater withdrawal on the river flow at Ahmedabad is evident from these observations (Bhandari et al., 1986).

It must be mentioned that the tube wells in this region mostly tap the confined aquifers and therefore there can not be a direct hydraulic connection between the river flow and deeper aquifers. However, it is possible that excessive lowering of piezometric levels of confined aquifers has resulted in a situation where induced leakage occurs from the unconfined aquifer underlying the river bed. The arrest of rapid decline of water levels in the tube wells also indicates the vertical leakage of water from the unconfined layer in to the confined aquifers adjacent to the river (Gupta, 1993).

SUBSURFACE WATER

Increasing urbanization and industrialization of the Ahmedabad-Gandhinagar area have necessitated extensive use of water for domestic, industrial as well as agricultural consumption. With limited availability of surface water, groundwater is being exploited as the principal source to meet these requirements. Sabarmati river water is utilised for supply to the Ahmedabad and Gandhinagar cities by constructing infiltration wells (French wells) on the river bed. Indiscriminate exploitation of groundwater has obliterated the original hydrogeological configuration. The progressive urbanization of the surrounding cultivated tracts has stressed on the groundwater resources of the area. Inspite of depletion of water level due to overdrawal, people are going for deeper level by sinking tube wells. This has posed a threat of contamination of both surface and groundwater resources in the Ahmedabad-Gandhinagar urban complex. As a result of heavy withdrawal in a limited area, water level in the tube wells have been falling at a rate of 2 to 3 m in a year and even higher in some cases (Patel et al, 1979).

Many studies on groundwater resources development have been carried out by central as well as state agencies. These studies are essential for evaluating groundwater potentials of the terrain. This study is considered as one of the important aspects of environmental geological set up of the area.

Geologically, the Sabarmati basin is a closed basin bounded by two almost parallel faults. It comprises of Archaean rocks in the north and NE parts, while alluvial deposits cover the central and southern parts of the basin. Above the Archaeans, Mesozoic group of rocks of cretaceous age is present. The close of Mesozoic era was marked by the outpouring of lava flows followed by a period of marine deposition, thus resulting in tertiary deposits, which mainly consist of blue shale or clay. This formation yields saline water and acts as aquiclude. The most recent Gujarat Alluvial lying unconformably over the Tertiary formations consists of about 400 – 700 m thick alternate layers of sand and clay with kankar and/or gravel deposits. The contact of alluvium and hard rock is along the NE-SW direction. This is under unconfined condition and acts essentially as recharge area for the deeper aquifers in the central and western parts of the terrain. The thickness of the alluvium increases from NE to SW direction.

HYDROGEOLOGY

The area forms a part of the Cambay basin and is characterised by 400 m thick Gujarat Alluvium deposits. This Quaternary sequence comprises unconsolidated to semi-consolidated deltaic, fluvial and aeolian sediments represented by a number of geological formations, namely, Sabarmati formation, Bavla formation, River terraces, Gandhinagar formation and Ahmedabad formation of fluvial origin and Vinjhol formation of aeolian origin (Roy et al. 1990).

Aquifer System

The Quaternary aquifer system providing water to most wells in the area consists of a thick sequence of conglomerate, course sand, silt and sandy clay inter bedded with shale and clay beds of lower permeability. Due to this variation the aquifer characteristics in the area are not uniform. Depositional variations owing to sea level changes, neotectonism, lateral shifting of river courses, aeolian activities, soil formations etc. are responsible for lateral and vertical variations of the lithological characters of the Quaternary sediments. Lateral continuity of any aquifer with uniform parameters is also not possible in this type of depositional environments. The Quaternary sediments form a multi-aquifer system in the area, which is dealt in the later paragraphs. Knowledge of aquifer characteristics is essential for the balanced use of groundwater. Table 6.3 gives the important characteristics with lithological types of the aquifers.

Table 6.3: Aquifer Characteristics

Formation (Aquifer)	Lithological description	Type and Form of Aquifer
Sabarmati Formation	Channel fill deposits: Sand, gravel.	Shallow aquifer
River Terraces	Along river channels: Clay, silt, sand	Shallow aquifer
Bavla Formation	Younger deltaic plain deposits: Clay, sand with calcretes.	Aquitard to aquiclude
Vinjhol Formation	Dune deposits: Coarse sand with lime leaching	Aquifer of limited aerial extent
Ahmedabad Formation	Conglomerate, sand	Shallow aquifer
Koba Formation	Clay, silt, sand, lime concretions	Aquitard to aquiclude
Mehmadabad Formation	Sand, silt, clay inter bedded with coarse sand and conglomerate	Forms main shallow aquifer of the entire area

(Modified after Roy et al. 1990)

The Sabarmati river is at places affluent to receive groundwater and influent to recharge groundwater. Considering the geology and regional trend of the groundwater table, the main recharge area occurs in the north-central part extending from Serisa in the west to Indroda in the east. The groundwater recharge of the aquifer system in the area is by natural infiltration of rain water through unconsolidated materials. The induced recharge is by infiltrating surface water through unconsolidated material from surface streams, retention ponds or irrigation canals located over aquifer during periods of heavy or prolonged rainfalls. The occurrences of buried channels also permit good local recharge. The Khari, the Vatrak and the Meshwo rivers flowing as tributaries of Sabarmati to the east are mostly dry in summer to have any perceptible effect on the water table. Presently the discharge or extraction of water is mainly from deep bore wells.

SUBSURFACE HYDROGEOLOGY

To study the subsurface geology with a view to determine the aquifer deposition, basement configuration, relation between confined and unconfined aquifers and control as well as structural features, subsurface geological cross sections have been prepard from the lithologs of tubewells drilled by GWRDC and AMC. These sections reveal that the alluvial deposits lie unconformably over the Tertiary formations and are represented by alternate bands of sand and clay. The alluvial deposits have no regular pattern of deposition and show tendency of swelling and pinching. Subsurface geological cross sections are described as under:

(1) Geological cross section across Bareja to Rajpur in S – N direction.

The cross section is taken along N – S direction. It represents a moderate ground slope from Rajpur (N) to Bareja (S). Top soil has almost equal thickness of 5 - 6 m and followed by alternate bands of sand and clay. It can be inferred that sand bands are thicker than clay layers. The thickness of sand bands is decreasing from north to south. There are several sand layers down to a depth of 40 – 180 m bgl. Below 80 m confined aquifers occur between 110 & 125, 130 & 155 and 180 & 200. In Rajpur blue clay is encountered below a depth of 125 m bgl (Fig. 6.5).

(2) Geological cross section across Sarkhej to Unawa in S – N direction.

The cross section is taken along N – S direction. Topographically the area is plain with gentle slope from Unawa (N) to Sarkhej (S). More than 8 persistent bands of sand have been encountered between 44 & 54, 95 & 115, 120 & 130, 132 & 150, 156 & 176 and 182 & 198 bgl. The overall percentage of sand is more than clay (Fig. 6.6).

(3) Geological cross section across Sanand to Kujad in W – E direction.

The cross section is taken along E – W direction. Topographically the area is flat with a little higher elevation at Telav. The section shows that sand beds are persistent and separated by clay beds. There is an increase in thickness of sand beds from east to west. There is thick sand beds between 78 & 95, 114 & 128 as well as between 140 & 150 m depth bgl. Sand beds below 50 m can be good unconfined aquifers while below 95 m they can be good confined aquifers (Fig. 6.7).

