CHAPTER - VIII

GROUND WATER RESOURCE

INTRODUCTION

Groundwater is an important resource in respect to environmental conditions in the district It occurs within a very complex hydrogeological framework and the mode of occurrence in the three units is not only distinct from one another, but in each case recharge potential and quality variations are also incomparable. The ERH and WSW units have rather low potential; the water quality is good in the former but very poor in the later. Compared to the above two units, CAP unit a very high potential with overall good quality.

The pattern of exploitation of groundwater in the district has registered a sudden rise since late sixties, and thereafter it has accelerated at an exceptionally high rate. This has happened as the consequence to a major change in the occupation of the people when the traditional pastoral economy changed to irrigated agriculture (Plate 8.1). The groundwater resource has been overstressed in the rich agricultural areas, resulting into disturbance of the recharge-extraction balance and leading to groundwater mining conditions in the CAP unit and the bordering areas of the adjoining units. The environmental and ecological degradation that was initiated by the unscientific development of the surface resources has been further aggravated by the overexploitation of the groundwater resource.

In this chapter an attempt has been made to critically review the hydrogeological framework, recharge pattern, aquifer characterization, and exploitation scenario.

HYDROGEOLOGICAL FRAMEWORK

The district exhibits quite a complex but interesting hydrogeological framework. The geomorphic configurations, tectonic history, structural geometry, stratigraphic

Plate 8.1 Irrigated fields from groundwater in Unconfined aquifers in Piedmont zone near village Atal

succession, lithological types and hydro-meteorological variations as described in the earlier chapters, have these collectively contributed to the present condition. Diversities of these factors are intricately reflected in the mode of occurrences of groundwater, hydrologic properties of aquifers, recharge potential, and quality variations. These have been aggravated further due to complexities of the prevailing exploitation pattern and development practices of the groundwater water resources.

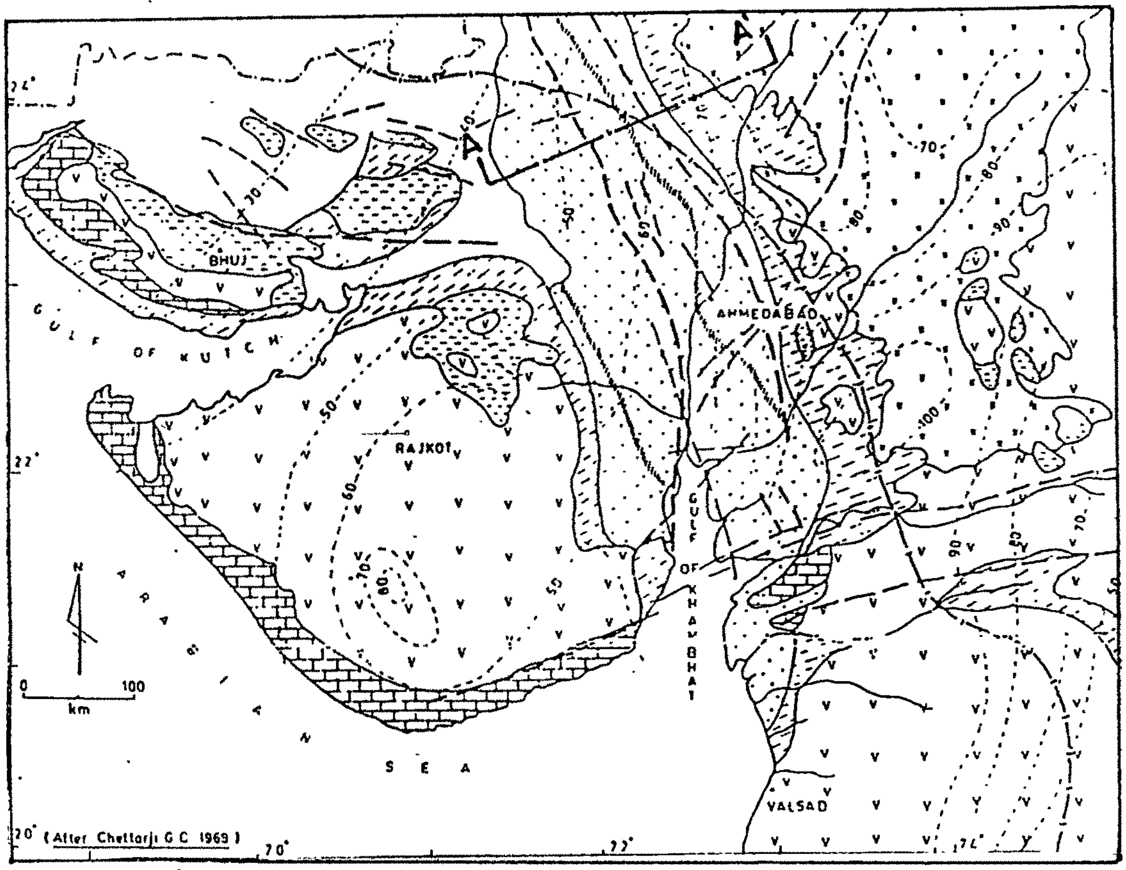
The different geological formations based on their hydrologic properties mainly related to transmission and storage of groundwater; generally are grouped into three major categories by several workers and organizations (GSI, 1969; Davis and Deweist,1970; Charlu and Datt,1982; Raghunath,1987; Karanth,1987; Phadtare, 1989; CGWB,1990; Todd, 1990;); as unconsolidated, semiconsolidated and consolidated formations. Hard undurated sedimentaries and all types of igneous and metamorphic rocks with very low porosity and permeability are grouped into consolidated formations. The Precambrians and Mesozoic rocks fall under this category. The uncemented soft and friable sedimentary rocks having moderate to high porosity and permeability belonging to Tertiary and some Quaternaries are classed as semiconsolidated formations. The loose deposits without any cementation, their granular members having very high porosity and permeability and belonging to Quaternary age group are classed as unconsolidated formations. However, some workers have also described the hydrogeological formations into two broad categories as hardrock formations and alluvial formations.

On the bases of the work of Charlu and Datt (1982); Phadtare(1989); UNDP (1976); HRW (1993), and data gathered by the author through personal discussions gathered with officers of the CGWB, GWRDC and GWSSB organisations a three fold classification has been adopted for the present study and accordingly the hydrogeological framework of the district has been described (Table 8.1).

Hydrogeological map of Gujarat including Banaskantha is given in Fig 8.1. A hydrogeological section (E-W) of Banaskantha district based on UNDP and CGWB exploratory works is given in Fig 8.2. The different types of hydrogeologic units are mainly separated on the basis of lithologic and tectonic features. It is interesting to observe that the lines delineating the geoenvironmental units (ERH, CAP and WSW) more or less coincide with the hydrogeologic boundaries. The central unit of CAP has been separated by the two marginal fault systems, of the Cambay graben. The East Margin Cambay Basin Fault (EMCBF) separates CAP unit in the east from ERH unit in the east, and the West Margin Cambay Basin Fault (WMCBF) separates it from WSW in the west. Lithologically also ERH unit comprises predominantly of consolidated formations (Precambrian crystallines), the CAP unit is of unconsolidated formations (Quaternary alluvium upto 500 m depth by under lying Miocene sediments) and the WSW unit of exposed unconsolidated Quaternary alluvium upto 150 m depth. This are underlained by mostly concealed and partly exposed semiconsolidated formations of soft Tertiary rocks about 300 m thick or even more. A local outlier patch of consolidated formation of Mesozoic sandstone also occurs near Eval. The three units in this respect form more or less independent hydrogeological formations which are briefly described as under.

CONSOLIDATED FORMATIONS

Hydrogeologically, the Precambrian crystalline rocks belonging to the Delhi Supergroup with associated igneous members exposed in the ERH unit fall in this category, which is also classified an area of hardrock formations. Towards the north, the



SYMBOL	AGE GROUP		LITHOLOGY	TECTONIC FRAMEWORK	GROUNDWATER CONDITIONS
	QUATERNARY UPPER TERTIARY	UNCONSOLIDATED FORMATION	CLAY, SILT, SAND GRAVEL, PEBBLES, BOULDERS, CALCAREOUS CONCRETIONS	GROUNDWATER BASIN OCCURING IN PLATFORM AREA AND FORE-DEEP ZONE.	GROUNDWATER BASIN HAVING EXTENSIVE LATERAL EXTENT AND THICKNESS OF AQUIFERS UNDER CONFINED CONDITIONS BEYOND ,100 m
				PLATFORM MARGINS IN PARTS OF MAINLAND RIVER BASIN COASTAL PLAINS OF KUTCH	MARGINAL AREAS OF GROUNDWATER BASINS HAVING AQUIFERS WITHIN 100 m WITH LIMITED EXTENSION DUE TO BOUNDARY CONDITIONS
	QUATERNARY AND TERTIARY	SEMI CONSOLIDATED FORMATION	LIMESTONES (Miliolite, Guj Kirthar)	COASTAL AREAS OF SAURASHTRA AND BETWEEN TAPI AND NARMADA MOUTHS	KARSTIC LIMESTONES (MILIOLITE AND GUJ) IN COASTAL AREA HAVING GROUNDWATER IN CAVERNS AND SOLUTION CHANNELS WITHIN 50m
	TERTIARY AND MESOZOIC		GRITS, SANDSTONS, SILTSTONES, SHALES, CONGLOMERATES, LIMESTONE	PLATFORM AREAS IN KUTCH AND NW SAURASHTRA OUTLIERS AND INLIERS IN E GUJARAT AND NARMADA VALLEY	TERTIARY AND MESOZOIC SEDIMENTARY ROCKS WITH RESTRICTED CONFINED AQUIFERS IN PLATFORM AREAS
	CRETACEOEOCENE	CONSOLIDATED FORMATION	BASALTS (WITH INTERTAPPEAN BEDS)	TERRESTRIAL VOLCANIC EFFUSIONS ON PLATFORMS	GROUNDWATER OCCURRENCE RISTRICTED TO WEATHERED ZONE, JOINT PLANES, ZONES OF SHEARING AND FAULTING AND VESICALS PHREATIC UNCONFIND CONDITIONS PREVAIL IN WEATHERED ZONE AND PIESTIC CONDITIONS IN DEEP FRACTURES
	PRECAMBRIAN		SANDSTONES, SHALES SLATES, PHYLLITES, QUATIZITES, DOLOMITES, MARBLES, SCHISTS, GRANITES, BASIC IGNEOUS ROCKS	ANCIENT PLATFORM AREAS OF ARCHAEAN FOLDING	GROUNDWATER OCCURRENCE RESTRICTED TO SOIL & REGOLITHIC COVER AND WEATHERED AND FISSURRED ZONES UNDER PHREATIC UNCONFINED CONDITIONS

