CHAPTER VII

HYDROGEOLOGICAL ASPECTS

CHAPTER VII

H Y D R O G E O L O G I C A L A S P E C T S

GENERAL

Coastal areas always pose problems of groundwater. By and large it is saline, and availability of sweet water is much restricted. It is common knowledge that the groundwater conditions in the coastal areas are unfavourable on account of the salinity of the available water. But it is equally true that favourable lithological, geomorphic and climatic factors do provide sufficient quantity of sweet water under surface and subsurface storage conditions. Occurrence and availability of water from phreatic aquifers is an important feature, and any evaluation of onshore geoenvironmental conditions of a coastal area cannot ignore this vital aspect.

In the course of his investigations the author having realised the importance of the porblems of drinking water faced by the coastal villages, made it a point to study the behaviour of unconfined to semiconfined groundwater along the Gulf coast in somewhat greater detail. The author could not get much information, published or unpublished on this subject because ~~nowhere~~ no agency or individual in the past have made an attempt to evaluate the groundwater conditions and the freshwater availability in the coastal areas around the Gulf Khambhat. By and large the groundwater in all coastal segment is saline and the sweet water supply is very limited and restricted to very shallow water table type unconfined aquifers.

HYDROGEOLOGICAL CATEGORISATION

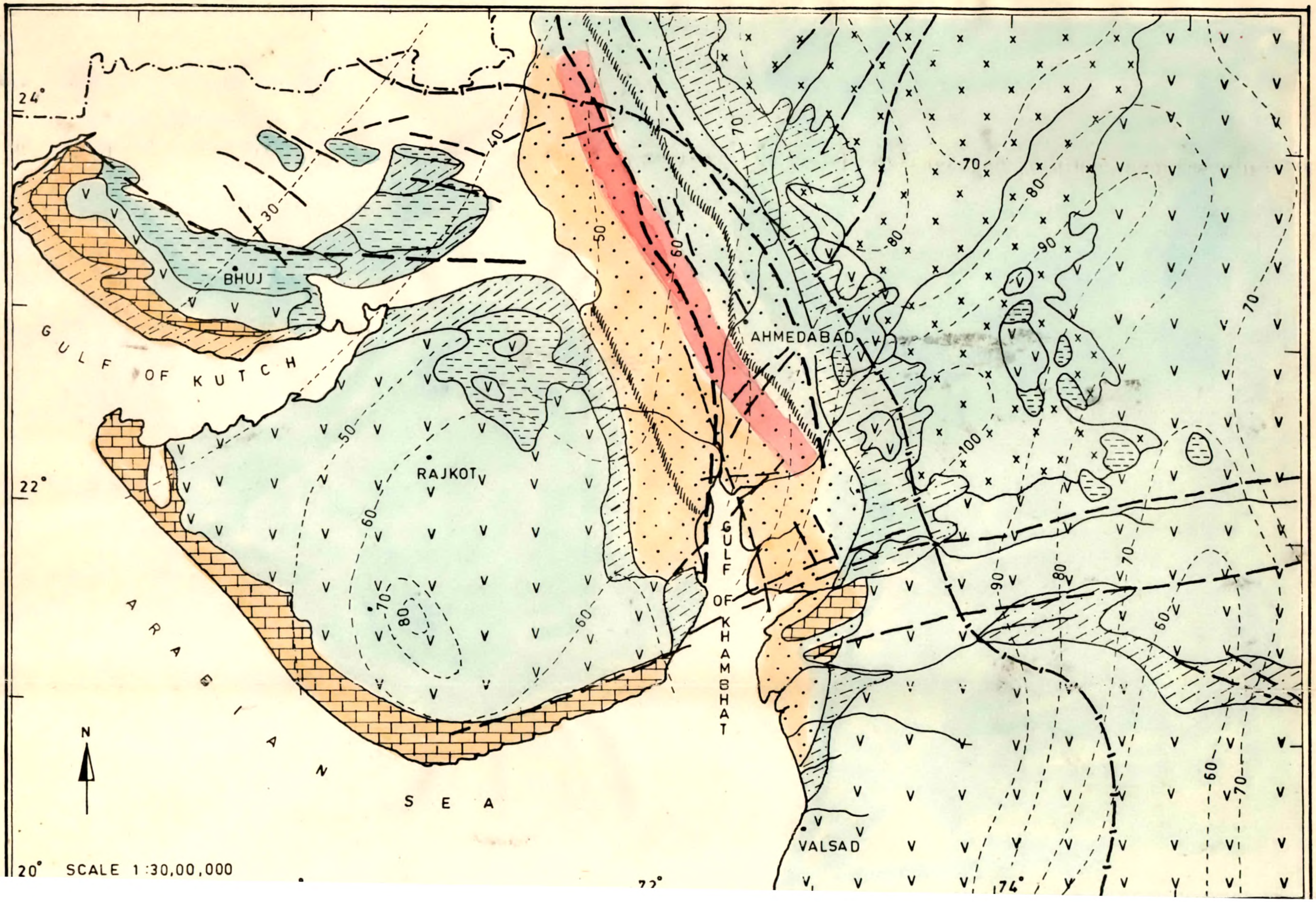
The entire coast of the Gulf of Khambhat exhibits variable hydrogeological regimes, which can be categorised in conjunction with the prevailing geomorphic and lithologic configuration and hydroclimatic variations. The occurrence of potable groundwater in the onshore areas of the Gulf, except south of Ghogha, to a large extent is influenced by the geomorphology and the sediment characteristics.

Geomorphic features or landform patterns have made significant contribution to the development of hydrogeological setup, as they have provided suitable depressions (surface as well as subsurface) for the accumulation of groundwater and thereby contribute towards the development of aquifer systems, enhancing the recharge to the aquifers and sites for the surface water storage. Hydroclimatic parameters have also played a vital role in the development of regional groundwater occurrence, the rainfall being the most important parameter as a function of aquifer recharge and stream flow. The other important parameters which have got direct bearing on groundwater conditions are humidity, insolation and evapotranspiration. The combined effect of all these factors and their changing pattern from area to area have provided an important basis to the author, to evaluate the shallow groundwater conditions of the various segments of the Gulf coast.

Hydrogeologically, the onshore coastal tracts of the Gulf represent lithostratigraphic units of Tertiary and Quaternary periods, and the diversity of these lithounits has given rise to a variety of aquifer systems of confined to phreatic nature. Further, the hydrogeological set up of the Gulf coast needs to be judged in the regional context as continuities exist with the aquifers and recharge zones of the inland areas. The availability or otherwise of even unconfined groundwater is controlled by the processes of recharge taking place from fairly far off terrains in the NE and E.

A delicate balance exists between the unconfined sweet water and the underlying saline groundwater in the coastal areas, and in the various segments of the Gulf coast it is observed that the hydrogeological conditions from segment to segment vary, and in turn influence the availability of sweet water.