FIG. 6.4 KEY MAP SHOWING GEOLOGICAL CROSS SECTION LINES

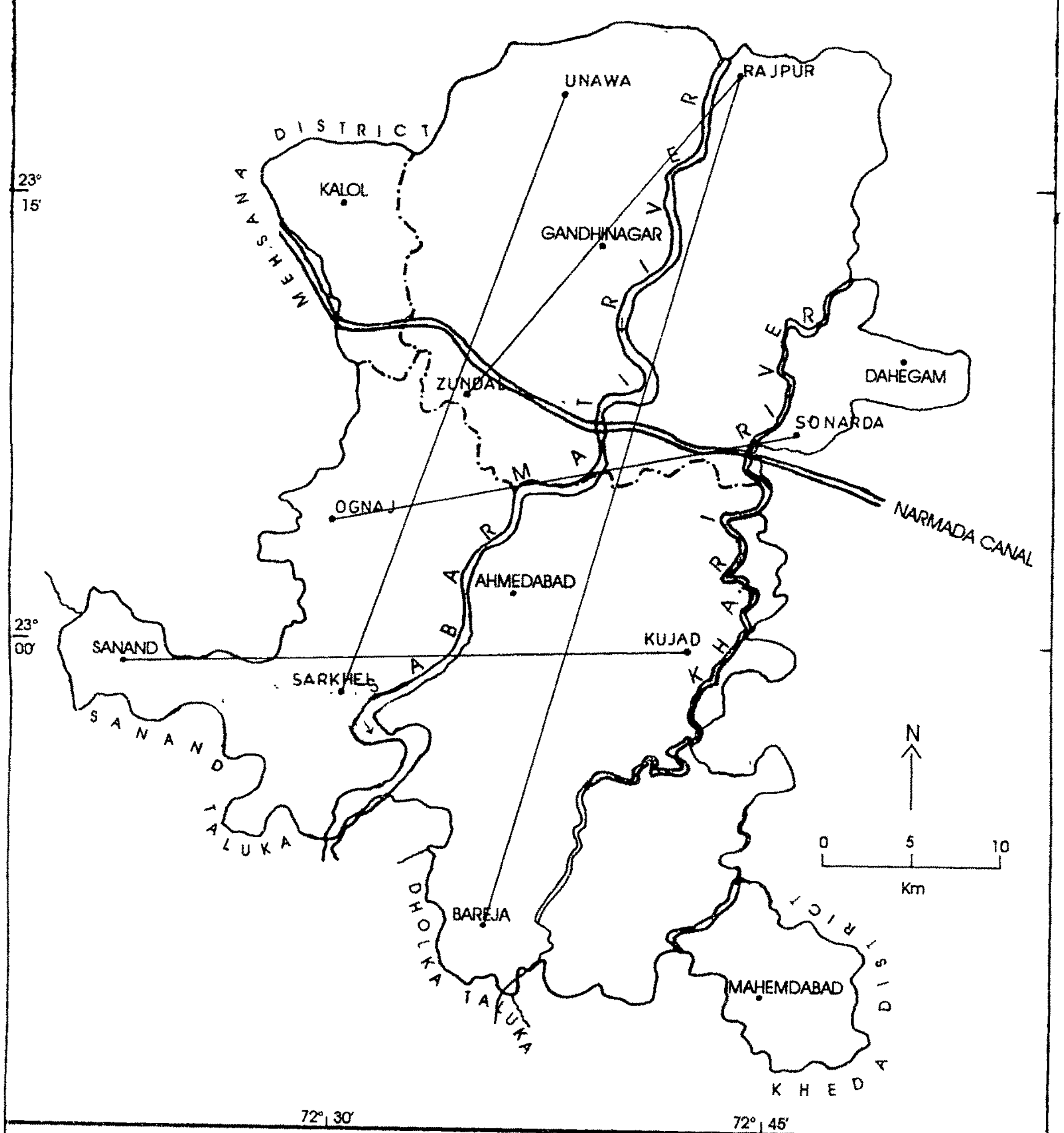


FIG. 6.5: GEOLOGICAL CROSS SECTION ACROSS BAREJA TO RAJPUR IN S – N DIRECTION

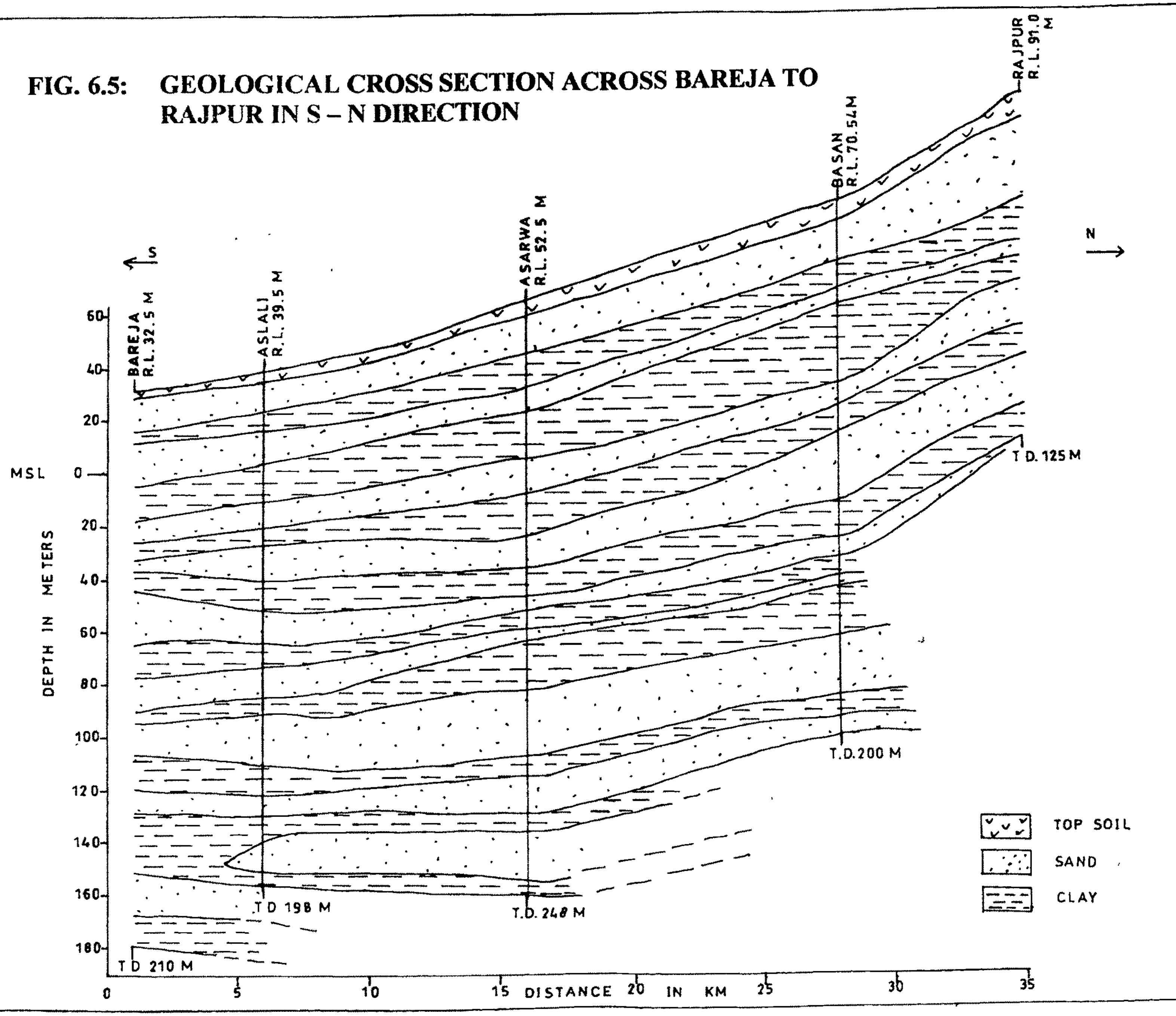


FIG. 6.6: GEOLOGICAL CROSS SECTION ACROSS SARKHEJ TO UNAVA IN S – N DIRECTION

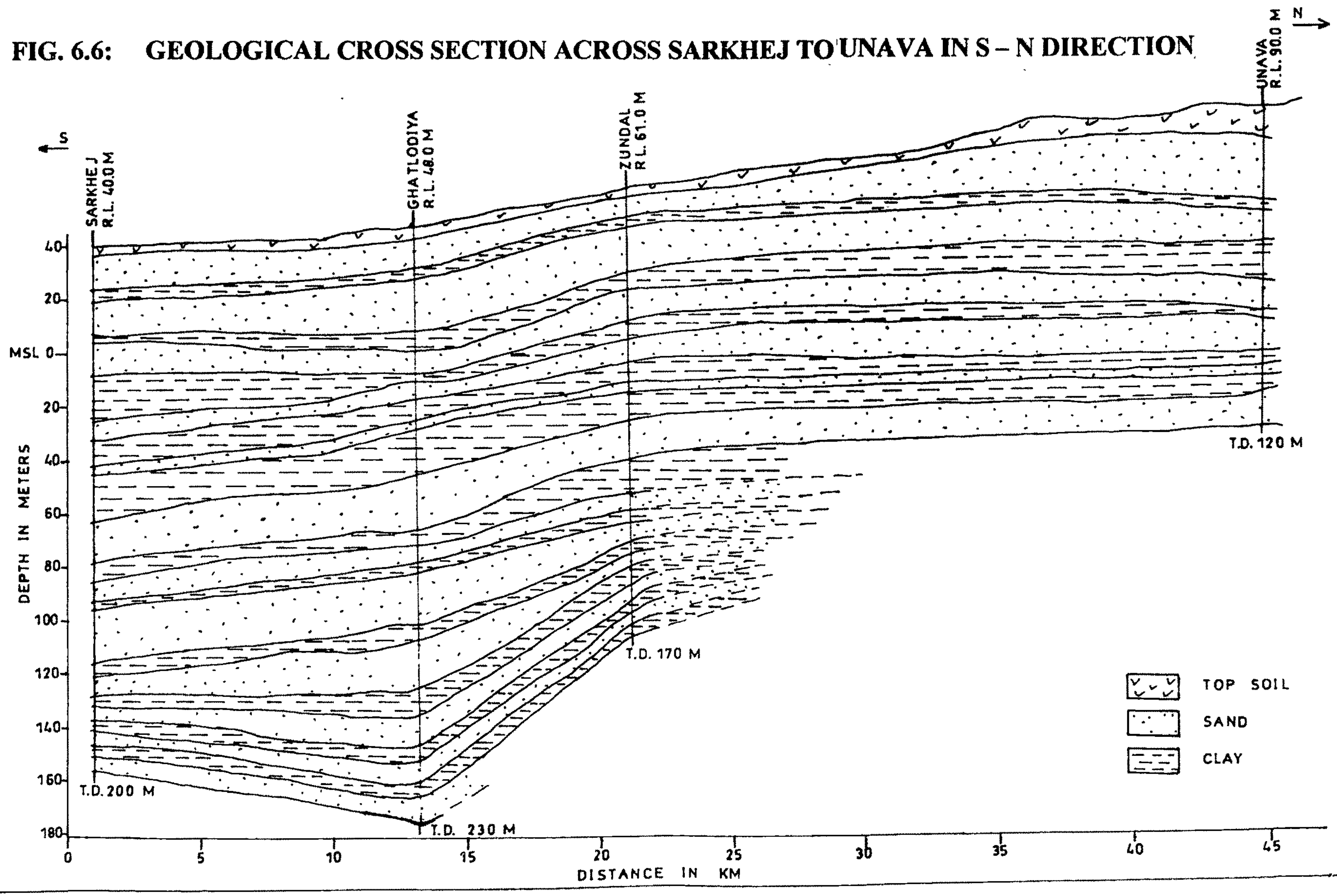
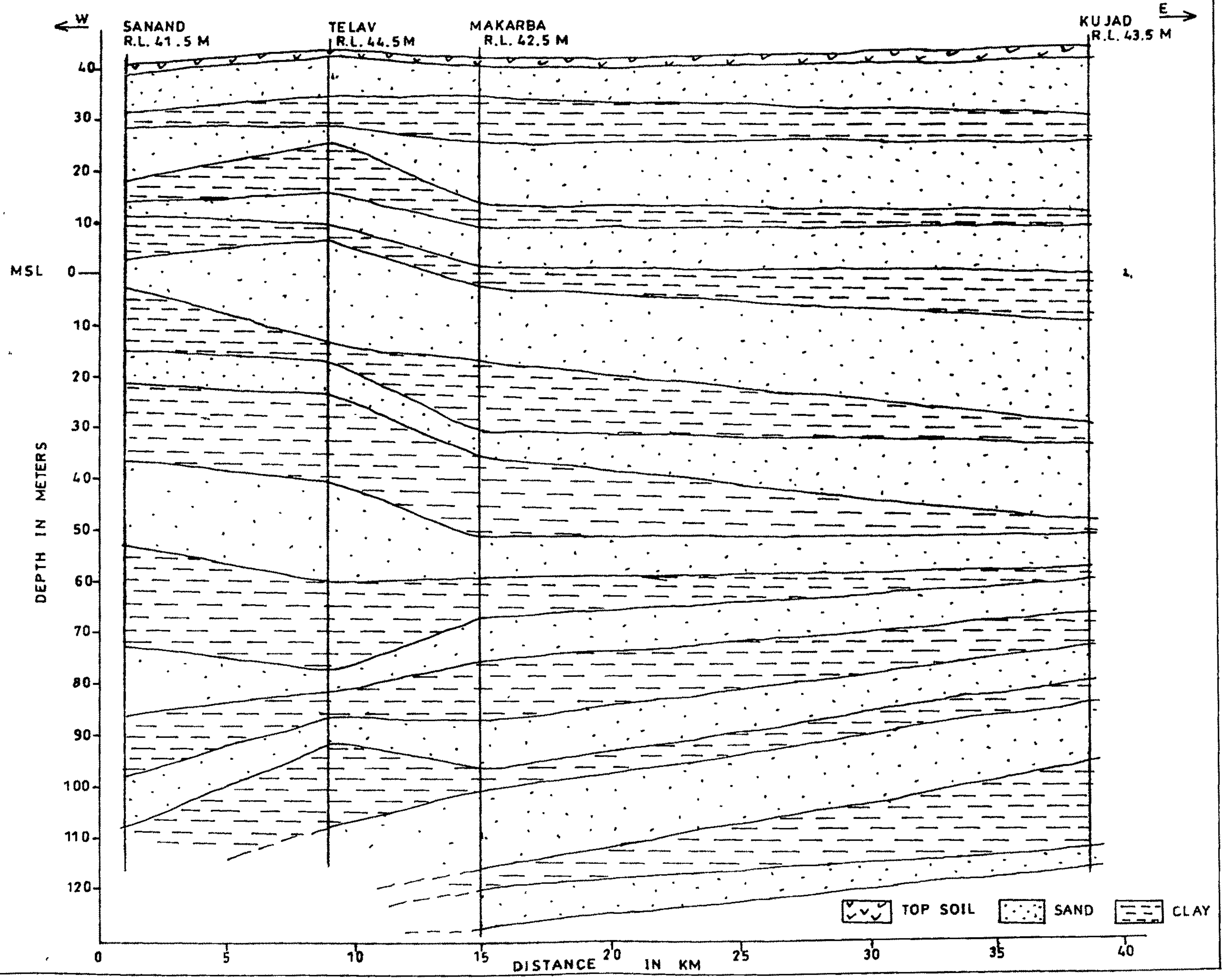


FIG. 6.7: GEOLOGICAL CROSS SECTION ACROSS SANAND TO KUJAD IN W – E DIRECTION



(4) Geological cross section across Ognaj to Sonarda in W – E direction.

The cross section is taken along E – W direction. The section represents a very gentle slope from Sonarda to Ognaj. Clay and sand layers occurs alternately under a 5 – 9 m thick top soil cover. Clay layers vary in thickness from 2 – 10 m. Sand layers dominating with their proportion varying between 45 and 75 %. A thick sand bed at a depth between 125 and 150 m at Sonarda and Medra can be a good confined aquifer (Fig. 6.8).

(5) Geological cross section across Zundal to Rajpur in SW – NE direction.