WATER QUALITY	SPECIAL HYDROLOGICAL FEATURES	GEOTECTONIC FEATURES
GROUNDWATER SALINITY WITH LITTLE POSSIBILITY OF ENCOUNTERING FRESH WATER AT DEPTH	BOUNDARY AREAS WITH ARTESIAN FLOWING CONDITIONS	MAJOR FAULTS
GROUNDWATER SALINITY INCREASES WITH DEPTH	50 ISOHYTES ANNUAL AVERAGE RAINFALL IN cm	MINOR FAULT
GROUNDWATER FREE FROM SALINITY HAZARDS		TECTONIC ZONAL BOUNDARY

FIG-8·1 HYDROGEOLOGICAL FRAMEWORK OF GUJARAT

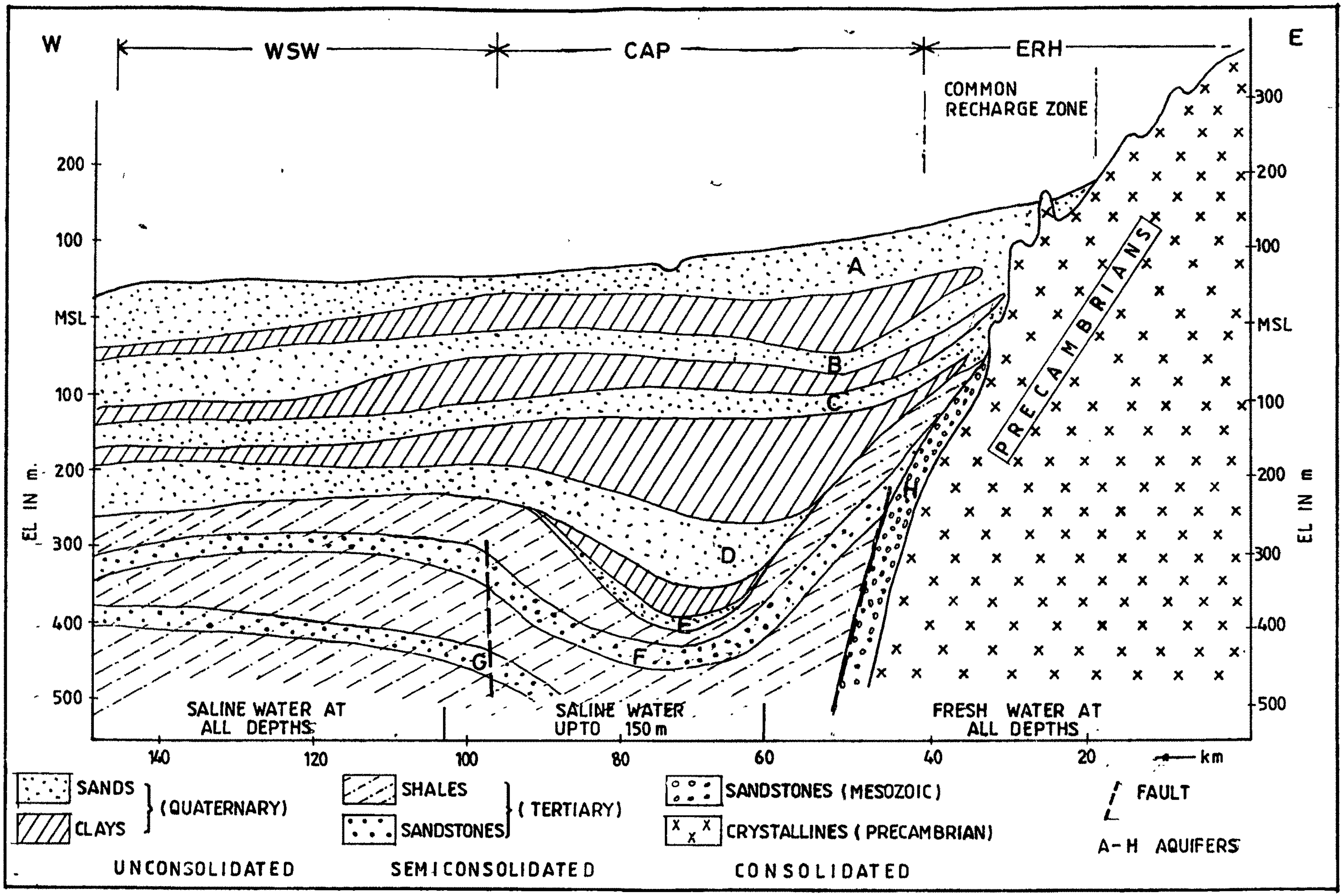


FIG- 8·2 SCHEMATIC HYDROGEOLOGICAL SECTION (E-W) OF BANASKANTHA DISTRICT

Table : 8.1 Hydrogeological classification and characterization of Banaskantha district .

HYDROGEOLOGICAL FORMATIONS / Geologic Age (Env. of deposition)	Lithology	Tectonic Setting	Groundwater Conditions	Areas of occurrence
UNCONSOLIDATED Quaternary (Fluvio–marine and Aeo-fluvial)	Clay, silt, sand, Gravel, pebbles, Boulders, Calcareous concretions etc	The Luni-Banas-Saraswati depositional basin occupying (Sanchor-Patan Block) of Cambay rift basin	Groundwater basin having extensive lateral extent and thickness of aquifers under unconfined conditions upto 150 m and confined aquifers extend upto 500 m	Entire CAP unit
		The zone between Eastern Margin Cambay Basin Fault (EMCBF) and exposed Precambrian crystalline rocks	Piedmont zone having wide seasonal fluctuations in groundwater storage and movement upto 150 m depth. Aquifers material consisting highly assorted material	Western part of the ERH unit
SEMI-CONSOLIDATED Upper Tertiary Pliocene (Fluvio-Marine)	Clay, Silt, Sand, (brown to greenish), and conglomerate	Middle parts of Cambay basin within Sanchor-Patan Block and western margin of Kutch basin	Areas of the lower parts of Cambay basin including its western margin along WMCBF	Entire CAP and WSW units at different depths
Miocene (Fluvio-marine)	Grey and greenish silts, Calcareous claystones, pyritic and Carbonaceous clays, etc	Lower part of Cambay basin within Sanchor Paten Block and western part of Kutch basin	Aquifers under confined conditions within 250 m to 850 m depths	Entire CAP and WSW units at different depths
CONSOLIDATED Jurassic (mainly Fluvial)	Sandstone, Conglomerate and shale beds	The easternmost terminal island a horst in the Kutch basin	Groundwater occurrence is restricted to porous sandstones beds unto about 200 m depth (?)	Western most part of WSW unit
Precambrian Delhi Supergroup and Intrusive	Phyllite, quartzites, schists, gneiss, granite, basic intrusive etc	SW part of the areas of Archean folding	Groundwater occurrence is restricted to regolith and weathered -fissured zones under phreatic unconfined conditions upto 50 m-100 m depths	Major part of the ERH unit

Table : 8.2 Hydrogeological succession and aquifer properties in the district.

Stratigraphy	Formation	Lithology	Depth to top of aquifer (m)	Thickness			Quality
				Range (m)	Average (m)	Parameters S-m³/h/m T-m²/d	
Recent to Post Miocene	Aquifer A	Course sand, gravel pebbles, medium and fine sands and clayey sand	5-71	35-125	62	S 1-31 T 300-1000	Variable
	Aquitard I	Clay interbedded with sand and sandy clay	78-162	13-88	39		-
	Aquifer B	Medium to coarse sand and gravel interbedded with sandy clay	78-162	10-80	45	S 1.8-4.9 T 47-400	Generally good
	Aquitard II	Clay interbedded with sand and sandy clay	-	13 80	37		-
	Aquifer C	Medium to coarse sand in north-east, and fine to medium in central part interbedded with sandy clay and clay	154-274	13.62	34	S2.8-21.3 T94	Variable
	Aquitard III	Clay interbedded with sand and sandy clay	-	19-172	73		-
	Aquifer D	Medium sand interbedded with sandy clay	229-402	11-105	52	S 1.3 T 69	Variable
	Aquitard IV	Clay interbedded with sandy clay	-	11-76	44		-
	Aquifer E	Fine to medium sand and sandy clay	300-542	15-57	24	S.1.1-1.7 T 59-70	Good
Miocene	Aquiclude V	Grey clay and claystone	-	13-148	41		-
	Aquifer F	Fine to medium sand, sandstone interbedded with siltstone	200-574	7-68	39	S 1.1-1.7 T 59-70	Variable
	Aquiclude VI	Clay and claystone	-	34-49	40		-
	Aquifer G	Fine to medium sand, sandstone interbedded with siltstone	264-513	9-124	48	S 1.1-1.7 T 59-70	Generally saline
Paleocene	-	Basalt	-		267		-
Cretaceous	Aquifer H	Himatnagar sandstone	214-547	98-145	121	S.1.4 T.86	Variable

formation extends into the adjoining districts of Sirohi and Udaipur of Rajasthan state, while in the east and south, it extends into the districts of Sabarkantha and Mehsana respectively. These are seen to gradually disappear all along the western border of ERH unit and get covered under alluvial deposits. The area along the western border of the ERH unit in fact, forms a piedmont zone comprising isolated hillocks of crystalline rocks, peeping out through a low level terrain comprising fluvial outwash and aeolian sand of Quaternary age (Plate 4.9). The consolidated formation in this unit has been covered beneath a maximum thickness of about 100 m of the Quaternaries as encountered in the exploratory drilling for tubewells(UNDP,1976; CGWB,1989; and GWRDC,1991).