According to the regional hydrogeological map of the Gujarat State (Tiwari,1986) in the eastern coast of the Gulf (Fig.VII.1) the aquifers between Mahi and Narmada rivers are of unconfined to confined in nature and of moderate TDS content whereas between Narmada and Tapi rivers the aquifers are of semiconfined to phreatic in nature with moderate TDS, here the major source of recharge is irrigation and canal seepage. In the Bhal area i.e. the area between Sabarmati river and Bhavnagar creek, the deep confined aquifers are present but since the area is occupying the site of a regressed sea, the water is brackish. Only shallow phreatic aquifers of limited thickness exist in this area. The west coast area of the Gulf exhibits two different hydrogeological conditions.



24°
22°
20°
72°
74°
BHUJ
GULF OF KUTCH
RAJKOT
AHMEDABAD
GULF OF KHAMBHAT
VALSAD
ARABIAN SEA
N
SCALE 1:30,00,000

SYMBOL	AGE GROUP		LITHOLOGY	TECTONIC FRAMEWORK	GROUNDWATER CONDITIONS
	QUATERNARY UPPER TERTI-ARY	UNCONSOLIDATED FORMATION	CLAY, SILT, SAND GRAVEL, PEBBLES, BOULDERS, CALCAREOUS CONCRETIONS	GROUNDWATER BASIN OCCURING IN PLATFORM AREA AND FORE-DEEP ZONE. PLATFORM MARGINS IN PARTS OF MAINLAND RIVER BASIN, COASTAL PLAINS OF KUTCH	GROUNDWATER BASIN HAVING EXTENSIVE LAT-ERAL EXTENT AND THICKNESS OF AQUIFFRS UNDER CONFINED CONDITIONS BEYOND 100 m MARGINAL AREAS OF GROUNDWATER BASINS HAVING AQUIFERS WITHIN 100 m WITH LIMITED EXTENSION DUE TO BOUNDRY CONDITIONS
	QUATERNARY AND TERTIARY	SEMI CONSOLIDATED FORMATION	LIMESTONES (Miliolite, Guj Kirthar)	COASTAL AREAS OF SAURASH-TRA AND BETWEEN TAPI AND NARMADA MOUTHS	KARSTIC LIMESTONES (MILIOLITE AND GUJ) IN COASTAL AREA HAVING GROUNWATER IN CAVERNS AND SOLUTION CHANNELS WITHIN 50m
	TERTIARY AND MESOZOIC		GRITS, SANDSTONS, SILTSTONES, SHALES, CONGLOMERATES, LIMESTONE	PLATFORM AREAS IN KUTCH AND NW SAURASHTRA OUTLIRES AND INLIRES IN E GUJARAT AND NARMADA VALLEY	TERTIARY AND MESOZOIC SEDIMENTARY ROCKS WITH RESTRICTED CONFINED AQUIFERS IN PLATFORM AREAS.
V V	CRETACEOEO-CENE	CONSOLIDATED FORMATION	BASALTS (WITH INTERTAPPEAN BEDS)	TERRESTRIAL VOLCANIC EFFUSI-ONS ON PLATFORMS	GROUND WATER 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.
x x x	PRECAMBRIAN		SANDSTONES, SHALES SLATES, PHYLLITES, QUATIZITES, DOLO-MITES, 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

- GROUNDWATER SALINITY WITH LITTLE POSSIBILITY OF ENCOUNTERING FRESH WATER AT DEPTH
- GROUNDWATER SALINITY INCREASES WITH DEPTH
- GROUNDWATER FREE FROM SALINITY HAZARDS

SPECIAL HYDROLOGICAL FEATURES

- BOUNDARY AREAS WITH ARTESIAN FLOWING CONDITIONS
- 50 — ISOHYTES ANNUAL AVERAGE RAINFALL IN cm

GEOTECTONIC FEATURES

- MAJOR FAULTS
- MINOR FAULT
- TECTONIC ZONAL BOUNDARY

HYDROGEOLOGICAL MAP OF THE GUJARAT AND ADJACENT AREAS

The area covered by the Deccan Trap basalts, shows moderate to good groundwater potentials. The majority of the aquifers are unconfined and located within the veneer of weathered and fractured basaltic flows. The TDS content is low. The groundwater behaviour in the limestone areas covered by the miliolites south of Shetrunji River is prone to serious salinity hazards due to sea water encroachement in the freshwater aquifers.

Irrespective of the hydrogeological conditions prevailing in the different parts of Gujarat specially in the vicinity of the coastal areas of the Gulf of Khambhat the most relevant aspect of the groundwater studies of the Gulf coast is that which pertains to the nature of unconfined or phreatic groundwater occurrence, in the form of shallow dug wells. It has been observed by the present author that such wells comprise the most important source of sweet water and together with surface accumulations of rain water in the form of ponds provide one of the vital resource for the coastal population. With a view to obtain authentic and dependable information on this environmental aspect, the present author carried out his own investigations and attempted to obtain adequate data, such that an interesting picture of the availability of sweet water along the Gulf coast has emerged. On the basis of his own personal observations together with the prevailing subsurface conditions as well as the physiographic features the author has categorised the Gulf coast into following five blocks:

Block - I	Between Methla creek and Kalubhar river
Block - II	Between Kalubhar and Sabarmati rivers
Block - III	Between Sabarmati and Mahi rivers
Block - IV	Between Mahi and Narmada rivers
Block - V	Between Narmada and Tapi rivers

BLOCKWISE DESCRIPTION

BLOCK - I

This coastal hydrogeological block is essentially rocky and as compared to other parts of the coastal area is somewhat rugged. The availability of sweet water here is dependent on the unconfined aquifer conditions identical to the rest of the Saurashtra coast. Between Methla creek and Gopnath, shallow dug wells of 17-20 m depths are encountered which are situated within the miliolite formation. Generally, miliolite provides good aquifer conditions and hence is a better source rock for water supply. In this area, the dug wells are the only source of sweet water supply but due to the cavernous nature of this miliolite limestone and overpumping of the limited water resources the saline water ingress from the sea side has caused increased salinity in the aquifers. The present author came across this problem near the village Jhanjhmer. To the north-east, near the Shetrunji river mouth, thick and extensive delta deposits provide a reasonably good supply of sweet water, the average depth of dug wells being 5 to 9 m. But as this water is being increasingly used for agricultural purposes, due to overexploitation, the sweet water supply is in danger of saline ingress.