The cross section is taken along NE – SW direction. This section represents a moderate ground slope from Rajpur to Zundal i.e. from NE to SW. the section shows maximum thickness of alluvium of about 200 m at Por and Gandhinagar. It is seen that in the NE part of Gandhinagar blue clay is encountered at a depth of 146 m bgl. But in the SW direction the blue clay disappears even at a depth of 210 m. The alternate layers of sand and clay provide a good aquifer system in the area. The thick sand beds found below 65 – 75 m from ground level form good confined aquifers (Fig. 6.9).

The geological cross sections reveal that there are several sand layers down to the depth of 50 m. These are intercepted by lenses of silt and clay but may be treated as a single unconfined aquifer. In the most parts of the area, a 20-50 m thick clay layer separates the deeper aquifers from the upper unconfined aquifers. These deeper aquifers are confined aquifers and have a large areal extent and supply most of the water consumed in the area.

FIG. 6.8: GEOLOGICAL CROSS SECTION ACROSS OGNAJ TO SONARDA IN W – E DIRECTION

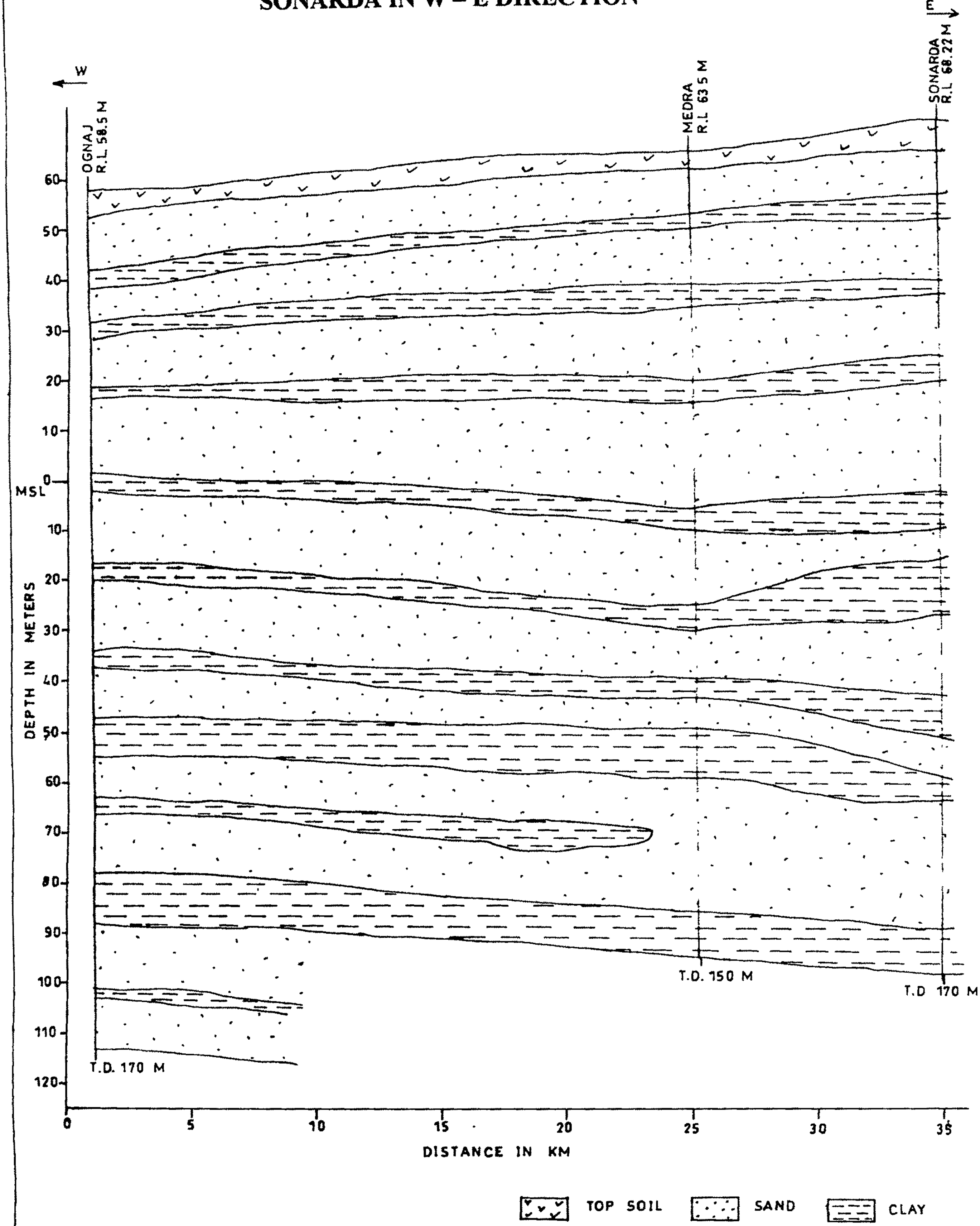
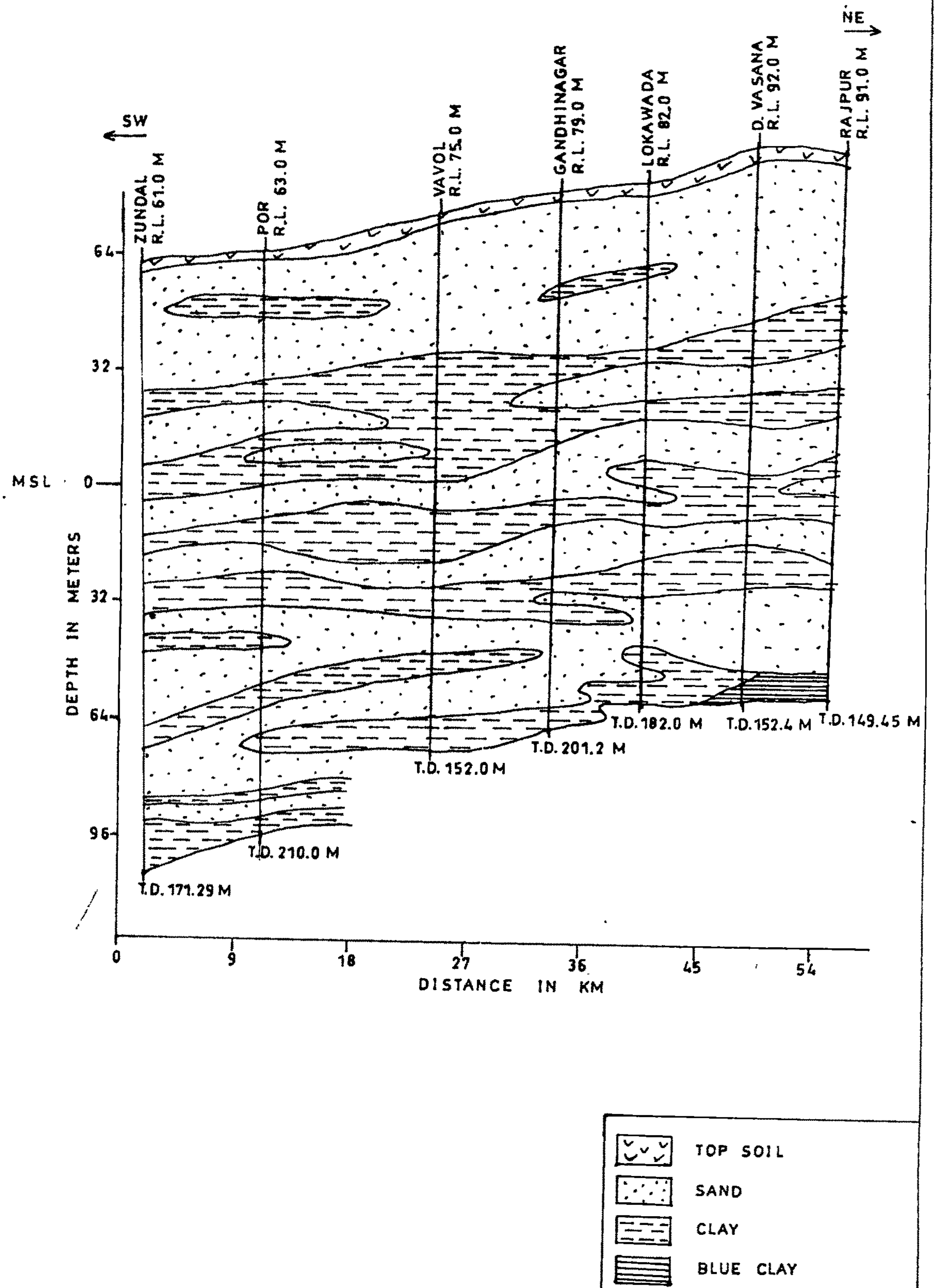