A patch of consolidated formations comprising Jurassic rocks covering about 100 sq. km, occurs in the WSW unit but this occurrance is not of much significant from the point of groundwater occurrence. Its local presence in the area of unconsolidated and semiconsolidated formations in Banaskantha infact, has hydrogeologic similarities with the adjoining Wagad area of the Kachchh district.

SEMICONSOLIDATED FORMATIONS

The semiconsolidated formations of Pliocene and Miocene ages occur in the WSW and CAP units. The Pliocene sediments have restricted occurrences in extreme western parts of WSW. They are predominantly clayey with thin granular layers forming insignificant aquifers, having generally saline groundwater. Miocene deposits occur at shallow depths (50 m to 100 m) below the Quaternary within WSW but in CAP they occur at the depth of 200 m to 500 m. The granular layers in upper Miocene form productive aquifers and the groundwater in them occurs under high piezometric head. Some of the deeper aquifer in WSW have, given rise to artesian flow. The quality is variable. But selective tapping of low salinity aquifers has proved a good source of tolerable quality of water for domestic and irrigation.

UNCONSOLIDATED FORMATIONS

The whole of CAP unit and some part of WSW unit consists of unconsolidated formations of Quaternary sediments extending to a maximum depth of about 500 m (ONGC,1982; UNDP,1976; Phadtare, 1989;). The sandy layers of Miocene age of more than 200 m provide a system of semi-confined and confined aquifers. Based on the results of the exploratory tubewells, a hydrogeologic succession for the alluvial formations of Mehsana-Banaskantha areas is constructed by UNDP (1976) which is applicable for the aquifer systems of CAP and WSW units as well (Table 8.2). Recent exploratory wells have penetrated to a maximum depth of 700 m in Quaternaries (personal communication from GWSSB). Most of productive aquifers are formed of Quaternaries down to maximum depth of 500 m. However, Miocene sands in the depth range of 200 m to 700 m have also shown some aquifers of good quality. The fluvial and shallow marine environments of deposition during Miocene and Quaternary have been reflected into groundwater quality variations.

OCCURRENCE OF GROUNDWATER

In the exposed crystalline rocky areas of the ERH, the groundwater occurrence is restricted to the regolith cover and within the zones of weathering and fracturing. The weathered zones are generally reflect the topographic depressions having limited depth in the range of 10 to 30 m with lateral extent of 1 to 10 km or even more. While the zones of fracturing are the reflections of the structural features like faults, fractures, shears etc. They have linear extensions of 5 km to more than 25 km with very limited width ranging from a few tens of meters to a maximum of about 200-300 m. But they have relatively much greater depths of the order of 100 to 150 m. The circulating water in such zones produce structurally controlled linear aquifers; more or less coincide they with the straight courses of higher order streams.

The aquifers so formed are of unconfined nature and have limited lateral extents and shallow depths. They contain groundwater under phreatic conditions. The granular water-bearing zones are restricted to the topographic depressions and structural lineaments. The phreatic aquifer system of this unit therefore comprises hydrologically unconnected aquifers, so the groundwater behaviour in different aquifers is independent of each other.

In the piedmont zone the crystalline rocks go down to a depth of about 150 m and are covered by coarse granular fluvial outwash and a thick accumulation of aeolian sand. The buried rocks are dislocated by the NNW-SSE trending system of step faults related to the EMCBF. Thus, the bottom unconfined aquifers in this zone many a times extend to more than 150 m. The palaeo-stream courses (Plate 4.1, 5.1 and 6.1)of rivers Sipu, Banas, Saraswati etc. have made deeper longitudinal and transverse cuts within the fissured basement (Fig 1.4 and Sridhar,1995). The phenomenon has not only increased the depths of aquifers but has selectively contributed to a much higher recharge. A greater part of the groundwater recharge in this zone is thus contributed by the various rivers. The recharge water flows down under gravity into the granular layers extending into the adjoining zone of the CAP unit. Thus, the aquifer systems of CAP receive a greater recharge contribution from the piedmont area. This zone forms a 'common recharge zone' (Fig 8.3) for the local aquifers in ERH, the adjoining system in CAP as well as the WSW unit, where they truncate at the N-S trending Varahi-Vav fault. These

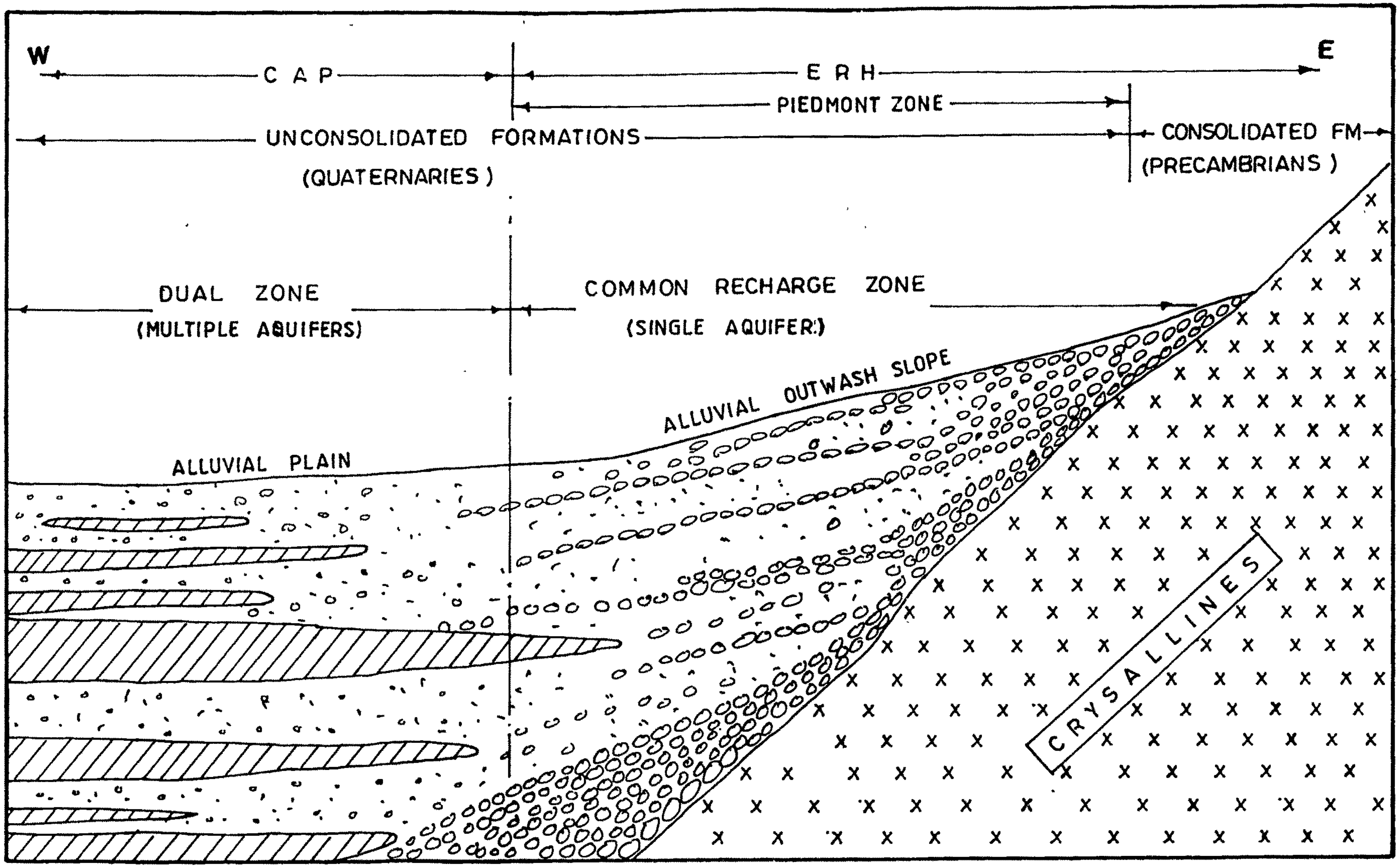
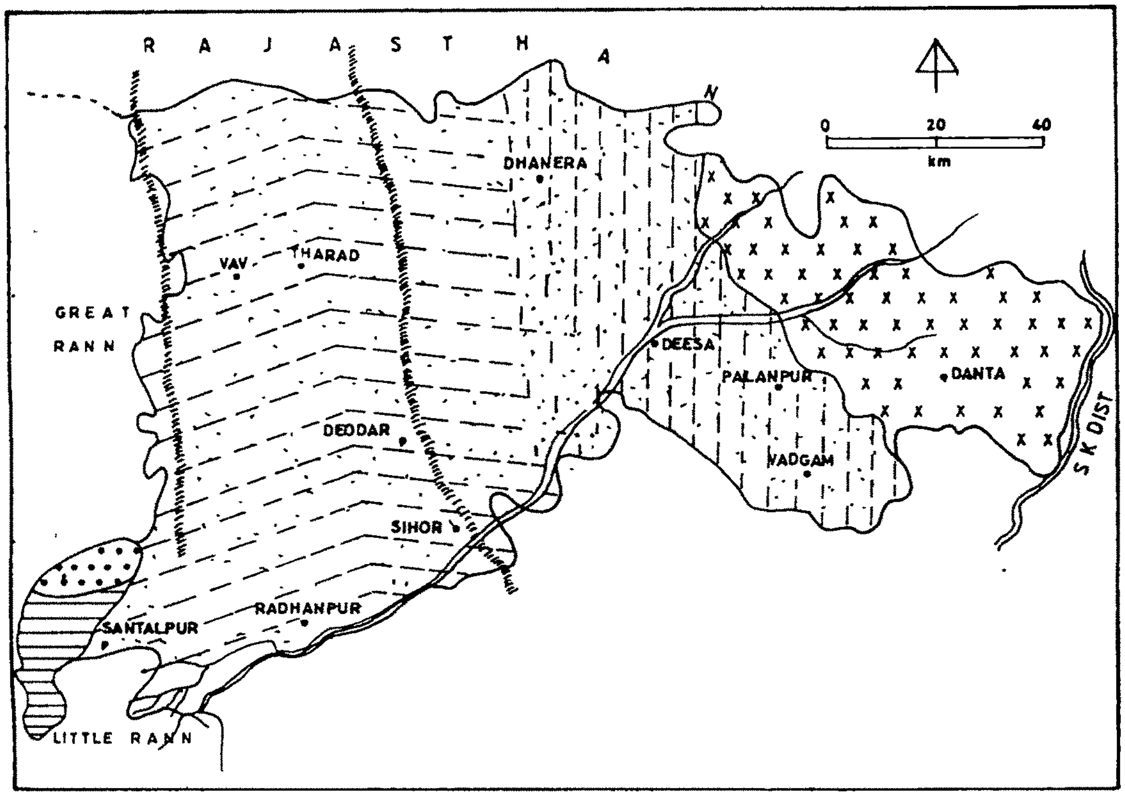


FIG-8.3 SCHEMATIC SECTION SHOWING COMMON RECHARGE ZONE aquifers occurring in WSW unit have high piezometric pressure head and form a free artesian flow (UNDP,1976).