The water table type aquifers from Shetrunji river to Ghogha show a well marked difference in their nature between that of the coastline proper and that of the backshore areas. The former consists of accumulated sweet water in the coastal sands and in the underlying Gaj beds, but these are observed to be getting saline especially in the pre-monsoon months. Such types of well are observed in the villages Kuda, Ratanpur and Alang where the average depth of sweet water phreatic aquifer is 7 to 10 m. On the other hand inland coastal areas are free from the influence of sea water ingress and hence hold enough water, which even finds use in small scale irrigation. Here the aquifers are located within the weathered top of Deccan Trap rock. Wells situated in Budhel, Thoradi, Badi are of this type. The average depth of dug wells encountered here are of the order of 12 to 15 m.

The coastal area around Ghogha and Bhavnagar has got its own distinct hydrological conditions. Here the demand of sweet water is being fulfilled through the surface ponds (Plate VII.1) and shallow dug wells and the average depth

<u>Plate VII.1.</u> A typical surface storage pond augmenting recharge to unconfined coastal aquifers at Gogha.

of sweet water availability is only 5 m. The water at greater depth tends to be saline as is evident from a well at village Akvada where brackish water is encountered at 7 m depth. Table 7.1 gives details of hydrogeological conditions prevailing in this block.

BLOCK - II

The vast coastal plain to the north of Bhavnagar comprises an almost flat terrain, a large part of which is under the tidal influence. Though above the highwater line, the tidal waters innundate this area during monsoonal storms. As the area marks an ancient mudflat, it is now made up of barren wasteland with an inherent palaeosalinity in the soil. This condition is reflected in the almost total absence of dug wells in this region. Drinking water demand is met in this block from the ponds dug by the local villagers. The availability of water in these ponds also depends directly on precipitation each year. Some of the big villages like Dholera, Navagam, Pipli etc. each have a relatively large sized ponds, on the periphery of which are located, what one could call as nearest to dug wells; these pond supported dug wells get simultaneously depleted with the drying of the ponds.

These ponds get dry during the summer months, but they provide sites for the villagers to dig numerous pits

Table 7.1 - HYDROGEOLOGICAL INFORMATION

BLOCK - I

Well No	Village Name	Aquifer Formation	Total Depth (m)	Water Level (m) Pre Monsoon	Water Level (m) Post Monsoon
1	Methla	Miliolite	7.00	6.50	4.80*
2	Jhanjmer		19.50	18.50	10.60*
3	Pithalpur		20.00	16.00	09.20*
4	Gopnath		17.00	12.00	07.50*
5	Saltanpur	Fluvio-marine sediments	09.00	7.20	04.60
6	Dakana		04.50	04.00	01.50
7	Lilivav		17.00	13.50	8.70
8	Kathva	Deccan Trap	18.00	16.00	12.80
9	Alang		17.00	15.00	09.60
10	Mithivirdi	Sandstone	20.00	19.00	15.40
11	Hathab	Dunal Sand	09.50	8.00	4.50
12	Badi	Deccan Trap	15.00	10.00	6.45
13	Kuda	Dunal Sands	5.00	3.00	2.00*
14	Kuda	Sandstone	9.50	9.00	2.60*
15	NavaRatanpur		5.00	4.00	2.20*
16	Ghogha		11.00	5.00	1.80
17	Thoradi	Deccan Trap	12.00	9.00	3.70
18	Budhel		11.50	7.00	3.40
19	Akvada	Trap covered by fluvio-marine sediments	7.00	4.00	2.90**
20	Karnej	Deccan Trap	35.00	29.70	20.40

* Become saline during late summer

** Brackish on account of salinity ingress of 0.50 to 2 m depth within the bed of the pond and these pits supply sweet water for a few days. This area is so chronically deficient in sweet water that all the villages along the northern part of this block (upto Dholera) are supplied drinking water by pipeline from Sabarmati river. Rest of the villages further south are supplied water by tankers. Table 7.2 gives details of hydrogeological conditions prevailing in this block.

Table 7.2 HYDROGEOLOGICAL INFORMATION

BLOCK II

Well No.	Village Name	Aquifer formation	Total depth (m)	Water level (m) Pre monsoon	Post monsoon
21	Madhavpura	fluvio-	3.00	0.50	P.L. *
22	Rahtalav	marine	-	-	-
23A.	Dholera	sediments	Artesian well **		-
23B.	Dholera	with	5.00	4.5	3.0 **
24	Pipli	dominantly	5.0	0.20	P.L.
25	Moti Baru	silty-clay	2.0	0.50	P.L.
26	Varna	fractions.	2.0	0.50	P.L.

*P.L. = Pond Level

** Brackish/Saline water

BLOCK - III

The coastal tract between Sabarmati and Mahi is also interesting from the point of view of the availability of sweet water, aquifer depth and recharge conditions.

Geomorphically, the tract between Sabarmati river and Khambhat town forms a low flat gradientless terrain whereas the ground to the east and north east of Khambhat shows a conspicuous rise of about 6 to 10 meters. The former portion represents an ancient tidalflat made up of marine sediments which now forms a saline wasteland liable to innundation during monsoon season. The latter is composed of typical alluvial deposits brought by the Mahi river.

In the areas west of Khambhat there are practically no sweet water aquifers because the sediments here have got inherent paleosalinity. The villages like Vadgam, Mitli, Golana, Navagam etc. are situated on this salt wasteland and the entire population of this part is totally dependent on the stored rain water in ponds dug by the villagers. By the side of these ponds, there are also dugwell supported by ponds, when the water get dry in the ponds these dugwell in or around the periphery of these ponds continue to supply sweet water for a couple of days at least (Plate VII.2 & 3).

Plate VII.2. A pond and pond supported dug wells serving domestic need of the village Vadgam.

Plate VII.3. A number of dugwells in and around the pond at Daheda.

On the other hand, to the east and northeast of Khambhat the area is very rich from the point of view of sweet water availability. Numerous wells are located here and these are the source of abundant water supply. The average encountered depth of groundwater in dug wells 18 meters the maximum being at Kathol 25 m and minimum at Undel 10.5 m. A perusal of the subsurface and surface conditions prevailing to the north east, points to 1) horizontallity of the ground and lack of surface drainage and ii) porous and permeable nature of the alluvial sediment upto considerable depth. These two factors have combined to generate ideal hydrological conditions such that the aquifers are being substantially recharged from the north-east. Table 7.3 gives details of hydrogeological conditions prevailing in this block.