FIG. 6.9: GEOLOGICAL CROSS SECTION ACROSS ZUNDAL TO RAJPUR IN SW – NE DIRECTION



The maximum depth of potential alluvial deposits is about 225 m below ground level (bgl). The sandy layer alternately deposited with semi-pervious clay beds forms the semi-confined aquifer system. The sand layers exhibits very good primary porosity. Groundwater is extracted from this formation through dug cum bore wells (DCB) and tubes wells. Most of the dug wells are dry due to deep water levels. Hydrological conditions favour the construction of DCB wells mainly between Sabarmati and Khari rivers.

The bore holes drilled by State Government Water Departments and Central Groundwater Board for groundwater exploration as well as by ONGC for oil and gas prospects have revealed the subsurface geological horizons in the area. The data generated by groundwater exploration wells extend down to a depth of about 400 m whereas by oil wells extend down to a depth of more that 2500m. This data has been synthesised and subsurface geology and aquifer system in the alluvium plain of the study area has been demarcated. Hydrogeological cross sections showing the subsurface geology and aquifers are presented in the fig. 6.5 to 6.9 from the section lines depicted in fig. 6.4. The generalised subsurface geology with a description of the aquifer properties of the various units is given in the table 6.4.

The Quaterna.y sediment deposits forming the Gujarat Alluvial Plain mainly consist of sand and gravel intercalated with clay bands. Sands are fine to very coarse grained with occasional gravel and bouldery beds. Clays are brownish buff or yellowish in colour and moderately sticky.

The subsurface geological cross sections show that the alluvial deposits overlie the Tertiary formations. The alluvial deposits mainly consist of sand and clay. The sand grains vary in size from coarse grained in eastern part to fine grained in western part. The grain size gradually reduces from east to west. The clay beds occur in lensoid form. Although the clay layers locally show development of confining conditions but on regional scale, they are discontinuous. The occurrences of clay layers control the development of unconfined and confined aquifer conditions in the study area. The alluvial deposits indicate occurrence of good water bearing aquifers. The thickness of alluvial formations varies widely and generally decreasing from NE to SW direction. The alluvial deposits, which are broadly unconsolidated sediments, indicate occurrence of multi aquifer system as evidenced from the geological subsurface cross sections.

Table 6.4: Subsurface geohydrology showing aquifer parameters.

Stratigraphy	Lithology	Formation (Aquifer)	Depth to top of aquifer (m)	Thickness range (m)	Av. Thickness (m)
Holocene	Coarse sand, gravel, pebbles, medium and fine sands and clayey sand	Aquifer I	5 – 71	35-125	62
	Clay interbedded with sand and sandy clay	Aquitard I	78 – 162	13 – 88	39
Pleistocene	Medium to coarse sand and gravel interbedded with sandy clay	Aquifer II	78 – 162	10 – 80	45
	Clay interbedded with sand and sandy clay	Aquitard II	-	13 – 80	37
	Medium to coarse grained sand	Aquifer III	154 – 274	13 – 62	34
	Clay interbedded with sandy clay	Aquitard III	-	19 – 172	73
	Medium sand interbedded with sandy clay	Aquifer IV	229 – 402	11 – 105	52
Miocene (Upper)	Clay interbedded with sandy clay	Aquitard IV	-	11 – 76	44
	Fine to medium sand and sandy clay	Aquifer V	300 – 542	15 – 57	24

The deep aquifers generally occur under leaky confined conditions. The unconfined as well as confined aquifers show a hydraulic continuity, except for local variations where because of bifurcation and coalition of clay layers, local discontinuities have developed. However, the common recharge of the confined aquifers occurs in NE parts of the study area where the groundwater generally occurs under unconfined conditions. The unconfined aquifer system in W and SW direction gives rise to semi-confined and confined aquifer systems.

The transmissibility and permeability are the two main factors, which control the occurrence and movement of groundwater. The evaluation of the available hydrological data from tube wells drilled by GWRDC indicates that the transmissibility and permeability of the aquifers are largely controlled by the variations in aquifer grain size and degree of compaction. The transmissibility of the confined aquifers varies from 2500 m^2 / day in NE parts to nearly 200 m^2 / day in the western parts.

The Pleistocene aquifers can be divided into 6 groups besides the unconfined aquifers. The details of the aquifers are given in table 6.5.

Table 6.5: Divisions of Aquifer Groups.

Aquifer group	Depth range (m)	Thickness (m)	Av. Aqu. Th. (m)	%
Group – I	50 – 70	20	7	35
Group – II	70 - 90	20	9	45
Group – III	90 - 100	10	4	40
Group – IV	100 – 115	15	3	20
Group – V	115 – 135	20	16	80
Group – VI	135 – 165	30	18	60
Total: 6	50 - 165	115	57	50

In the NE part of the area, the aquifers of group I and II types have been tapped, whereas in the SW part, the aquifers below group III are tapped. This observation suggests that the area where group I and II are tapped is the recharge area and the other group of aquifers are tapped in the discharge area (Bhandari et al., 1986).

Unconfined aquifers

DCB wells have an annual draft of .005 MCM/year. The hydraulic parameters of unconfined aquifers were analysed by GWRDC considering specific capacity, coefficient of transmissibility, permeability, specific yield etc. are given in the table 6.6.

Table 6.6: Unconfined Aquifer Characteristics.

Parameters	Units	Values (range)
Specific capacity	m^3 / min / m	- 0.362 - 1.117
Co- efficient of transmissibility	m^3 / day	105 - 730
Field permeability	m / day	1.40 - 41.66
Specific yield	%	9.10 - 12.50

From these parameters, the average value of safe distance between two wells was calculated to be 100 m.

Confined aquifers

The impervious clay layers deposited below the depth of 80 m are found sticky and compact which favour the development of confined aquifer conditions below the depth of 80 m from the ground level. The confined aquifers are excavated to a maximum depth of 240 bgl. On account of the water levels gradually declining due to increasing extraction of groundwater through DCB wells, now the groundwater is extracted by means of tube wells only. Aquifer characteristics of confined aquifers are given in the table 6.7.