Occurrence of groundwater in the district is under a complex system of unconfined and confined aquifers in areas as traced from ERH towards CAP and WSW units. A hydrogeologic map of Banaskantha district is given in Fig 8.4. Along the Banas river the hydrogeological section is prepared based on the tubewell data of GWRDC which shows the aquifer pattern between Bhandotra (in ERH) and Sardarpura (in WSW) in a length of about 125 km (Fig 8.5). Two major aquifer units have been identified within explored depth of more than 700 m in the central part of the district. The CGWB and UNDP under their exploratory programmes have drilled upto about 600 m depth. Recently, GWSSB (personal communication) while exploring for fluoride free aquifers in Saraswati river bed 10 km south of Sihori in the southern limit of the district has successfully drilled a few wells upto a depth of about 700 and have tapped aquifer with potable water within Miocene aquifer.

UNDP (1976), upto its explored depth of about 600 m has identified seven different successive aquifers and designated them as A to H (Table 8.2). The upper four aquifers (A,B,C and D) upto the depth of about 550 m are formed by the Quaternary sediments. These are separated by four alternate layers of aquitard (I to IV). The aquifers F and G formed by the Miocene sediments having maximum thickness of about 300 m underlie the Quaternaries. GWSSB has drilled through Miocene (aquifer F and G) near Kamliwada for about 300 m below 450 m of Quaternaries. Kamliwada is just 10 km south of Sihori in CAP. The lowermost aquifer H formed by the Mesozoic sandstone having thickness of about 350 m lie below Miocene and Quaternary and rests above the Precambrian granitic rocks.



REFERENCES

SYMBOL	FORMATION	AQUIFER CONDITIONS
	UNCONSOLIDATED (QUATERNARY)	UNCONFINED UP TO 150 m CONFINED UP TO 700 m
	SEMICONSOLIDATED (TERTIARY)	AQUITARD TO POOR AQUIFER
	CONSOLIDATED (JURASSIC)	POOR AQUIFER
	CONSOLIDATED (PRECAMBRIAN)	LOCAL UNCONFINED AQUIFERS

SALINITY AT ALL DEPTHS

SALINITY INCREASES WITH DEPTH

FRESH WATER AT ALL DEPTH

BOUNDARY AREAS WITH ARTESIAN FLOW

FIG. 8.4 HYDROGEOLOGICAL MAP OF BANASKANTHA DISTRICT

UNCONFINED AQUIFER SYSTEM

The uppemost phreatic aquifer A, consisting of medium to fine grained sands with increasing percentage of clay westward towards CAP and WSW units. It extends in the piedmont zone in ERH unit and forms the major recharge zone of the artesian aquifer system for the adjoining units. The thickness of aquifer ranges from 35 m in the east to about 150 m in the central and western parts. Phreatic conditions predominate in the eastern parts, but in the central and western parts there is a gradual change to semiconfined conditions. The hydraulic properties (UNDP, 1976) show a wide range of variation along E-W axis. Specific capacity varies from 31 $m^3/h/m$ to less than 1 $m^3/h/m$ while transmissivity from 30 m^2/d to about 1000 m^2/d. The higher transimissivity characterises the eastern piedmont zone (300-1000 m^2/d) and generally the lower transmissivities reflect the finer material of the aquifer in the central and western parts.

CONFINED AQUIFER SYSTEM

The system comprises of seven successive aquifers. The uppermost confined aquifer is 'B' extending over a large part of the unconsolidated formations. It consists of medium to coarse grained sands and gravels, locally interstratified with clay lenses. In the eastern foothill zone this aquifer unites with the phreatic aquifer on account of the wedging out of the separating clay layer. It is in this zone that large-scale recharge takes place (Fig 8.3). The top of this aquifer is found at depths of 80 -160 m below surface. Its thickness ranges from 10 to 80 m, the greatest thickness being found in the central part of the area. Its specific capacity ranges from 1.8 $m^3/h/m$ to 49 $m^3/h/m$ and transmissivity varies from 47m^2/d to 400 m^2/d; the quality of water is generally good.

The Aquifer C consists of fine to medium grained sand with several lenses of yellow clay. It is found at depth between 150 m to 275 m and has a specific capacity of 2.8 to 21.3 $m^3/h/m$ and of transmissivity 94 m^2/d. Quality of water is usually highly saline. The inflow from this aquifer is always blocked through cement sealing in the tubewells (Fig 8.5).

The Aquifer-D, found in central and western part comprising of fine to medium grained sand interbedded with sandy clays. Its top is encountered at a the depth range of 200 to 400 m; the thickness varies from 11 to 105 m. The wells showed sub-artesian conditions in the intial period of development but now the piezometric levels have considerably fallen down. The aquifer shows specific capacity of 1.3 $m^3/h/m$ and transmissivity of 69 m^2/d. The quality of water is variable.

The Aquifer-E, consisting of fine to medium grained sand with clay lenses is restricted only in the central part (CAP unit}. Its thickness ranges from 15 to 57 m and is encountered between depths of 300 to 542 m. Its water quality is variable. This aquifer was not tested during exploitation and hence no hydraulic properties are available.

The Aquifers F and G found in Miocene deposits, below grey clay marker bed defined as Upper Miocene. The sediments are fine to medium grained sand and sandstone. The thickness of these aquifers range from 7 to 6.8 m and 9 to 124 m respectively. The aquifers are found at 200 m to 574 m depths and even more. They show specific capacities of 1.1 $m^3/h/m$ and 1.7 $m^3/h/m$ and transmissivities of 59 m^2/d and 70 m^2/d respectively with variable water quality.

The Aquifer H exists on the edges of the eastern and western margins of the Cambay basin. It comprises poorly cemented sandstone, shale and conglomerate of 98 to 145 m thickness and occur at the depths of 214 to 577 m below surface on eastern side;

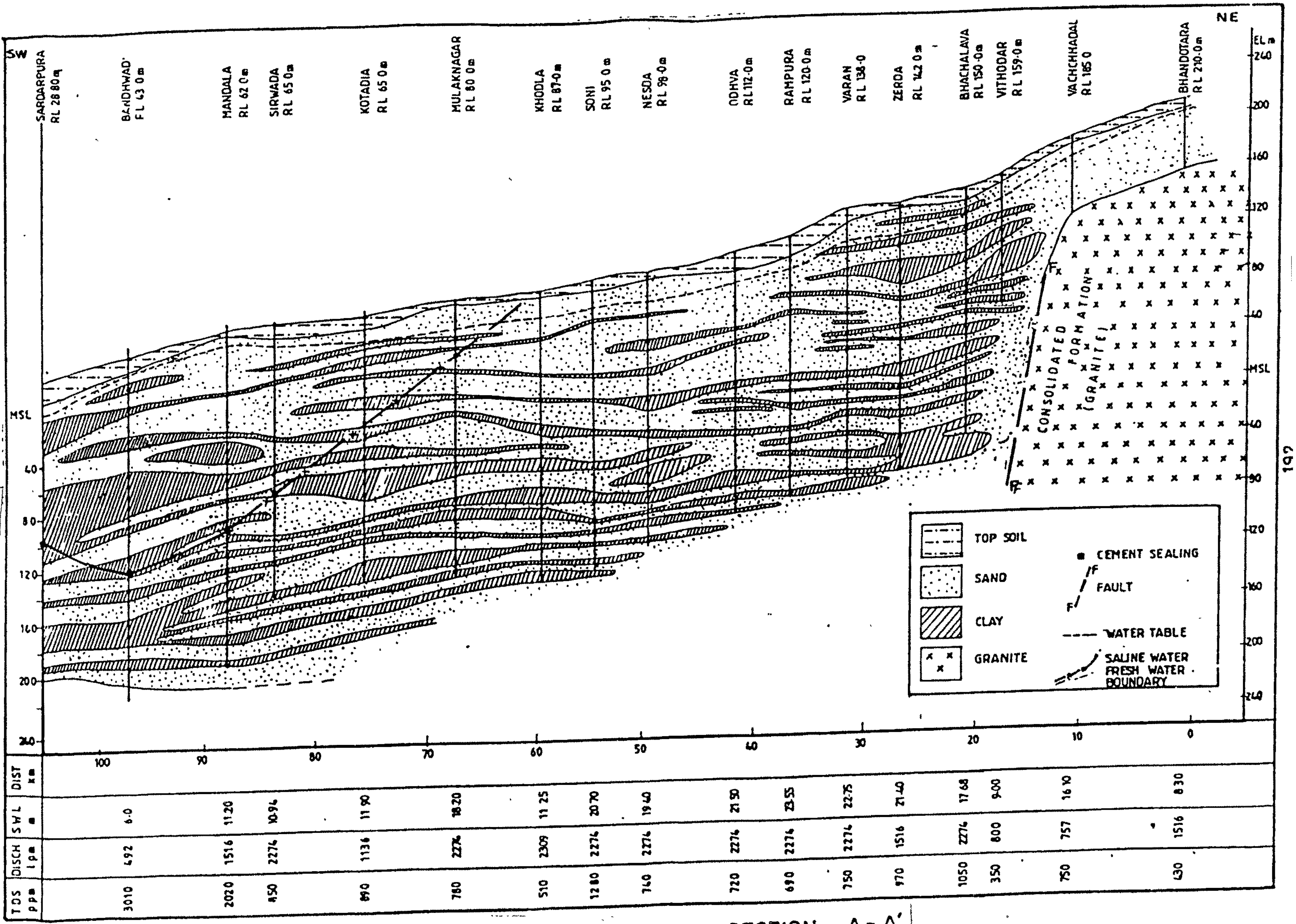


FIG- 8·5 HYDROGEOLOGICAL SECTION A-A'

the thickness is uncertain on the western side of the basin. It shows specific capacity of 1.4 $m^3/h/m$ and transmissivity of 86 m^2/d with quality of water variable.