BLOCK - IV

On crossing Mahi, the hydrogeological characteristics of the coast between Mahi and Narmada again show some difference. The tract between Mahi and Dhadhar is sandy to silty in nature while that between Dhadhar and Narmada shows sandy to clayey types of alluvial sediments. This difference has made the two segment to show somewhat distinct hydrogeological regimes. As the drainage density in this area is less and the area receives moderate

Table 7.3 HYDROGEOLOGICAL INFORMATION

BLOCK III

Well No	Village Name	Aquifer formation	Total depth (m)	Water level (m) Pre monsoon	Post monsoon
27	Vadgam	Fluvio-marine sediments of clayey silts	8.00	7.40	1.60*
28	Pondad		6.80	6.50	1.50*
29	Rohini		5.00	4.00	1.20*
30	Navagam		5.00	3.90	1.00*
31	Daheda		6.5	5.80	2.00*
32	Neja		6.00	4.50	2.00*
33	Sakarpur	Fluvial sediments of sands and silts	16.00	15.80	10.00
34	Wasna		11.00	17.00	13.00**
35	Undel		10.50	9.50	5.00
36	Watra		24.00	22.50	17.00
37	Indranaj	Fluvio-marine sediments	9.00	7.80	2.60**
38	Tarapur	Fluvial sediments of sandy gravels and silty sands with clay bands	10.00	8.30	1.50
39	Bhurakui		18.00	5.50	1.40**
40	Dhuran		18.60	6.00	1.80
41	Daheyan		16.00	12.00	9.00
42	Kathol		25.00	14.00	10.45
43	Bhadran		19.00	16.00	14.00

* Pond supported dug wells

** Brackish/saline water

precipitation (750-850 mm/year) the source of aquifer recharge is through rain water only which is either through direct percolation or through storage in ponds, pond supported dug wells and other surface depressions. Away from the coastline the alluvial cover provides aquifers upto the depth of 10 to 25 m, but in the immediate vicinity of the coastline the ponds and pond supported dugwells are the only source of fresh water supply for domestic purposes (Plate VII. 4 & 5). These ponds are of 6 to 7 m depth and the dugwells are sunk within or on the periphery of the ponds which are 1.5 to 2.5 m deeper than the pond bottoms. These wells supply water almost year round, even when the ponds get dry during late summer. Table 7.4 gives details of hydrogeological conditions prevailing in this block.

BLOCK - V

South of Narmada the geology and geomorphology changes and so does the hydrogeology. Here the alluvial thickness is much less, the gradient somewhat more and the coast is cut by a number of west flowing rivers. On the whole, this coastal block is much more dissected by streams and channels of various orders and this fact has considerably influecned the freshwater storage as ponds and dugwells. The rainfall also is quite high, of the order of 900-1100 mm year.

Plate VII.4. Freshwater dugwells located within and around a pond at Nada.

Plate VII.5. A dug well located near the pond at Padriya.

Table 7.4 HYDROGEOLOGICAL INFORMATION

BLOCK IV

Well No	Village Name	Aquifer formation	Total depth	Water Level (m) Pre monsoon	Post monsoon
44	Chokari	Intercalated sequence of sandy gravel, silty clays and clays of fluvial origin	17.50	16.40	13.80*
45	Wedack		19.00	18.00	15.20
46A	Sarod		8.00	6.00	3.60*
46B	Sarod		15.00	14.50	9.40
47	Kavi		14.00	11.50	8.50
48	Degam	Fluvio-marine sediments with dominantly silty clay and clays	12.00	11.40	8.00
49	Sigam		15.00	12.80	7.00
50	Chhidra		13.20	10.50	6.50*
51	Jantran		7.00	6.30	G.L.
52	Bhadkodra		7.00	6.50	5.10*
53	Sindhvav		6.50	4.50	1.00
54	Devla		4.00	DRY	G.L.
55	Nada		6.00	DRY	G.L.
56	Tankari		7.50	6.50	1.00
57	Kalak		8.00	7.20	1.40
58	Uchhed		17.00	16.40	2.20
59	Matar		10.00	8.90	4.60
60	Nahryer		14.00	12.20	4.50
61	Achhod		6.50	6.00	4.00
62	Tankaria		9.00	8.50	3.00
63	Chanchwel		6.5	DRY	G.L.
64	Gandhar		-	-	***
65	Aladar		7.00	4.50	0.5**
66	Padria		7.00	5.00	3.00
67	Dahej		6.00	5.00	2.00
68	Lakhigam	Dunal sands	-	-	***
69	Luhara		7.5	6.80	4.20
70	Bhensi	Fluvio-marine sandy & silty clay and clays	6.00	4.70	G.L.
71	Navetha		14.00	8.50	3.50
72	Kantharia		16.00	14.00	12.10
73	Bharuch		11.00	9.50	6.00*

* Saline/Brackish water
** Salinity increases during late summer
*** Pond

NOTE: Almost all the dug wells are pond supported

In between Narmada and Tena creek, as usual a close relationship is seen to exist between the availability of sweet water in wells and their location near the ponds. It is observed that the large number of ponds in this part represent water impounded by construction of artificial barriers at appropriate spots across small streams and palaeochannels of Narmada, Kim and Tena rivers. The average encountered depth of sweet water in dug wells are 3 to 7 m from the ground level. During monsoon period a majority of wells are either free flowing or water table is close to the ground level.

Field data have shown that the average depth of sweet water in this area is limited to 7-8 m below ground level.

Another interesting feature of the unconfined groundwater occurrence is observed in the immediate vicinity of the shoreline where wells are located on coastal sand dunes. Only a few meters away from the high water line these wells contain 2 to 3 m thick fresh water column. Local inhabitants sustain their drinking water requirements on these wells. So long as the balance between the recharge and the draft is not disturbed, the quality of the water is maintained.

To the south of Tena Creek upto Tapi river, on account of over-irrigation and seepage through unlined canals, the groundwater table has risen to the surface causing water logging. As this water does not have appropriate surface or subsurface drainage it is not in a position to drain off and the stagnating waters through capillary action is adding to the salinity of soils. As this subject matter is still under investigation one has to await at least for a few years to get a clearer picture of the water logging vis-a-vis groundwater conditions. Table 7.5 gives details of hydrogeological conditions prevailing in this block.

CHEMICAL QUALITY

The entire Gulf coast environs comprise variety of Quaternary formations with equally a large number of sediment types of various origin. Groundwater circulating in different lithologies would develop a chemical character conformable to the constituent minerals. Contamination of fresh water by sea water too adds significantly to the dissolved constituents which is ultimately reflected in the chemical quality of the groundwater and the hydrogeological environmant of groundwater occurrence.