Table 6.7: Confined Aquifers Characteristics

Parameters	**Units**	**Values (range)**
Co-efficient of transmissibility	m^2 / day	98 – 3693
Co-efficient of Field permeability	m / day	3.82 – 66.43
Specific capacity	L / sec / m	1.60 – 18.11

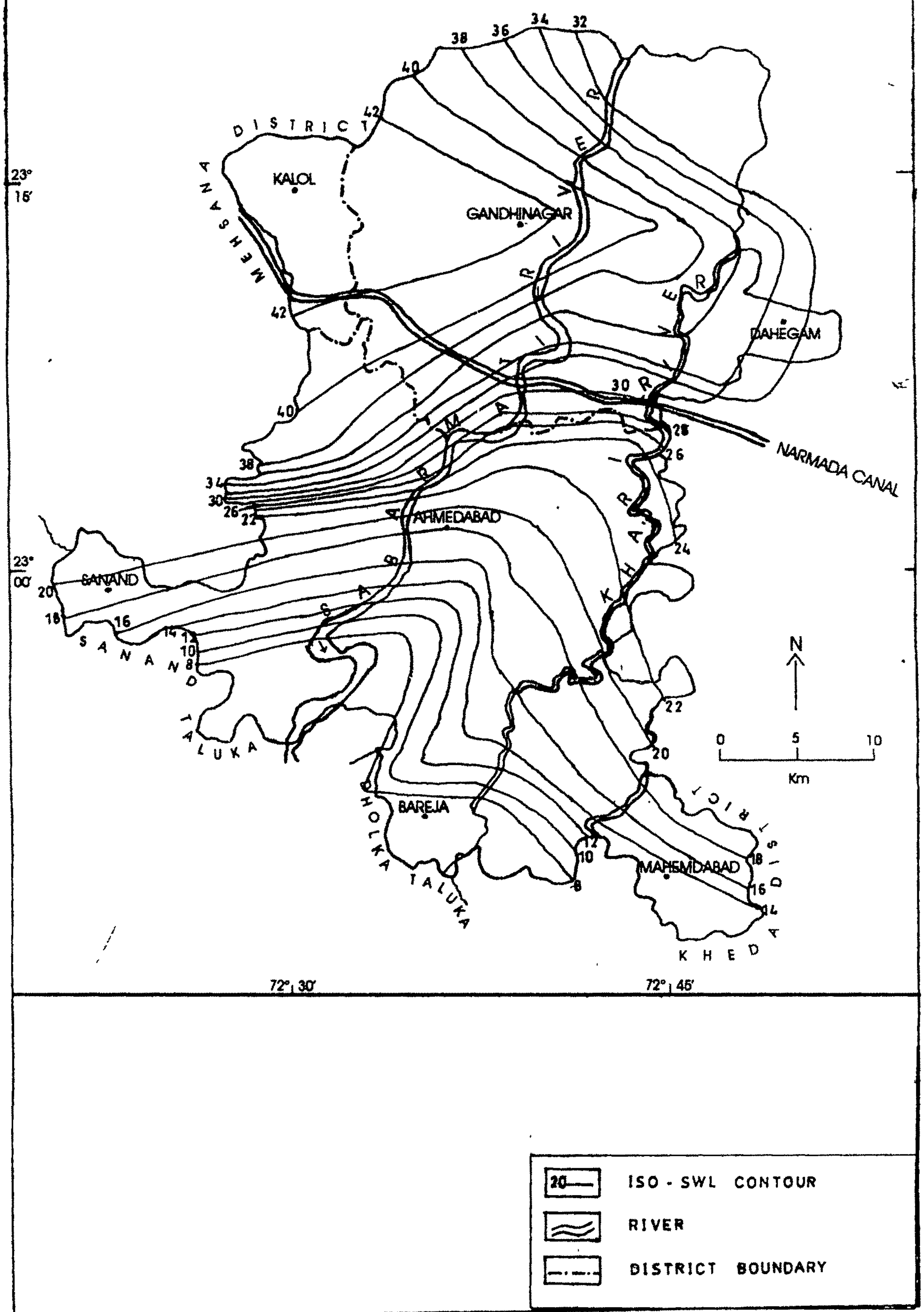
Water levels

Shallow water levels of less than 20 m are rarely observed. In general, phreatic water levels during May 91 vary between 30 and 45 m bgl. The water table map of May 91 shows that during the period of 5 years the water levels have considerably declined. A fall of about 8 m is observed. The average premonsoon water level in different parts of the area varies from 25.32 to 32.26 m bgl. Regional groundwater pumping and below normal rainfall during past decade is considered responsible for successive lowering in water levels.

Static water level (SWL) contour map of confined aquifers (fig.6.10) indicates that the water level becomes shallow from NE to SW direction. This indicates the groundwater flow pattern. The SWL data of 1997 depicts a fall of about 3 to 4 m

FIG. 6.10: SWL CONTOUR MAP OF CONFINED AQUIFERS (1994)

(PREMONSOON)



in water levels. Formation of groundwater trough between Gandhinagar and Kalol is largely due to increasing number of tube wells in this area.

Reduced water level (RWL) counter map of confined aquifers of 1994 shows much lowering of water table in the southern part of the area. Infect the water table has gone down below mean sea level. This calls for immediate measuring steps as this situation may create a reverse hydraulic gradient and contaminate fresh water aquifers. RWL contour map is given in fig. 6.11.

Groundwater flow

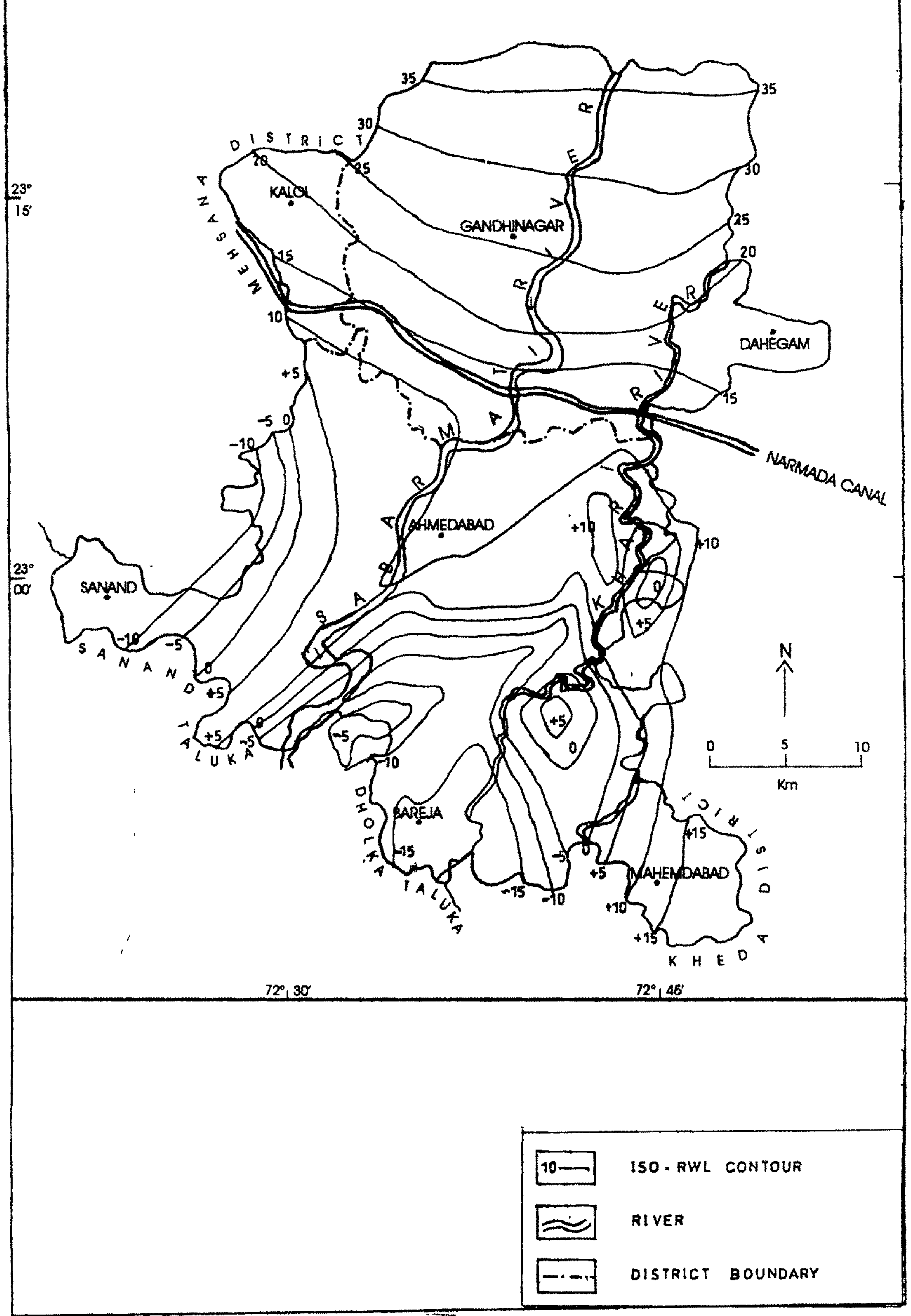
The trend of groundwater flow broadly follows the topography and drainage pattern of the area. The water level elevation during premonsoon period was 61.20 m above MSL in NE part. The flow indicates a very gentle hydraulic gradient of about 1:1000.