GROUNDWATER RECHARGE

The various consolidated formations in ERH unit receive direct rainfall recharge. The soil cover of coarse grained sandy loams facilitate faster rate of percolation. But the steeper ground slopes and rather low porosity of crystalline rocks decreases the rate. The recharged water under the action of gravity gets drained out during the non-monsoon period.

The recharge mechanism in the alluvial area of CAP and WSW is somewhat different. The top phreatic aquifer is recharged by direct rainfall. It gets further augmented by the flows in the river beds. The under-seepage in the form of outflows from the aquifers in the ERH unit also indirectly add to the recharge of the aquifer systems in the CAP and WSW units. As per CGWB methodology, monsoon recharge of the aquifer has been computed by GWRDC (1991) using two different methods; Water Table Fluctuations(WTF) and Rainfall infiltration (RIF). The GWRDC, taking taluka as unit, recharge has evaluated the recharge using WTF method. But where water level observations are not available, RIF method is adopted.

The average annual groundwater recharge for the whole district has been computed by GWRDC (1991) as 1027.9 MCM and TEC (1995) as 1027.9 (Table 8.3). This value is considered at average rainfall. But in reality it would vary as per rainfall of the respective year. The recharge expressed as percentage of average rainfall in the district, varies from 8% in consolidated formation of Danta taluka to 39% in the piedmont zone of ERH unit . The areas in the CAP unit show recharge variation from 22 to 39 % while the saline tract of predominant clayey sediments in WSW shows an intermediate recharge range of 16 to 22 %. Generally 85% of the gross recharge is considered as utilisable, which amounts to 873.49 MCM for the study area.

Table 8.3 Geoenvironmental unitwise groundwater recharge .

Unit	Taluka	Area for recharge (sq km)			Recharge				
		Suitable All.	Hard Rock	Non Suitable	Rainfall MCM	Other Source MCM	Gross MCM	Gross depth mm	As % of Rainfall
ERH	Danta	00	857	00	41.2	4.4	45.6	53.0	39
	Palanpur	665	806	140	175.7	42.8	218.6	80.9	186
	Dhanera	748	357	85	107.1	50.2	157.5	143.5	134
	Vadgam	403	120	42	54.3	3.6	54.6	104.4	46
	Total\Av	**1816**	**2140**	**267**	**315.9**	**101.27**	**476.3**	**95.2**	**405**
CAP	Deesa	1434	15	12	105.1	70.7	175.8	122.8	150
	Kankrej	822	00	50	97.9	26.0	124.3	151.3	107
	Deodar	1012	00	00	112.5	1.0	113.5	112.1	97
	Total\Av	**3268**	**15**	**62**	**315.6**	**97.73**	**413.8**	**138.2**	**352**
WSW	Vav	851	00	851	12.8	1.22	44.9	52.8	38
	Tharad	679	00	679	54.7	1.5	56.2	82.8	48
	Santal-pur	270	00	1081	7.9	8.5	16.5	60.8	14
	Radhan-pur	270	00	325	18.5	2.05	20.5	75.8	17
	Total\Av	**2070**	**00**	**2937**	**93.9**	**13.38**	**138.2**	**23.5**	**117**

GROUNDWATER DEVELOPMENT

As per the TEC (1995) analysis of the GWRDC (1991) data, the gross groundwater draft for the district works out as 1845.83 MCM (Table 8.4). There are 15996 of openwells and 5664 of tubewells. The total average annual draft computed for the openwells as 4 TCM/Yr and that for the tubewells is 75 to 500 TCM. The draft over the period of 12 years (1978 and 1991) has showed a remarkable rise as observed from the GWRDC records. In 1978 it was 435.87 MCM which increased to 1845.83 MCM in 1991 indicating a 323 % rise during the period. This has adversely affected the water level and as a result 33 % of open wells went out of production. There was however, a significant increase of 1140 % in the number of tubewells. This phenomenal increase in extraction rate which has out weighted the recharge rate and has resulted into groundwater mining conditions, causing a progressive depletion of water levels and deterioration of water quality. As per extraction data by GWRDC for 1991, a total of 100745 ha irrigation potential has been created. Taking 100% development of the available potential, GWRDC considers 7415 new tube wells are feasible for the area. In this computation, 15% potential has been reserved for domestic and industrial supply.

Table 8.4 Geoenvironmental unitwise details of groundwater draft 1978 and 1991.

Unit	Taluka	No. of Dugwells		No. of Tubewells		No. of Pumpsets		Gross discharge	
		1978	1991	1978	1991	1978	1991	1978	1991
ERH	Danta	2747	2834	00	04	703	1570	18.60	30.58
	Palanpur	4066	1679	23	876	5177	8250	90.96	193.32
	Dhanera	5535	1000	30	249	1116	8341	38.68	130.31
	Vadgam	1661	803	35	1042	1184	6046	25.51	188.04
	Sub-Total	14009	6316	88	2171	8188	24207	177.75	542.24
CAP	Deesa	2615	5303	156	266	94	4521	44.88	131.75
	Kankrej	4766	2612	110	632	1942	4740	89.40	888.30
	Deodar	1369	00	57	1778	1161	2603	59.65	138.87
	Sub-Total	8750	7914	323	2676	4047	11864	193.93	1158.93
WSW	Vav	144	555	04	192	110	95	2.91	7.30
	Tharad	162	730	65	249	588	8165	13.18	16.55
	Santalpur	508	425	26	163	64	41	3.69	17.57
	Radhanpur	230	56	36	213	1498	279	51.41	103.26
	Sub-Total	1044	1766	191	817	2260	8580	68.19	144.66
	District Total	23803	15996	602	5664	14495	44651	435.87	1845.83

WATER LEVELS

The water level of confined and unconfined aquifers show quite complex and interesting behaviour. For different geoenvironmental units it is quite independent. The data of water level monitoring by the GWRDC (1984 to 1994) and CGWB (1978 to 1988) are quite useful in understanding the recharge-draft relation and related environmental issues. The data (Table 8.5) show a general declining trend. The rate of water level fall is less in extreme eastern and western parts as compared to that in the piedmont zone in ERH, in the entire CAP and in the eastern parts of WSW units (Fig 8.6) The falling trend is due to increasing exploitation for the irrigation purpose.

Table 8.5 Waterlevel characterisation of unconfined aquifers in the district

Obs. Sts.	Unit	Obsr. Years		Waterlevel Obsr. Period				Total Fluc.	
		From- To	Total	Intial [m]	Rise [m]	Fall [m]	Max. [m]	Min. [m]	Max. [m]
Ambaji	ERH	1969-88	20	16.85	6.55	-	15.21	3.06	4.2
Danta	ERH	1978-88	11	6.66	-	8.54	15.2	5.44	3.07
Danti-wada	ERH	1978-88	11	12.25	-	10.67	22.92	11.82	1.94
Palanpur	ERH	1969-88	20	13.18	-	21.83	35.01	11.24	1.85
	Av.		15	12.23		8.6	22.08	7.89	2.75
Dhanera	CAP	1969-88	20	10.89	2.03	-	11.08	8.86	1.83
Deesa	CAP	1969-88	20	15.17	-	2.95	18.12	5.91	6.28
Bhabhar	CAP	1969-88	20	10.59	-	0.66	11.25	7.09	1.27
Sihori	CAP	1969-88	20	9.41	-	1.6	11.65	7.94	1.39
	Av.		20	11.5	-	1.06	13.03	7.45	2.69
Radhan-pur	WSW	1969-88	20	4.00	-	0.43	10.88	1.87	3.11
Santal-pur	WSW	1969-88	20	7.91	1.51	-	7.25	5.1	7.32
Suigam	WSW	1969-84	16	4.99	-	0.41	6.58	3.79	4.64
Tharad	WSW	1969-88	20	4.95	-	4.15	9.1	2.91	1.47
Agarthala	WSW	1969-88	20	5.61	-	5.99	17.7	2.34	4.52
Vav	WSW	1981-88	09	10.28	3.96	-	11.57	6.32	1.69
	Av.		18	6.29	-	2.00	10.51	3.72	3.71
District			18	10.01	-	3.43	15.2	6.3	3.08