As discussed earlier, there is no significant data available on coastal hydrogeology and the author himself analysed the samples collected from various locations for determining their hydrochemistry. In all 92 samples were

Table 7.5 HYDROGEOLOGICAL INFORMATION

BLOCK - V

Well No.	Village Name	Aquifer formation	Total depth (m)	Water Level (m) Pre monsoon	post monsoon
74	Sajod	Fluvio-maine silty clays and sands derived from trap wash	5.50	3.60	G.L.
75	Hansot		10.00	6.00	4.00
76	Umarwada		8.00	7.20	2.00
77	Kanthiajal		6.00	DRY	2.00
78	Elao		8.00	6.80	2.00
79	Moti Naroli		8.00	DRY	6.50
80	Olpad		8.50	3.00	1.50*
81	Saras		6.00	3.00	1.50
82	Saras		5.00	3.50	1.50*
83	Veluk		7.50	5.50	1.75
84	Bhatha		7.00	6.00	2.00
85	Ichhapur		5.50	4.50	2.00
86	Mora	Dunal sands	8.00	7.50	5.00
87	Suvali		6.00	5.00	2.50*
88	Suvali		7.00	5.00	3.00
89	Hazira	Silty clay and sandy gravels	5.50	4.50	3.00
90	Navagam		12.00	8.00	3.00

* Saline/Brackish water

NOTE: 1) Well No.80-85 falls under canal irrigation and area is waterlogged.

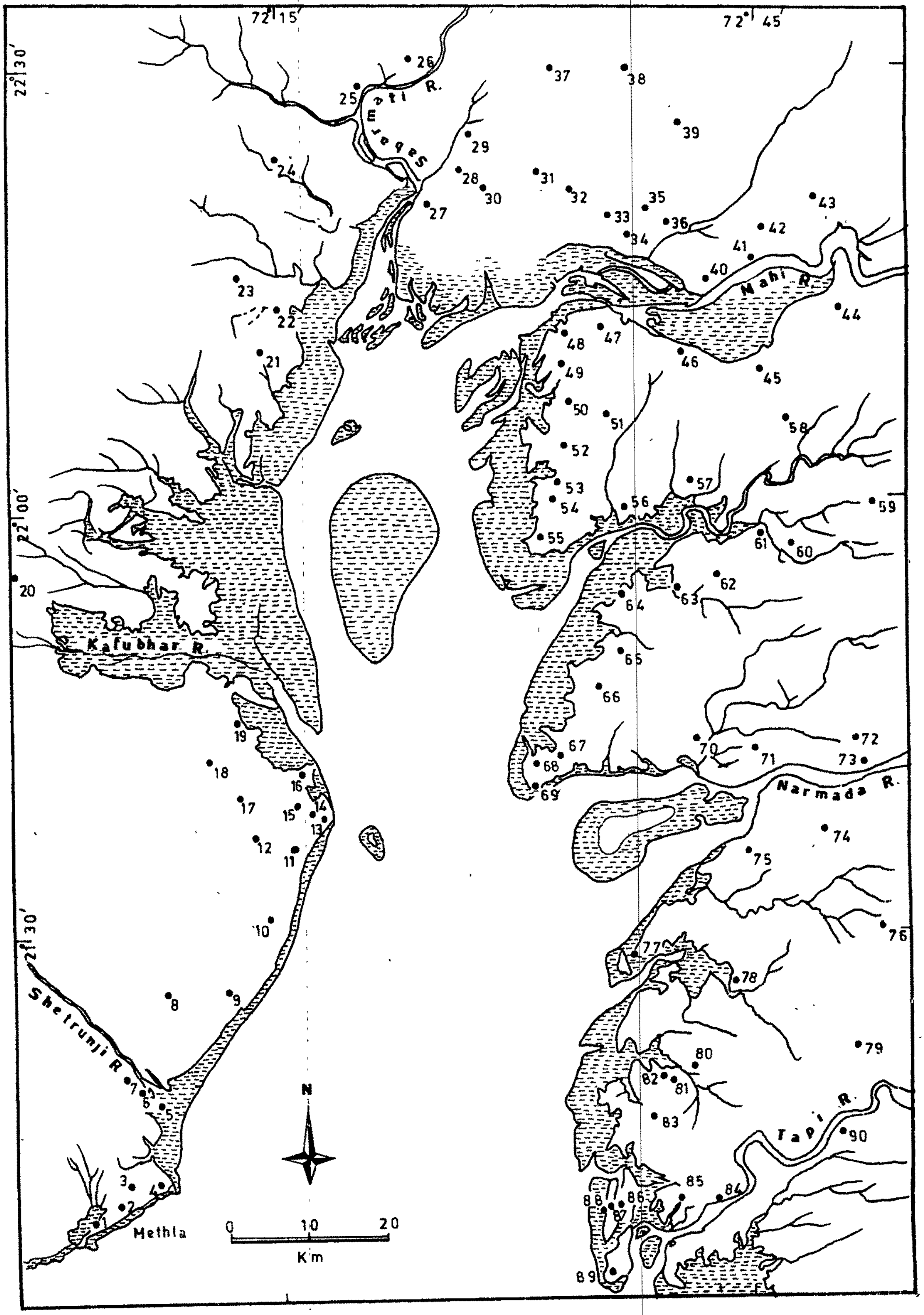
2) Majority of the wells are pond supported

analysed (Fig. VII.2) for determining their Total Dissolved solids (TDS). Hydrogen Ion Concentration (pH), Cations : Sodium (Na), Potassium (k), Calcium (Ca) and Magnesium (Mg); Anions: Carbonate (Co_3), Bicarbonate (HCO_3), Chloride (Cl) and Sulphate (SO_4). Table 7.6 gives the details of the chemistry of analysed samples.

The chemical quality of the groundwater along the Gulf coast is dominantly influenced by the sea water ingression. The blockwise percentile variation of various dissolved constituents gives a good indication of the over all quality of the groundwater along the Gulf coast.

In Block-I between Methla creek and Kalubhar river ~~as~~ in general the groundwater no doubt is somewhat saline but the TDS content is within permissible limits and quality wise the water is usable. The TDS ranges between 3374 to 474 ppm. In the cations, sodium ions predominate though the overall percentage of calcium as compared to other blocks is also higher, which could be attributed to the miliolitic limestones and basalts of the area. Among anions, bicarbonates and chlorides show higher proportion. The sulphates are of moderate percentage. The very low percentage of carbonates could be attributed to the normal hydrogen ion concentration (pH=7) which has prevented the dissociation of bicarbonates to