GROUNDWATER RECHARGE

Gupta (1993) has divided the aquifer system of the study area into two major groups such as an upper phreatic aquifer (unconfined) separated from the lower artesian aquifer (confined) by a layer of semi-permeable aquiclude to understand the recharge method of the groundwater. These aquifers have their areas of recharge in the piedmont terrain and the hilly country, towards E and NE directions. Most of the aquifers coalesce into one phreatic aquifer in the recharge area. Due to over exploitation, the water levels in the phreatic aquifers have declined alarmingly rendering them almost dry. Presently the upper confined aquifers down to the depth of approximately 150-200 m are the most exploited aquifers.

FIG. 6.11: RWL CONTOUR MAP OF CONFINED AQUIFERS (1994)

(PREMONSOON)



A number of abondened river channels occur in the area which are of significance for the development of groundwater and its recharge. Direct groundwater recharge due to deep percolation of rain water to the upper phreatic aquifer is assumed to be 15% of average annual precipitation. Indirect recharge to the phreatic aquifer is due to (I) seepage of water of Sabarmati river surface/subsurface flow and (II) subsurface inflow from surrounding regions in response to steep groundwater gradient towards the city from all directons.

Artesian aquifer receives indirect recharge from induced leakage of phreatic aquifer caused by reduction of artesian head due to pumping.

Of the 132 MCM of water pumped out in 1984 within municipal limits, nearly 25 MCM was contributed by induced leakage from the Sabarmati riverbed alone. Another 75 MCM was derived from the induced leakage from the surrounding areas (Gupta et al., 1984).

If the average per capita daily water consumption is assumed to rise to 310 litres from 180 litres at present, the projected groundwater requirement for the year 2001 would be 222 MCM for the Ahmedabad city alone. The induced leakage form the river bed and from the other surrounding areas are estimated to be 56 and 72 MCM respectively, with water level in western, central and eastern parts of the city falling to approximately 70, 85 and 125 m respectively (Gupta, 1993). However, in view of increasing groundwater utilisation out side AMC, subsurface inflow will be substantially lower and water level in western, central and eastern zones of the city are estimated to be between 45 - 60 m, 50 - 70 m and 80 – 90 m respectively.

Gupta (1985) has established that even though nearly all groundwater pumped in Ahmedabad city is from the artesian aquifers, the leakage from overlying unconfined aquifer, induced due to the lowering of artesian head contributes very significantly to indirect recharge. This implies that recharging the upper unconfined aquifer during rainy season and by suitably treated wastewater during rest of the year, the recharged water will be available by pumping from the confined aquifers.

While computing the annual recharge to groundwater, the contributions from precipitation, return seepage from surface irrigation, canal seepage, surface water bodies, flood prone and water logged areas are taken in to consideration. In the study area, rainfall precipitation is the only major source of recharge to groundwater. The recharge contribution by surface water bodies is mainly through the existing irrigation tanks. The annual groundwater recharge estimation considers two factors such as monsoon recharge and non-monsoon recharge. Since the rain fall is generally not the only cause of water table rise but several other factors such as seepage from irrigated fields, tanks, ponds and similar other surface water environs as well as flood areas during monsoon also contribute towards recharge to groundwater. The recharge computed from different aspects worked out by GWRDC in the area along with net draft, stage of development and category of the talukas are given in the table 6.8.

Table 6.8: HYDROGEOLOGICAL DATA OF THE STUDY AREA.

PARAMETERS	AHMEDABAD				GANDHINAGAR
	CITY/ DASKROI	DAHEGAM	SANAND	DHOLKA	GANDHINAGAR
Total geographical area (sq km)	985.6	619.5	800	1728.4	651.3
Total suitable area for ground water (sq km)	985.6	619.5	560	949.6	651.3
Average annual rainfall for last 35 years (mm)	768	700	639	633	674
Rainfall volume (area x rainfall) (MCM/year)	742.1	434.13	505.3	1131.96	438.98
Recharge from rainfall (MCM/year)	103.76	158.72	75.88	28.54	95.74
Run-off (MCM/year)	668.01	275.41	514.49	1005.56	344.38
Recharge from other sources (MCM/year)	82.97	26	76	97.85	15.5
Gross annual recharge (MCM/year)	186.73	184.72	151.88	126.39	111.24
Average rise in water levels (m)	0.30-3.05	0.6-4.86	0.26-5.07	0.96-3.46	1.25
Specific yield (% range)	8-9.5	13-15	4.5-6	10-Sep	9
Utilisable recharge from all sources (MCM/year)	158.72	98.75	62.02	107.43	84.85
Utilisable recharge from all sources in 1996 (MCM/year)	765.83				84.85
Total number of dug wells	Nil	939	1420	481	524
Total number of pump sets	3230	2207	1284	3937	1869
Total number of private tube wells	1502	1634	446	874	1700
Total number of government wells	66	62	19	29	70
Gross ground water draft (MCM/year)	238.58	239.35	89.16	179.07	100.92
Net draft (MCM/year) @ 70%	167	167.54	62.14	125.35	70.64
Net draft in 1996 (MCM/year)	179.9	180.48	67.23	135.03	76.09
Ground water balance (MCM/year)	-8.27	-68.78	-0.38	-17.92	14.21
Ground water balance in 1996 (MCM/year)	-45.22	-66.99	-94.93	-55.11	-34.98
Level of ground water development (%)	105.22	169.66	100.62	116.68	83.25
Level of ground water development in 1996 (%)	142.73	142.62	94.33	101.6	136.98
Category of taluka in 1991	Over expolited	Over expolited	Over expolited	Over expolited	Grey
Category of taluka in 1996	Over expolited	Over expolited	Over expolited	Over expolited	Over expolited

(Source: GWRDC, 1997)

Groundwater Balance

In order to estimate the net potential of groundwater available for safe exploitation, it is imperative to estimate the quality of groundwater pumped annually from the aquifer and the quantity replenished by various input sources. Groundwater is largely pumped through DCB wells and tube wells within the framework of geological formations. The occurrence of groundwater is mainly from the unconfined, semi-confined and confined aquifers. In the area located closer to the river Sabarmati, the groundwater occurs under unconfined and semi-confined conditions, where it is mainly explored by means of DCB wells. Whereas in the rest of the part of the study area, the groundwater is exploited through deep bore wells tapping confined aquifers. The annual draft of private tube wells is estimated to be 0.045 MCM/year while those of government tube wells is 0.018 MCM / year. Groundwater flow pattern in confined aquifer follows the topography of the area. Highest water level of 49.80 m above MSL at Rajpur and lowest water elevation of 28.25 m above MSL near Chandkheda village have been recorded.