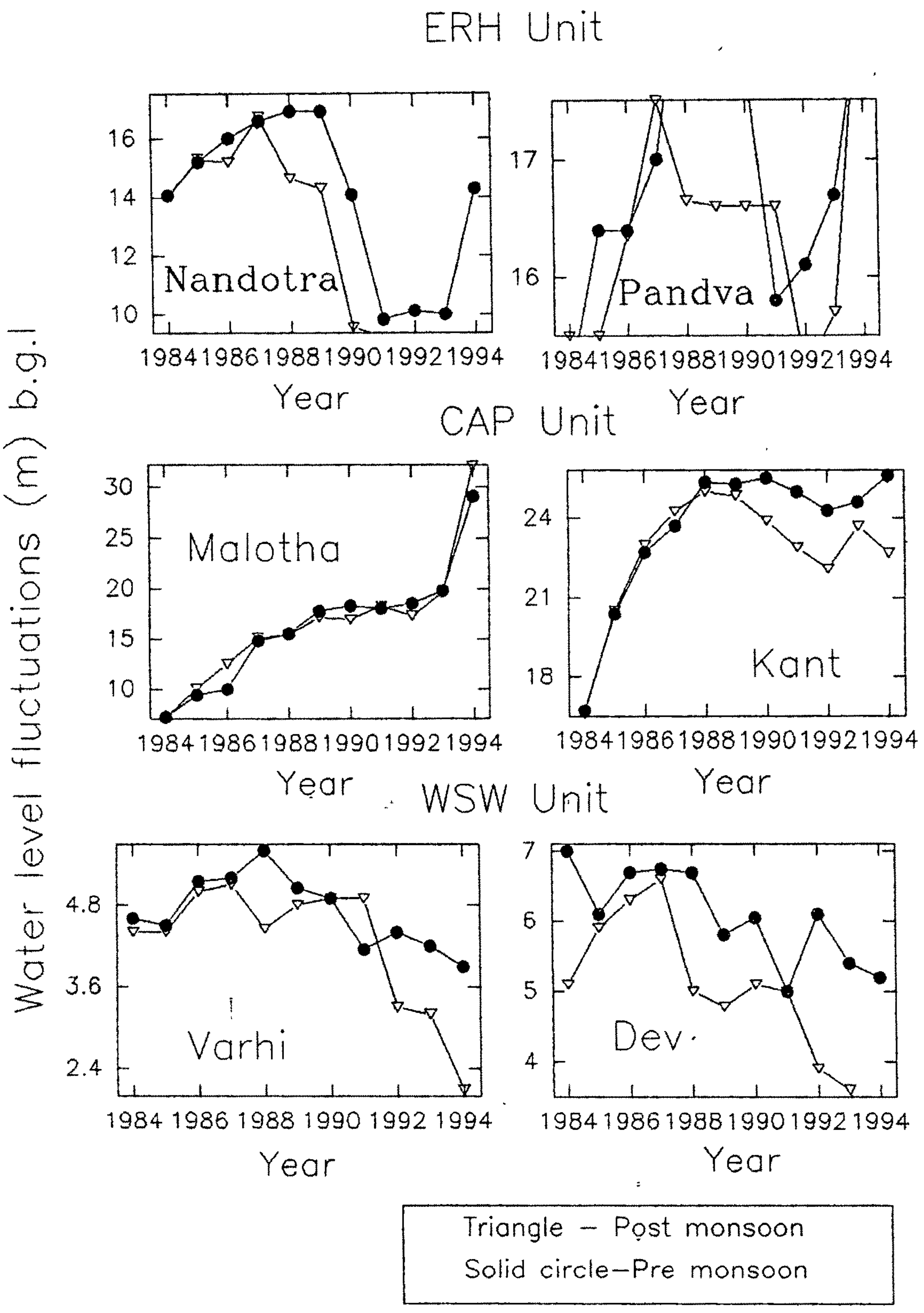


Fig 8.6
Water level fluctuations of Phreatic aquifers in 3 units of Banaskantha district

area of the ERH unit, where aquifers are under unconfined conditions, the watertable occurs within a depth range of 5 to 15 m below the ground level. Here, the watertable shows seasonal fluctuations in range of 1 to 10 m. It generally reflects the combined conditions of rainfall recharge, extraction pattern and gravity outflow. The increasing trend of extraction in the past years is also reflected in a general lowering of the water level and widening the gap of seasonal fluctuation.

In the piedmont zone the water level is around 15 to 30 m and seasonal fluctuation is of 2 to 5 m. The well yield in the area is generally high, of the order of 500 to 1000 lpm and there is a very high rate of well extraction. This has also caused a permanent lowering of water table. In the year 1984, the watertable was around 15 m which has fallen down to 30 m in the year 1994. It means the average rate of fall is 1.4 m/yr. The complex situation of water levels in the zone is on account of its special hydrogeologic conditions. The area forms the dominant recharge zone in the district. It is the common recharge zone for the unconfined aquifer in western parts of ERH and confined aquifers of the CAP. Its recharge rate is highest (20% to 30% of rainfall) in the district. The extraction of groundwater is also very high in this zone, the average well yield is 1500 lpm.

In the CAP unit the water table in the unconfined aquifer in the depth range of 12 to 26 m. It shows narrow seasonal variation in the range of 2 to 5 m only. The well yield from the aquifer is generally very low being of the order of 50 to 100 lpm. The aquifer has been exploited fully and this has caused more or less permanent depletion of the waterlevel. In period of 11 years (1984-1994) maximum depletion has been observed to be about 19 m, registering a general rate as 1.7 m/ year. The recharge of the aquifer is also subjected to losses due to leakage to lower confined system. That also contributes to the lowering of the water table. As a result of the overall depletion trend of the water level, the large number of shallow wells have been rendered dry and the yield from the existing wells has been greatly reduced.

The water level in the tubewells i.e, the piezometric pressure level of the confined aquifer system in the CAP shows an entirely different pattern from that of the unconfined aquifers in the area. The piezometric levels varied from 7 to 22 m during the year 1984 while the depth range from 35-45 in the year 1994. In a period of eleven years, it has fallen by 12 to 30 m, an average fall rate is of 2.5 m/yr. Such a phenomenal fall reflects the situation of groundwater mining. The level shows some sensitivity to seasonal rainfall pattern. But it registers a progressively increasing fall of permanent nature. The indifferent behaviour of the water levels in the CAP unit at a same location from the unconfined and confined aquifers is quite interesting as shown in Fig 8.7(a and b). At Pilucha and Khimat villages the differences between phreatic and piezometric levels in 1984 was 4 and 6 m respectively. The same after 11 years (1994) have widened to 31 and 24 m respectively.

The WSW unit also have two aquifers; and the water level behaviour in them is comparable to as those of the CAP unit. The phreatic water table occurs in the depth range of 4 to 10 m. Over the period of 11 year it has however shown a rather low rate of permanent depletion, of the order of 4 m (0.36 m/yr). The quality being variable, its extraction is also limited. Observation and recording of piezometric levels of confined aquifer started only in the year 1992. Its present level is from 27 to 47 m. Such a short period of observation thus does not establish any specific trend of rise or fall of level (Fig.8.8)).

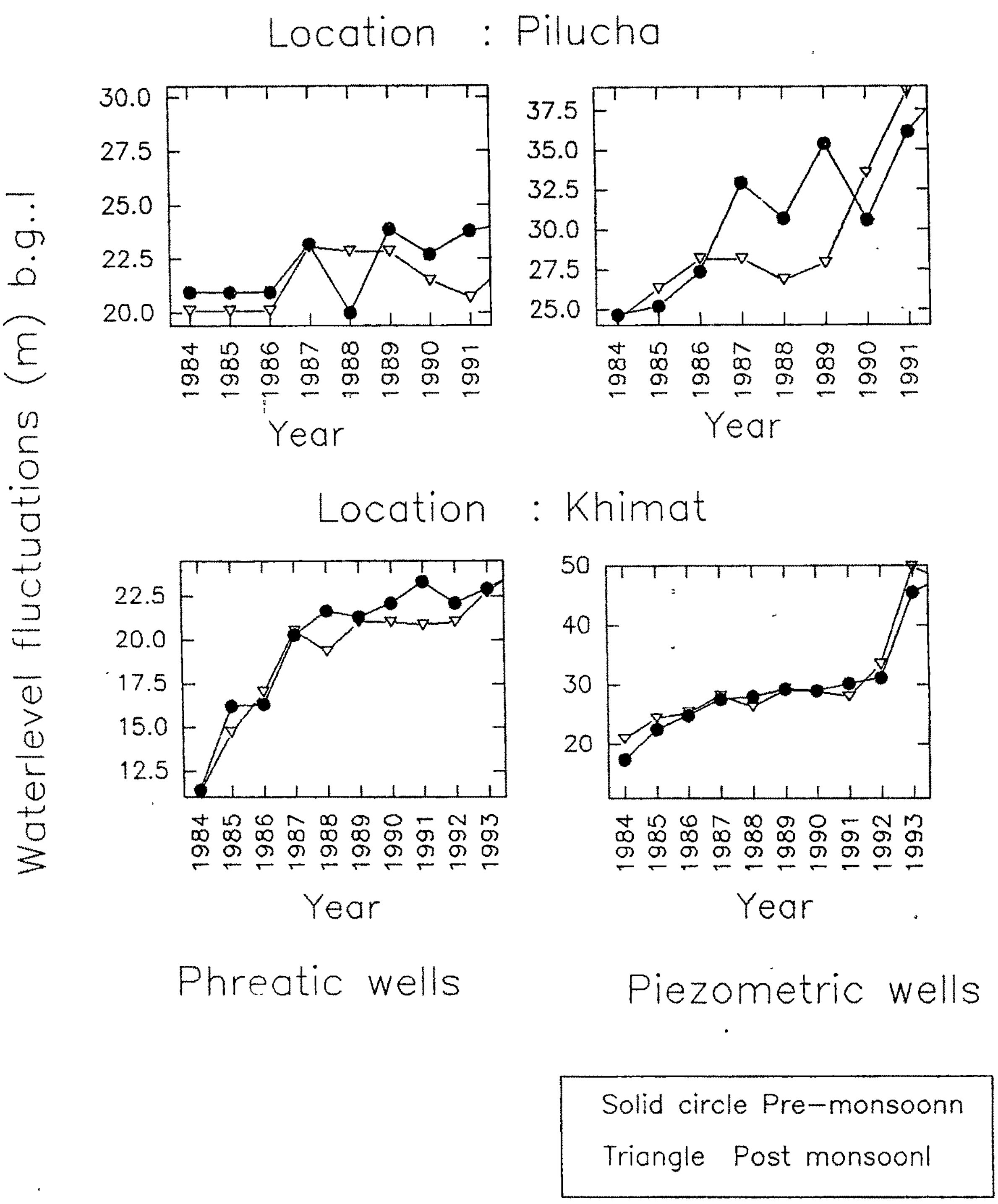


Fig 8.7 (a) Difference in Piezometric and Phreatic water levels at the same location in Banaskantha in the district