FIG. VII .2



LOCATION MAP OF HYDROGEOLOGICAL OBSERVATIONS

Table 7.6 - CHEMISTRY OF THE GROUNDWATER OF THE GULF COAST

Sample Number	Depth (m)	TDS (ppm)	CATIONS (ppm)				ANIONS (ppm)				pH	REMARK
			Na	K	Ca	Mg	Co_3	HCO_3	Cl	SO_4		
1	06.50	2669	1100	42	73	91	30	488	540	238	7.5	BLOCK I
2	18.50	474	160	03	01	11	7	442	670	85	7.7	
3	16.00	645	180	01	06	02	30	442	465	68	7.6	
4	12.00	1225	130	02	109	48	-	153	603	56	6.9	
5	07.20	1905	270	39	120	79	-	198	735	346	7.1	
6	04.00	2541	560	35	67	64	60	885	845	620	7.7	
7	13.50	943	125	01	95	106	-	290	358	256	7.2	
8	16.00	657	50	02	14	62	-	259	248	44	7.3	
9	15.00	645	90	03	31	51	15	229	355	262	7.4	
10	19.00	478	65	05	27	21	-	198	952	96	7.3	
11	08.00	2990	500	03	69	35	120	610	1100	242	7.1	
12	10.00	790	80	02	02	31	-	381	465	43	7.8	
13	03.00	1110	220	42	23	53	-	503	867	398	7.6	
14	09.00	1153	315	01	11	52	-	702	1166	567	7.7	
15	04.00	1003	235	02	09	38	45	290	1228	64	7.7	
16	05.00	3118	535	04	70	108	30	275	1242	620	7.4	
17	09.00	854	95	01	07	35	T	244	177	76	7.5	
18	07.00	1238	270	09	08	34	T	473	355	148	7.7	
19	04.00	3374	560	80	93	201	-	580	348	284	7.3	
20	29.70	1090	360	03	10	18	165	702	635	443	7.6	BLOCK II
21	00.50	777	190	11	19	15	-	366	465	189	8.3	
22	-	704	185	09	14	12	-	244	1238	69	9.3	
23A	-	4698	780	15	135	12	-	214	5680	274	7.3	
23B	04.50	15163	6800	330	330	1150	30	900	1265	28	7.4	
24	00.20	2520	340	42	72	11	30	336	1242	116	7.4	
25	00.50	666	145	20	20	22	T	336	248	96	7.7	
26	00.50	2242	360	54	70	165	T	488	958	28	7.2	

Table 7.6 - (contd)

Sample Number	Depth (m)	TDS (ppm)	CATIONS (ppm) Na	K	Ca	Mg	ANIONS (ppm) CO_3	HCO_3	Cl	SO_4	pH	REMARK
27	07.40	910	95	37	11	53	75	564	355	146	7.6	BLOCK III
28	06.50	875	205	33	08	132	60	366	355	98	7.1	
29	04.00	598	130	63	06	31	60	381	177	107	7.8	
30	03.90	619	140	21	06	28	90	320	248	86	7.5	
31	05.80	1012	255	53	09	44	75	381	390	74	7.1	
32	04.50	1264	320	12	37	01	135	747	603	72	7.2	
33	15.80	1495	380	09	16	91	120	275	710	63	7.2	
34	17.00	1410	370	16	16	61	90	519	710	28	7.3	
35	09.50	1239	360	10	14	42	90	564	532	18	7.3	
36	22.50	961	275	09	09	44	75	564	390	12	7.5	
37	07.80	713	100	48	09	36	T	275	284	84	7.0	
38	08.30	538	135	01	-	46	60	351	248	85	7.0	
39	05.50	3127	650	10	42	63	330	1980	674	82	7.3	
40	06.00	499	180	01	-	22	90	458	106	68	7.5	
41	12.00	982	365	01	09	11	-	946	248	62	7.7	
42	14.00	773	210	79	14	31	135	641	426	54	7.2	
43	16.00	1132	260	09	18	83	120	390	390	37	7.0	
44	16.40	683	180	06	-	40	135	488	177	68	7.8	BLOCK IV
45	18.00	384	30	22	-	21	T	259	106	80	7.0	
46A	06.00	3418	810	04	63	66	165	732	1846	241	7.5	
46B	14.00	640	730	26	06	44	90	488	213	65	7.4	
47	11.50	769	135	65	08	69	60	351	284	450	7.3	
48	11.40	1538	270	19	14	05	60	290	852	680	7.4	
49	12.80	811	230	02	06	25	-	473	319	1230	7.6	
50	10.50	512	790	450	180	346	T	305	284	385	7.2	
51	06.30	918	115	320	22	62	60	335	319	269	7.7	
52	06.50	2243	390	700	59	74	165	564	852	148	7.7	

Table 7.6 (contd)

Sample Number	Depth (m)	TDS (ppm)	CATIONS (ppm)				ANIONS (ppm)				pH	REMARK
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4		
53	04.50	427	95	19	05	23	30	380	142	674	7.9	
54	04.60	256	92	14	09	25	-	229	106	865	7.8	
55	06.00	299	90	29	04	24	T	366	106	1437	8.1	
56	06.50	1153	280	74	18	38	15	610	390	755	7.7	
57	07.20	363	35	13	03	40	-	320	177	984	7.6	
58	16.40	3183	680	06	48	209	105	686	1846	636	7.2	
59	08.90	991	210	03	05	88	60	381	461	627	7.4	
60	12.20	320	110	01	-	24	60	427	106	864	7.8	
61	06.00	397	140	09	03	25	T	351	142	1085	7.9	
62	08.50	893	310	02	09	05	150	645	177	682	8.1	
63	06.50	397	55	09	15	15	T	153	213	1235	7.4	
64	POND	2136	50	25	14	06	T	244	71	1474	7.8	BLOCK IV
65	04.50	1704	400	30	42	77	60	305	1029	1320	7.6	
66	05.00	469	100	42	05	02	T	427	142	1267	7.8	
67	05.00	918	280	27	10	26	240	763	177	1140	7.8	
68	POND	1068	820	24	14	11	276	1190	177	1425	8.7	
69	06.80	1516	465	390	21	92	135	467	603	1484	7.9	
70	04.70	555	180	09	06	12	105	381	177	1098	8.1	
71	08.50	469	155	05	-	18	90	458	142	860	7.9	
72	14.00	1397	390	06	-	88	120	717	639	945	7.8	
73	09.50	2712	675	11	43	41	285	869	1633	786	7.8	
74	03.60	2200	505	11	15	38	150	610	816	682	7.8	
75	06.00	747	90	09	02	25	T	336	70	843	7.8	
76	07.20	2777	540	02	70	79	T	458	1242	994	7.6	
77	06.00	1282	250	51	17	24	T	702	355	1235	8.0	
78	06.80	854	70	09	05	23	T	153	177	1185	7.7	

Table 7.6 (contd)

Sample Number	Depth (m)	TDS (ppm)	CATION (ppm)				ANIONS (ppm)				pH	REMARK
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4		
79	08.00	1923	450	01	14	36	210	641	640	934	7.6	
80	03.00	1495	270	150	30	28	90	503	461	969	7.3	
81	03.00	747	70	10	01	12	T	305	142	1146	7.5	
82	03.50	5341	580	09	380	423	-	275	3337	1287	7.1	
83	05.50	940	160	08	-	50	30	458	177	1087	7.5	
84	06.00	2329	495	13	35	22	135	686	781	965	7.6	
85	04.50	1282	270	26	10	45	120	427	461	1234	7.8	BLOCK V
86	07.50	940	210	07	06	25	75	610	106	924	8.2	
87	05.00	1132	105	45	07	98	150	519	213	679	7.7	
88	05.00	2414	430	300	47	136	285	1000	745	738	8.0	
89	04.50	747	130	20	-	22	-	473	70	1267	8.2	
90	08.00	1175	300	01	05	06	90	519	320	752	8.2	