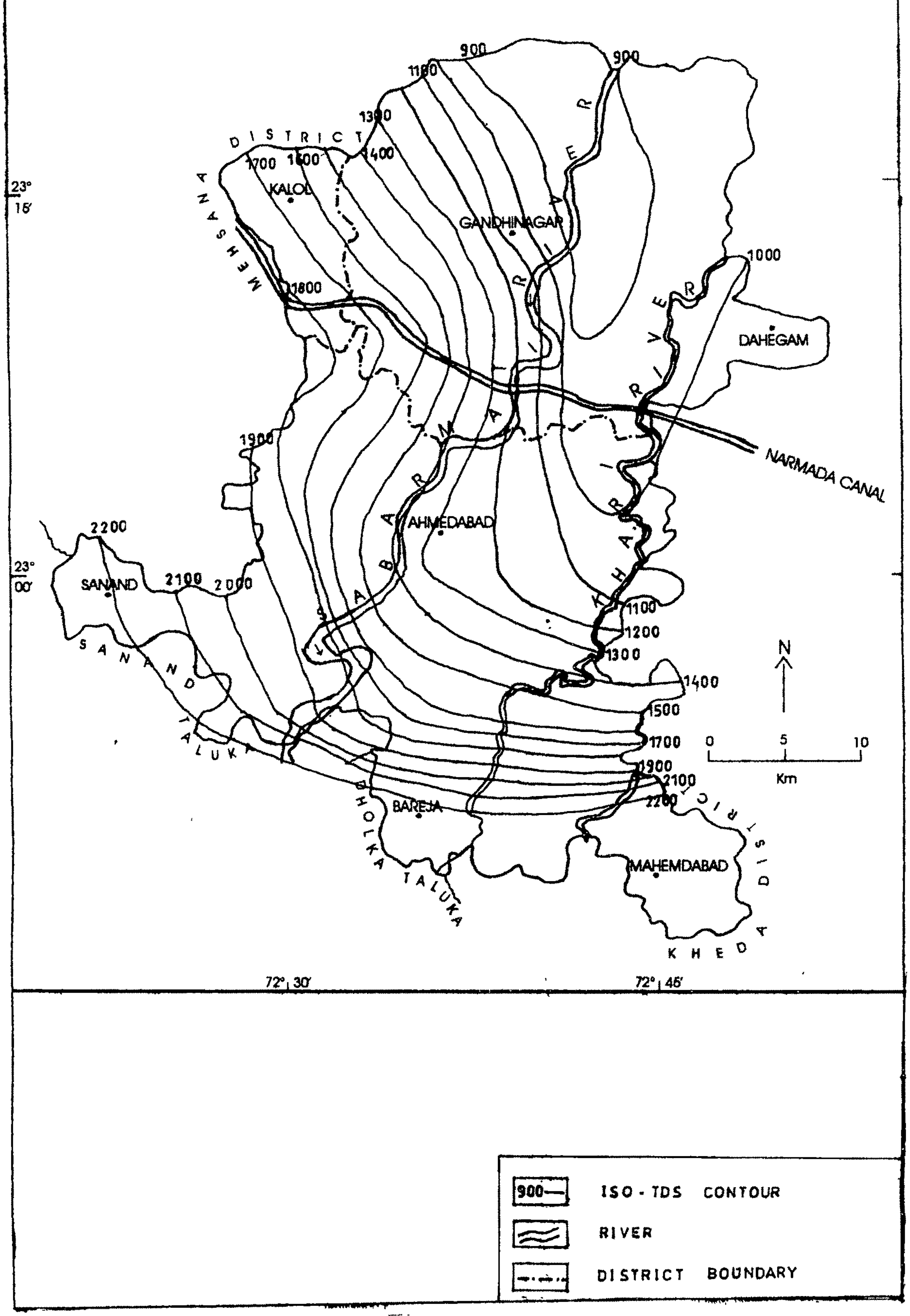
Groundwater Quality

There is keen demand for full development of the available water resources. The area falling in to Sabarmati river basin is endowed with good groundwater potential due to favourable under ground geological conditions. More than 10,000 tube wells have already been constructed in the basin and the development is continuing at many places at an alarming high rate. The geochemical data of groundwater collected for many years by the groundwater resources departments of state and central governments give a fair idea of about the general chemical quality of the groundwater. Recently however, major departures from the equilibrium conditions which prevailed for long periods of time in terms of quantity and quality, have occurred due to increased demand of water leading to vigorous exploitation of aquifers. In addition, the construction of Dharoi dam on Sabarmati river has also changed the groundwater situation considerably. The system is continuously diverging from the equilibrium where information available so far can hardly be useful in water management. A major part of the groundwater infiltrates through the soil and therefore it acquires mineral composition characteristics of soil.

The quality of groundwater is the prime factor in determining its suitability for domestic, agriculture and industrial purposes. Water quality mainly deals with pH, Total Dissolved Solids (TDS) and various cations and anions like calcium, magnesium, sodium, carbonate, bicarbonate, sulphate, chloride etc. pH value of groundwater ranges from 7.6 to 8.4 indicating moderately alkaline water. ISO-TDS contour maps have been prepared from the data provided by the GWRDC and presented in fig. 6.12. It is found that the average TDS varies from 850 ppm in 1985 to 1770 ppm in 1996 indicating increasing salinity over the past decade. The water contains mainly bicarbonate and chloride salts and sodium ions. The quality is found deteriorated towards W and SW of the area.

FIG. 6.12: ISO-TDS CONTOUR MAP OF CONFINED AQUIFERS (1994)

(PREMONSOON)



Most of the tube wells and/or bore wells drilled in the area tap more than 2 aquifers and as a result the quality of groundwater from individual aquifers is not known. However, the quality of groundwater encountered at different depths by few observation wells of GWRDC and AMC is given as under:

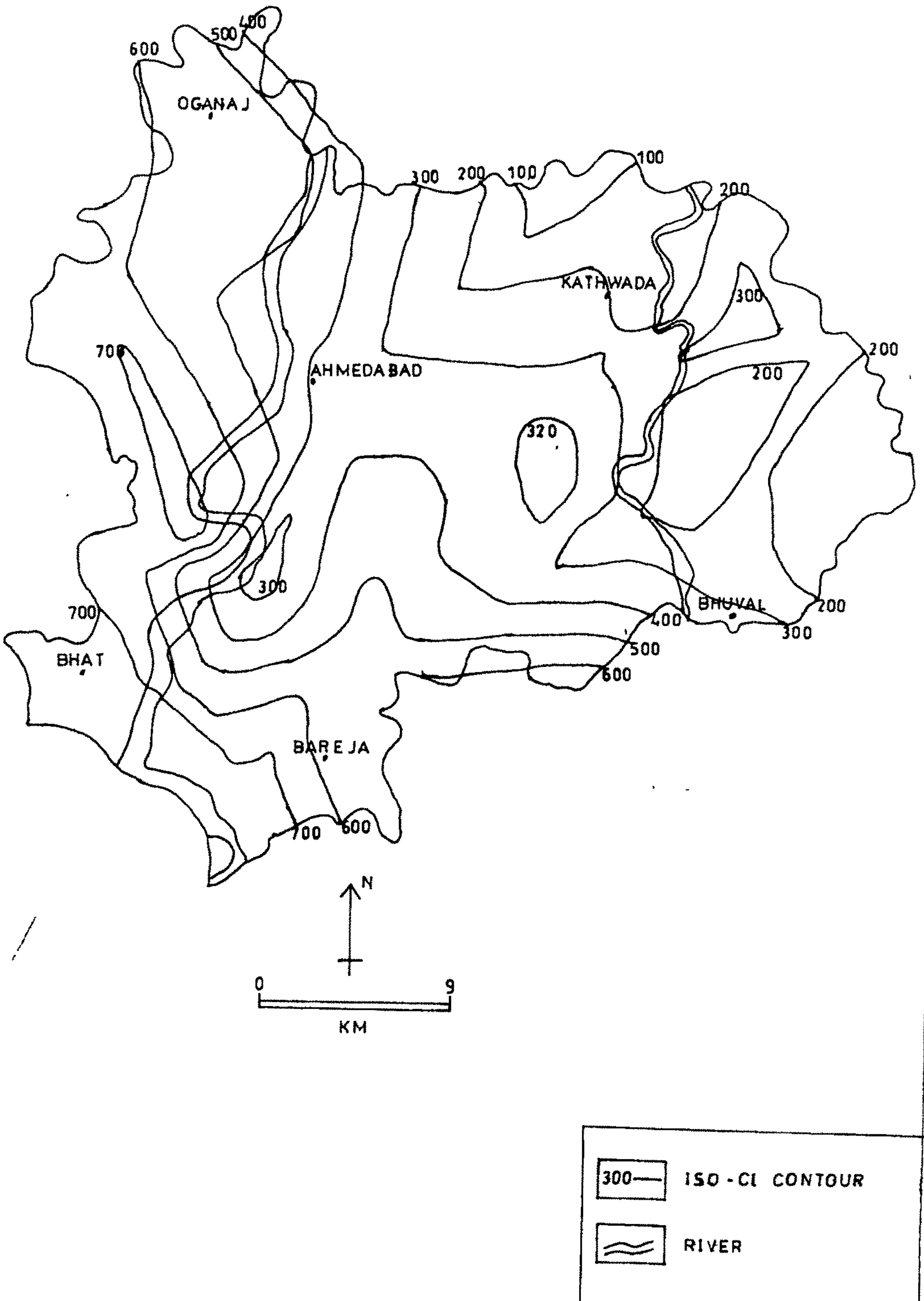
TDS: 880 – 7500 ppm, pH: 7.5 – 8.6, HCO_3: 335 – 550 ppm, Cl: 351 – 2000 ppm, Total hardness as $CaCO_3$: 38 – 438 ppm.

The salinity of groundwater from aquifer system range from around 300 ppm to 13,000 ppm TDS with an average of about 2000 ppm. The groundwater with high TDS occurs in the vicinity of Santej (13,000 ppm), Vinjhol (11,000 ppm) and Racharda (6100 ppm). The TDS is high because of higher concentration of Na, Cl, HCO_3 and SO_4. Nitrate concentration ranges from 0.1 to 187 ppm which occurs near Ghuma (124 ppm), Vatva (179 ppm) and Chandkheda (124 ppm). The quality of groundwater in the area is a result of recharge-discharge processes influenced by man's activities particularly those associated with the urbanization and industrialization of the urban area. ISO-Chloride contour map (fig. 6.13) of Ahmedabad shows an increase in the chloride content from north to south.

In general water quality and water levels deteriorate from north towards south direction.

FIG. 6.13: ISO-Cl CONTOUR MAP OF AHMEDABAD CITY (1994)

(PREMONSOON)



HYDROGEOLOGICAL SCENARIO

Hydrogeological framework in the area is mainly controlled by the geological set up, distribution of rainfall in the time and space, the intergranular openings available for the recharge and movement of water through the various aquifers. The unconsolidated to semi-consolidated alluvial deposits form multi-aquifer system. Groundwater occurs, both under phreatic and confined conditions. Thick alluvial deposits form most prolific multi-aquifer system. Groundwater extensively developed by dug-cum-bore well (DCB) and tube wells. Depth of DCB varies from 25 to 65 m bgl. In most of the region, DCB are generally dry and groundwater is extracted directly from the bore and/or tube wells that tap deep aquifers. The tube wells are the main groundwater withdrawal structures, which range in depth from 60 to 300 m. The depth to piezometric surface of deeper confined aquifer range from more than 80 m bgl. The discharges of tube wells range from 20 to 60 lps for 8 to 13 m of drawdown. The average yield of a 250 m deep bore well is around 20 lps. The transmissibility of deeper aquifer varies from 300 to more than 1200 m^2 / day.

A very rapid pace of groundwater development from deep aquifers over the years with practically no control in the use pattern combined with prolonged years of deficit rainfall in the eighties has resulted in tremendous lowering of the piezometric surface. This has ultimately given rise to well failures, lowering of discharge and increased in the depth of tube wells over the past decade.

Tube well drilled down to a maximum depth of 268 m tapping three or more confined aquifers in the area yield between 410 l/min and 4000 l/m for a draw down ranging from 6.1 m to 15.24 m. The population of 5 million and the water demand of urban, rural and industrial sections aggregate to 221.7 MCM /yr, the total groundwater exploitation in AUDA and AMC is 200 MCM/yr. The waste water availability is 182.5 MCM. By the year 2011 the enhanced demand for water is estimated to be 301.7 MCM/yr with waste water availability of about 241.6 MCM/yr (Gupta, et al., 1997).