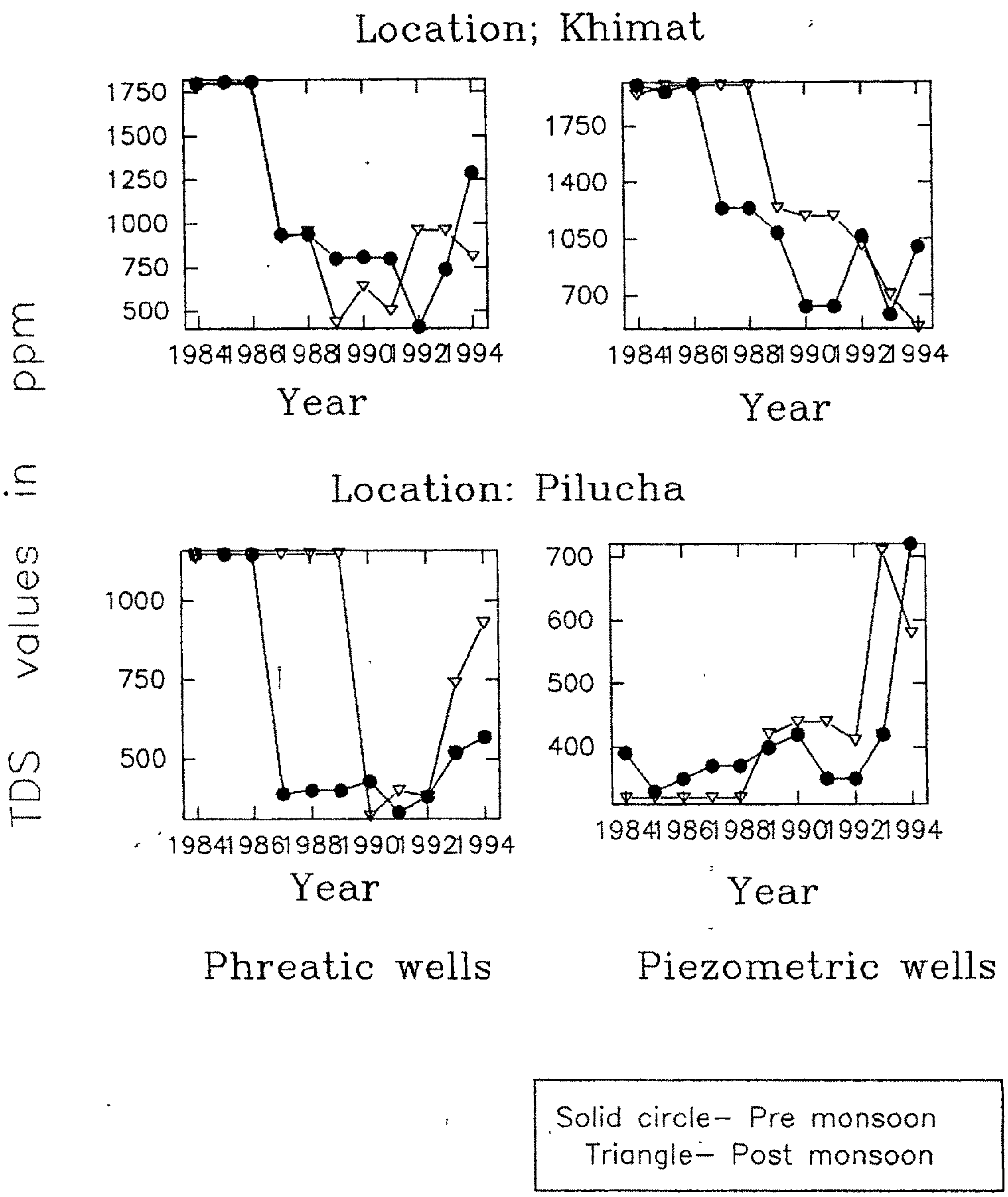


Fig 8.7 (b) Difference in quality variations at same location in the district

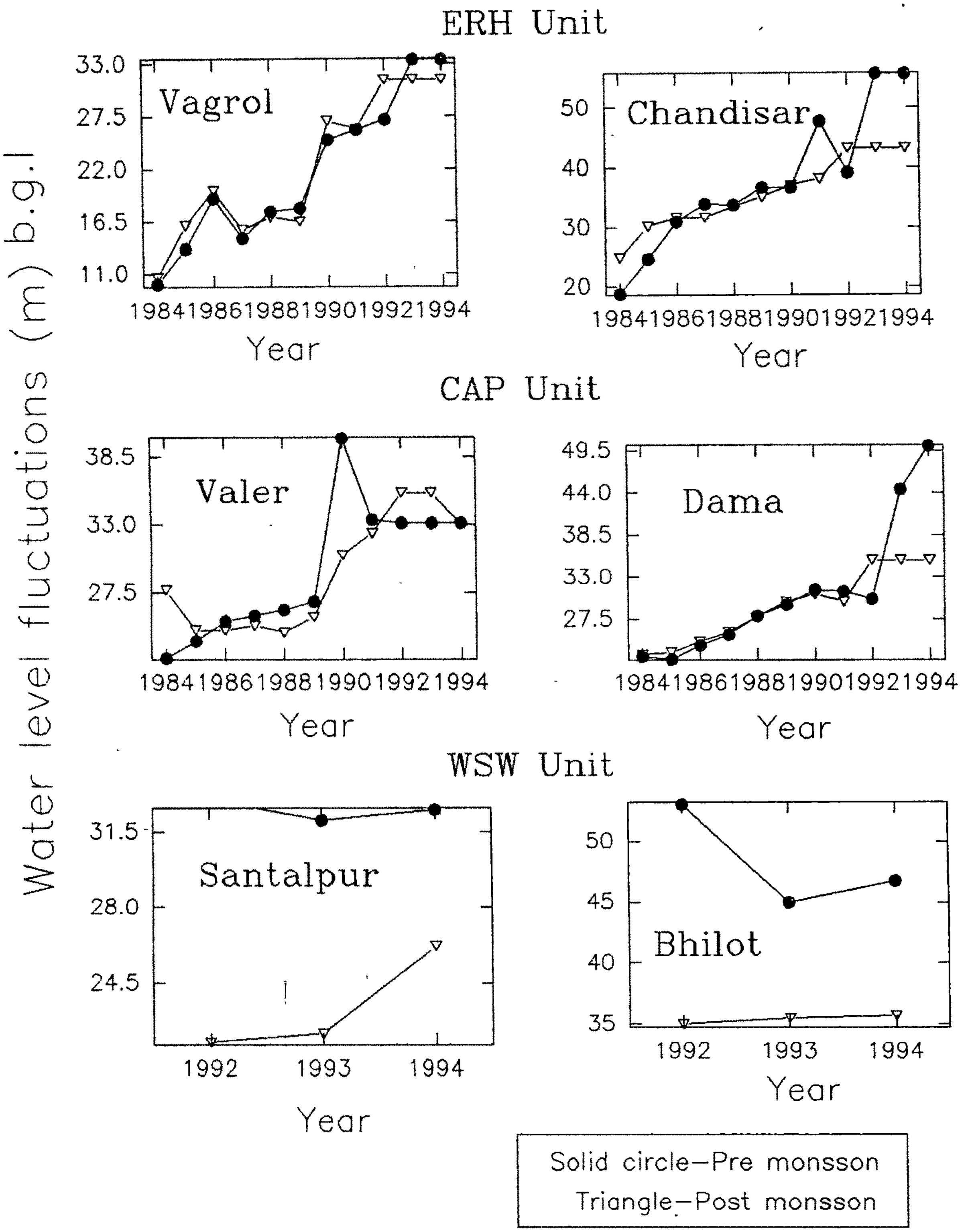


Fig 8.8

Water level fluctuations of confined aquifers in three units of Banaskantha district

The GWRDC has recently established two piezometric nest in the WSW unit; one at Santalpur (Plate 8.2) and other at Vav to observe the pressure head and quality in different aquifer at depth. The results (Table 8.6) are quite interesting.

Table : 8.6

Piezometric levels and water quality in confined aquifer system in WSW unit.

Location of Piezometric Nest	Aquifer Parameters	Unit	Confined aquifer I	Confined aquifer II	Confined aquifer III
Santalpur	Depth Range Piezometric level below G.L. Piezometric- pressure Head Water Quality(TDS)	m-m m m ppm	44 to 53 6.7 37.3 -	130 to 141 6.9 123.1 -	205 to 214 5.5 199.5 -
Vav	Depth Range Piezometric level below G.L. Piezometric -pressure Head Water Quality(TDS)	m-m m m ppm	45 to 54 7.5 37.5 1300	127 to 142 5.5 121.5 4650	226 to 235 free flow 226 4070

It is observed that the piezometric pressure progressively increases with the increasing depth of aquifers. The deep exploratory wells piercing the lower aquifers at depths more than 600 m at Suigam and Dev in Radhanpur taluka have even higher pressure which is manifested by the free artesian flows. However, the water quality is of independent the depth of the aquifers. The quality variation reflects the environment of deposition of sediments that form the aquifers.

It is relevant to mention here that during the three year period from 1985-1988, consecutive drought periods influenced the water levels in the state. On the whole the aquifers were relatively overdrawn and there was an overall decline of water levels of both the aquifer systems, unconfined and confined. The good monsoon of 1988 that followed, resulted in an overall rise of water levels.

Plate 8.2 A view of piezometer nest at Santalpur

WATER QUALITY

Like water level the quality of groundwater also shows complex pattern over the district, with general degradation trend when traced from east to west. The quality of groundwater in the ERH unit is generally good, with most of the chemical parameters being well within the portability and irrigability standards. But the same progressively deteriorate in CAP and WSW units.

Water quality monitoring data as obtained from the CGWB (1978 to 88) and GWRDC (1984 to 94) for the wells located in the district (Fig 2.6 and Annexure 8.1) and the variations not only in the geographic spread but also in terms of depths of aquifers. In this study the water quality discussions have been restricted to the variations mainly in total dissolved solids (TDS) in view of the data availability. High fluoride content in the drinking water is also a problem in the district.