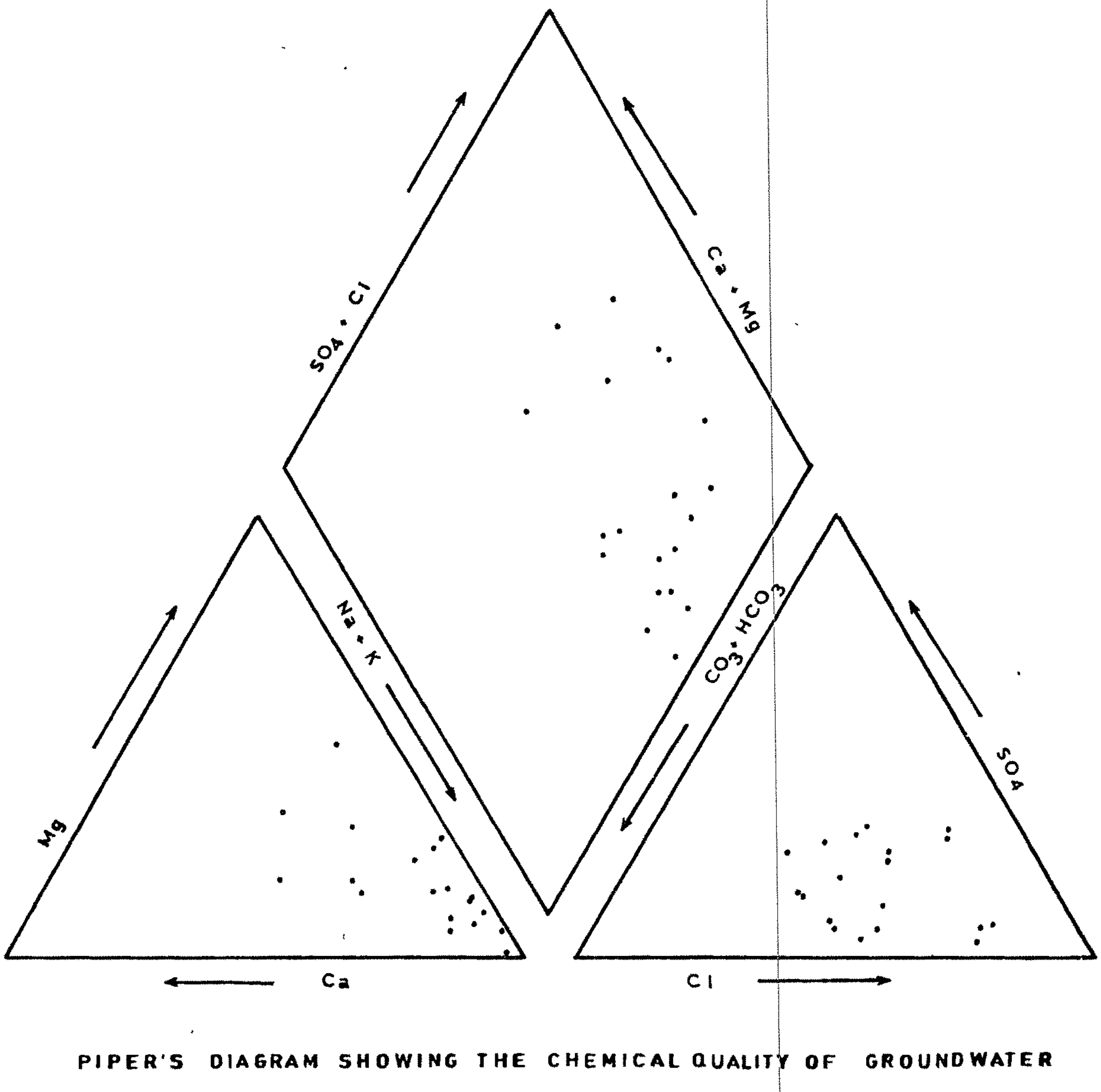
T - Trace

carbonates. The Piper Trilinear diagram (Fig.VII.3) shows the overall distribution of cations and anions in this block.

In the Block-II, the coast between Kalubhar and Sabarmati river which constitutes mostly a saline wasteland, the groundwater is dominantly enriched with dissolved constituents. The deeper confined aquifers of saline water show TDS of above 15000 ppm. The average TDS range between 704 to 2242 ppm. The inherent palaeosalinity with the sediments and annual monsoonal inundation has further raised the concentration of constituents. Among cations and anions, sodium, potassium and chlorides respectively are dominant. This very obviously points to the salinity having been contributed by the sea water. The Piper trilinear plot (Fig.VII.4) shows the saline nature of the groundwater.

The Block III between the rivers Sabarmati and Mahi, is characterised by occurrence of good quality groundwater. Though the sodium content is moderately high, the other dissolved constituents are within the permissible limits. The chemical quality of the water, especially in eastern part of the block, is good and points to much less sea water contamination. The concentration of all the plots in Piper Trilinear diagram (Fig.VII.5) is confined to the central part of lower half of the diamond field. The most significant character of the block's groundwater is the low