HYDROGEOMORPHOLOGY

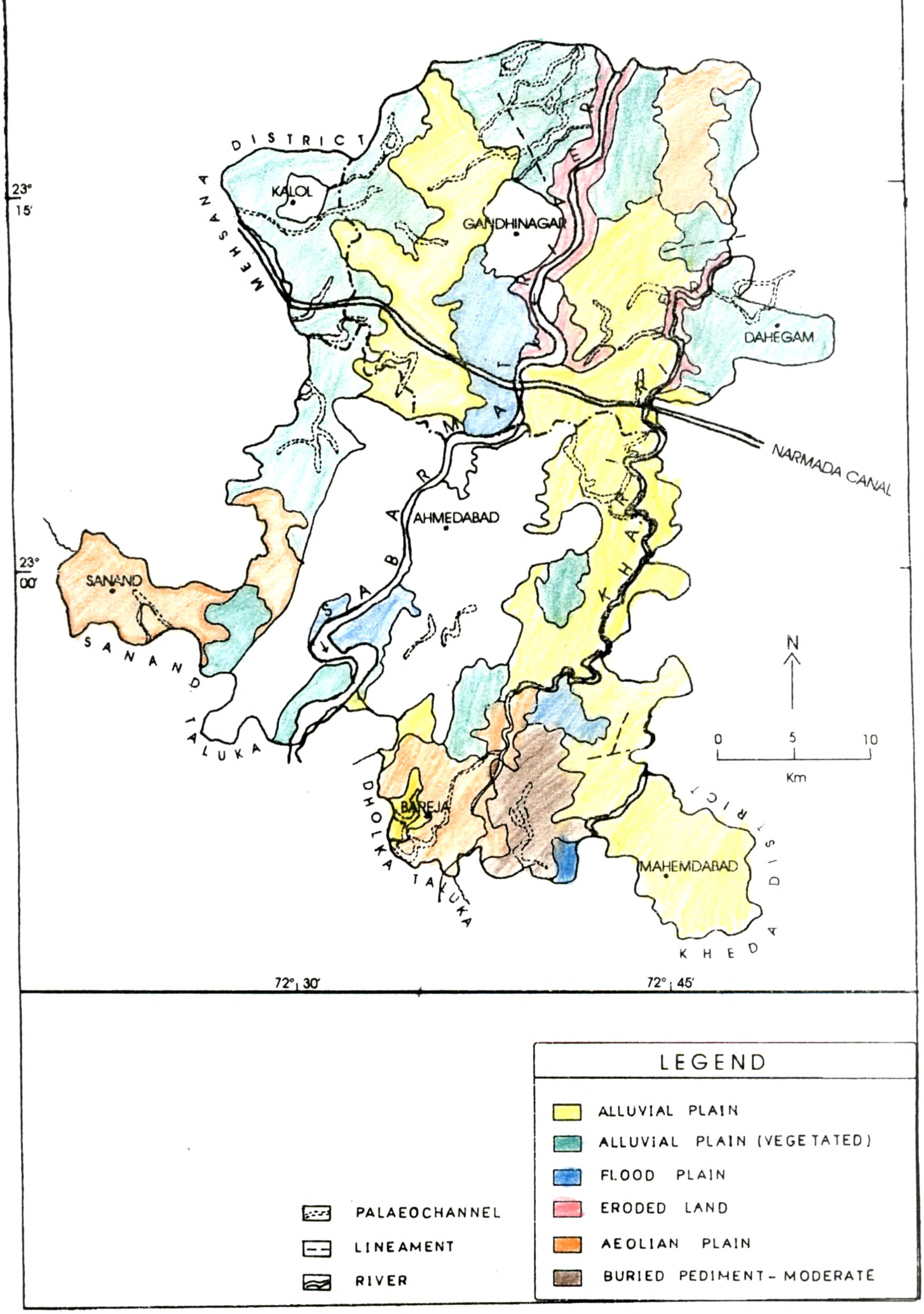
Hydrogeomorphological study of the area deals with the depiction of important geomorphological units and landforms which provide a better understanding of the various processes and materials composing the landforms as well as the underlying geology and structure with reference to groundwater occurrence and its prospects.

Geomorphology deals with relief, landforms and their chronological development along with material composed and structures, plays an important role in terrain evaluation for groundwater development of the area. Hydrogeomorphological studies with special reference to groundwater occurrence has been attempted based on visual interpretation of IRS – 1C LISS –III satellite data. The geocoded imageries were studied on 1:50000 scale and ground checks along selected traverses were also taken. Different photo characters like tone, texture, colour and geotechnical events like drainage, topographic expressions, and lineaments etc. were taken into consideration while demarcating different physiographic units (Fig. 6.14).

The major geographic unit present in the area is alluvial plain. The vast alluvial plain has come into existence owing to the deposition of sediments by the river Sabarmati. At places the alluvial plain is covered by sand sheet and also by stabilized sand dunes formed of wind blown sediments. Thus the geomorphic features in the study area owe their origin to depositional cycle of fluvial and aeolian processes. The sediments have been deposited during the Quaternary period, composed of loose to semi-consolidated sand, silt, clay and gravel up to a depth of more than 400 m.

Geological and structural aspects have played important role in occurrence and movement of groundwater in the area. The hard crystalline rocks of the Aravalli Super Group occurring in the northern part form the main recharge zones for confined aquifers. Lineaments play an important role in this zone as recharging structures. They are expressed by a variety of features. In the study area, straight drainage as well as vegetation and soil-tonal alignments can recognize them. They mainly represent fractures or faults in the region. The drainage is also controlled by these lineaments. The prominent trend is N-S and NE-SW. Structurally, very few lineaments can be traced on the surface from satellite imagery.

FIG. 6.14: HYDROGEOMORPHOLOGICAL MAP



The different hydrogeomorphic units present in the study area in context to groundwater have been discussed here:

Alluvial Plain (AP)

Alluvial plain has covered almost entire tract of the study area. This unit is flat to very gentle surface formed by extensive deposition of alluvium brought by the rivers Sabarmati and Khari and made up of loose to semi-consolidated sand, silt, clay, and gravel with varying lithology. This hydrogeomorphic unit covers Ahmedabad, Gandhinagar and surrounding areas. Here in, general thicker sandy layers incorporating thin clay layers occupy northern areas, while in S and SW parts, the silty clay layers dominant over thin sandy aquifers. Grain size is coarser in the N and becomes finer towards S. The effect of urbanization is seen more in this unit. Study of pre-monsoon imagery suggests that this part in the urban area is reclaimed and mainly used for construction and other uses. Whereas, in the surrounding areas, this unit is extensively cultivated and is represented as AP (V) on the map.

Groundwater prospects are excellent in this unit and shallow groundwater may be present near palaeochannels. Majority of small lakes and natural water bodies in this unit are found lying along such palaeochannels, palaeomeanders and meander scars. These areas are porous and permeable providing excellent groundwater potentiality. Due to continuos excessive withdrawal of groundwater in the region, all such shallow zones have been dried out. Many aquifers in this unit are basin or syncline shaped producing semi-confined to confined aquifer system, where recharge area is extreme north and northeastern hill ranges. The semi-confined and confined aquifer conditions in alluvium are due to occurrence of alternate clay deposits. The flow of groundwater and slope of aquifer is from NE to SW direction.

Flood Plain (FP)

This is mainly found along the banks of Sabarmati river and its tributaries in areas of meanders and curvatures. It represents a flat surface adjacent to the river and constitute unconsolidated fluvial sediments comprising gravel, sand and silt where normally sand or silt dominates with few thin clay bands. Porosity and permeability are high due to unconsolidated nature of the sediments and hence the groundwater prospects are very good. This unit shows gentle to moderate slope towards the river. Through these wide flood plains, near Gandhinagar, Vasna barrage and south of Sarkhej, continuous recharge is possible.

Eroded Land (EL)

This unit is mainly found along the banks of Sabarmati river, north of Ahmedabad city, in form of small pockets and elongated stretches. Deep vertical and highly inclined cuts can be seen in form of undulating ravines near Kotarpur. This unit is produced due to extensive gully erosion. It comprises of fine grained, semi-consolidated sediments of mainly silt and clay. Groundwater prospects are poor in this unit.

Aeolian Plain (EP)

This geomorphic unit is also very wide spread covering alluvial tracts at many places. It is mainly represented by barren sand sheet and stabilized sand dunes. The sediments are fine-grained sand and silt free from moisture. Cultivation is less and vegetation is sparse in this unit. Groundwater prospect is poor to moderate.

From the hydrogeomorphological studies and groundwater prospects, it is clear that porosity, permeability and transmissibility of sediments along with its morphological expression in an area plays an important role in the groundwater development and quality. With the help of hydrogeomorphological information, prospects of groundwater can suitably be inferred and summarized in the table 6.9.

Table – 6.9: Hydrogeological framework and groundwater prospects of the area.

Parameters		**Description**			
Age		Quaternary, Upper Tertiary			
Geomorphic Unit		Alluvial Plain			
Lithology		Clay, silt, sand, gravel, calcareous concretions			
Tectonic Framework		Groundwater basin occurring on platform area			
Groundwater Conditions		Groundwater basin having extensive lateral extent and total aquifer thickness under confined conditions ranges more than 50 m			
Depositional Environment		Fluvial and aeolian			
Aquifer Type	Aquifer Characters	Depth (m)	Yield (lpm)	TDS (ppm)	Groundwater prospect
	Phreatic	20 - 150	250 - 500	1000 – 2000	Over exploited
	Confined	150 - 400	1000 - 3000	1200 – 1800	Over developed