The phreatic aquifers of the consolidated formation in ERH unit. Its average TDS content is around 800 ppm. At different location it varies in the range of 500 to 1100 ppm. There is marked difference in seasonal variation. Dilution due to monsoon recharge is quite significant. The post monsoon dilution is as much as 200 to 500 ppm. Over the period of 11 years of monitoring, the quality has more or less remained constant (Fig 8.9 a and b)

In the phreatic alluvial aquifers in the piedmont zone of ERH unit and that of entire of CAP unit, the TDS have remained within the range of 500 to 1300 ppm. The quality is good for irrigation and drinking purposes. In this context, it is interesting to observe that the tubewells tapping in the CAP unit have generally lower value of TDS; in the range of 500 to 800 ppm. Towards the western parts of the CAP unit the upper

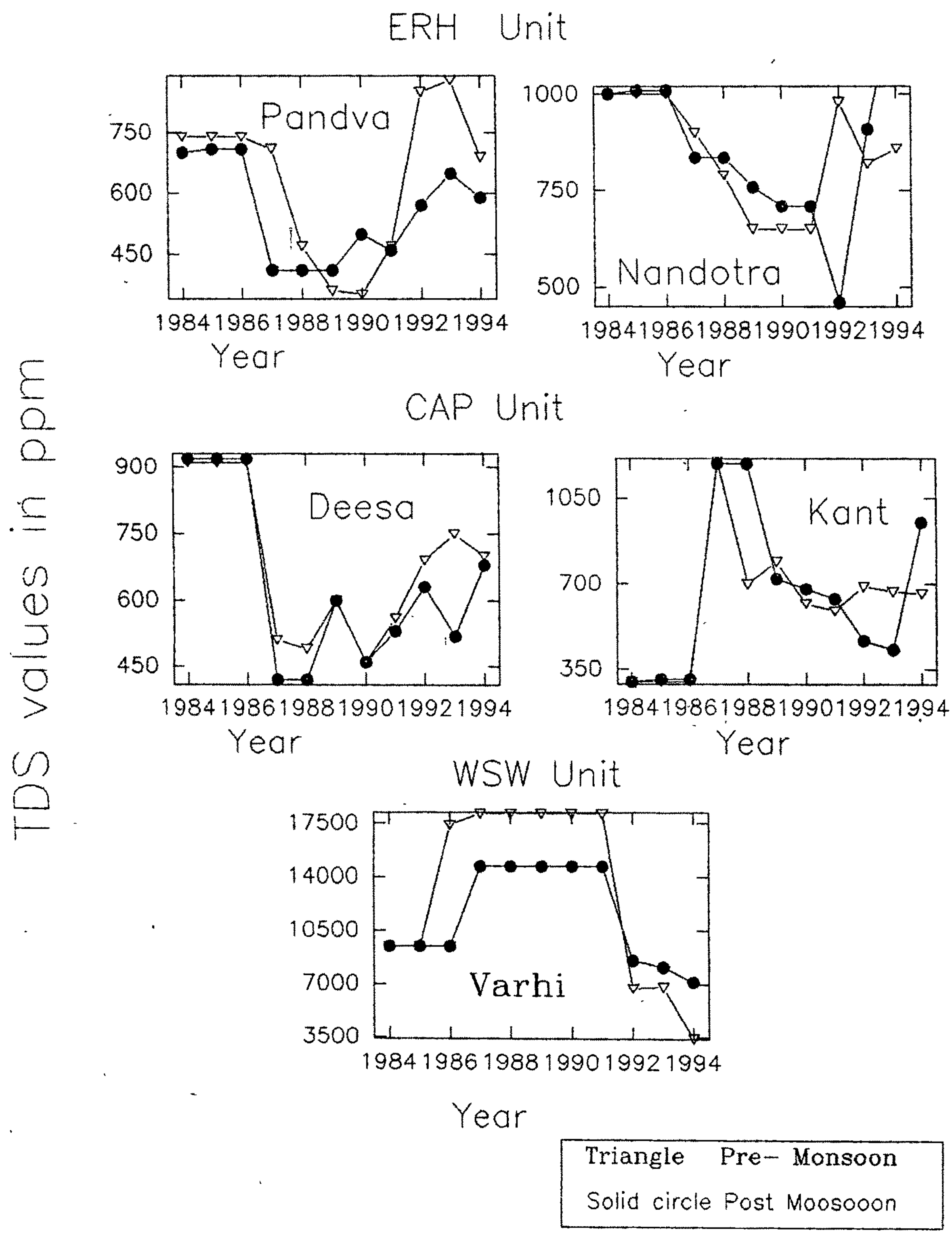


Fig 8.9 (a)

Groundwater quality variations in Phreatic aquifer of the district

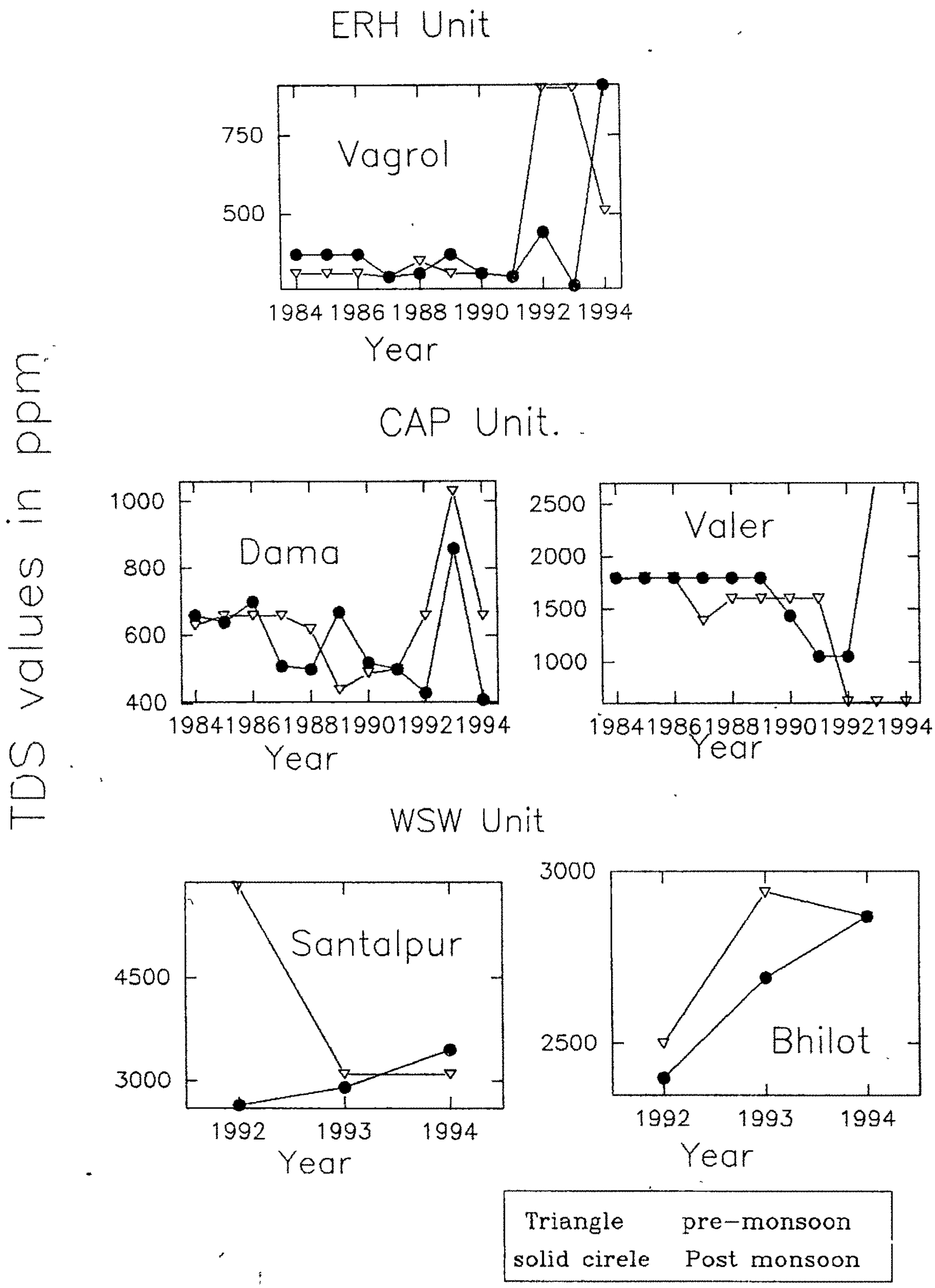


Fig 8.9 (b) Groundwater quality variations in confined aquifers in of the district

confined aquifer (Aquifer C of UNDP classification) is highly saline. Prior to the sinking of actual tubewells, generally a pilot bore is made, electrologged and saline aquifer zone (eg. Aquifer C) is delineated, which is then blocked by cement sealing so that poor quality water does not enter the tubewells and the quality control is maintained.

The range of water quality variations is quite wide in the western parts of the district, covering by WSW unit. The overall water quality is also poor. The unconfined aquifers have the average TDS of 4000 ppm, and the range is from 3000 to 60000 ppm. Seasonal variations due to monsoon recharge dilution is quite significant. Though, almost all the water from the unconfined aquifer system is very poor quality and unfit for domestic or agricultural use, the open wells located within the fresh water recharge mound of the surface water bodies like village ponds filled by rainwater provide good quality potable water; with (Fig 7.3) TDS around 500 ppm only. In the WSW unit, there are numerous wells supported by such local surface water bodies and these serve as a good source of domestic needs of local population.

The confined aquifers in WSW unit, have relatively better quality of water as the tubewells with arrangement of selective tapping of the aquifers, generally have a good quality control. The TDS generally remain within 1500 to 2500 ppm, used for irrigation and for growing salt tolerant crops.

A large number of villages in the western parts of the district have no source of potable water. The State Water Supply Board (GWSSB) have established an elaborate network of piped water supply system governing hundreds of villages upto a distance of more than 125 km from the sources. The sources comprises deep tubewells drawing different confined aquifers two well fields one near Deesa and other near Sihori on the bank of Banas river in CAP unit. The TDS content of Sihori well field is around 700 ppm, which is well within the potable limits. The scheme has been commissioned since 1978 under Indo-Dutch Bilateral Assistance Programme known as Santalpur Regional Water Supply Scheme. The scheme aims to cover more than 3 lakh population of about 270 villages, with a total pipe line length of more than 500 km, at a cost of about Rs 220 million. The scheme gives an idea of the seriousness of the problem of the scarcity of good quality potable water in the western parts of the district. The scheme however encounters problems of falling water levels (3-6 m/yr) and increasing fluoride content (above 1.5 mg/d , limit for drinking water.) During the period from 1988 to 1994 the fluoride content has increased form 1.5 mg/l to 2.5 mg/l; this has been brought within safe limits by blending radial well water from nearby Banas river bed . Blending is also being done from the nearby Saraswati river deep tubewells (+ 700 m Miocene aquifers) and the quality of water is being maintained within acceptable fluoride limits.