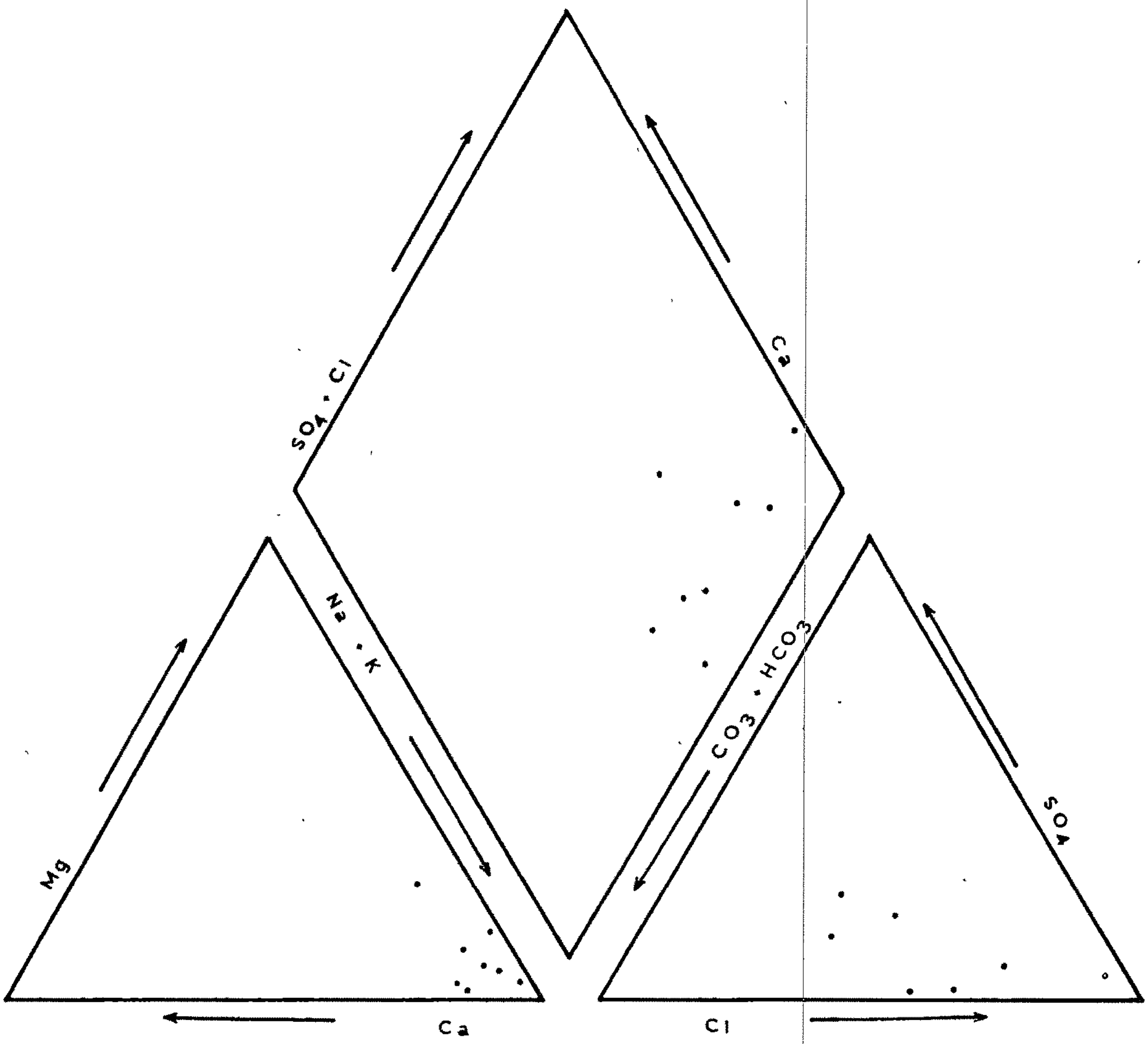
FIG. VII.3



PIPER'S DIAGRAM SHOWING THE CHEMICAL QUALITY OF GROUNDWATER

BLOCK - I.

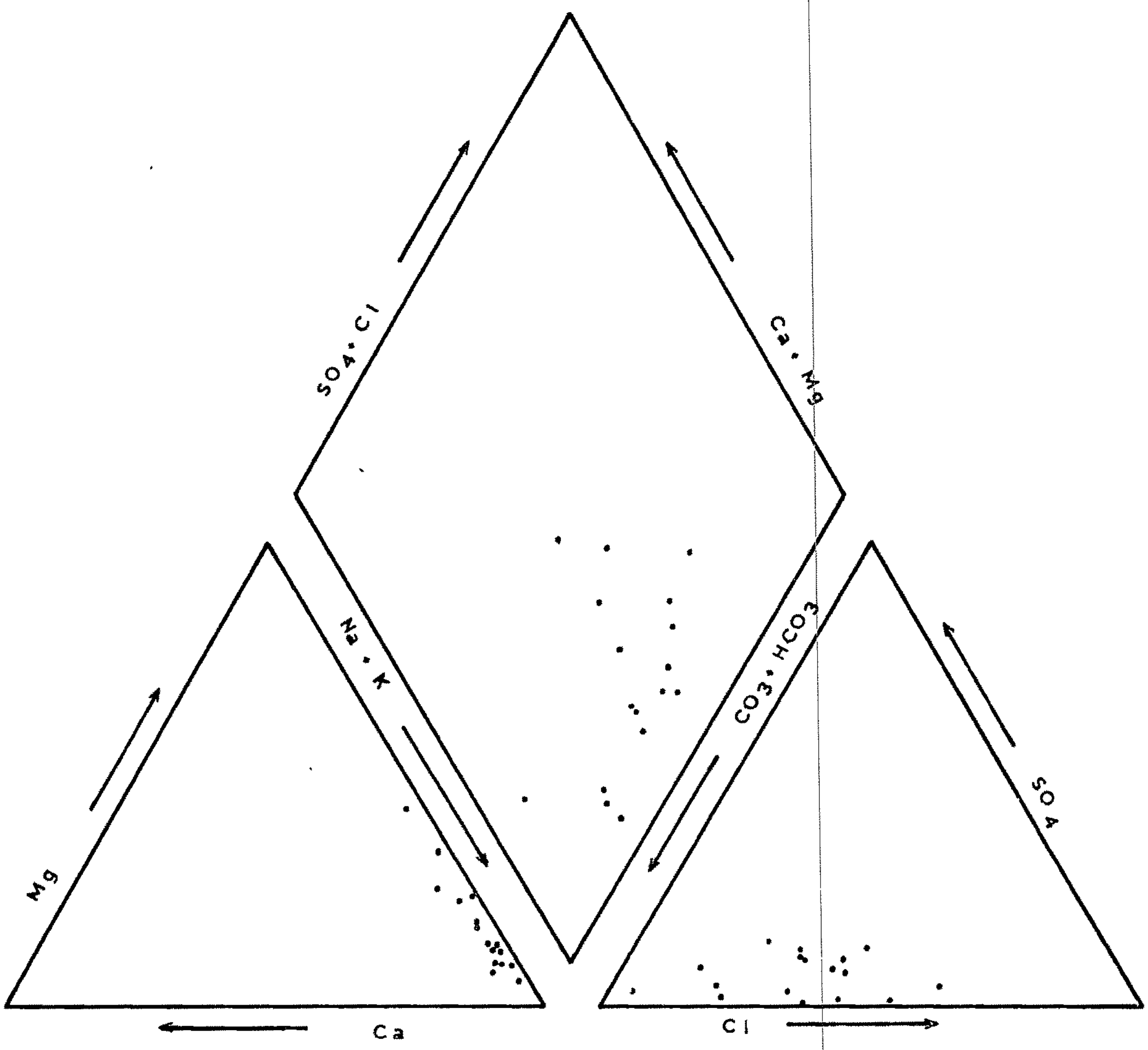
FIG. VII.4



PIPER'S DIAGRAM SHOWING THE CHEMICAL QUALITY OF GROUNDWATER

BLOCK - II

FIG. VII.5



PIPER'S DIAGRAM SHOWING THE CHEMICAL QUALITY OF GROUNDWATER

BLOCK - III

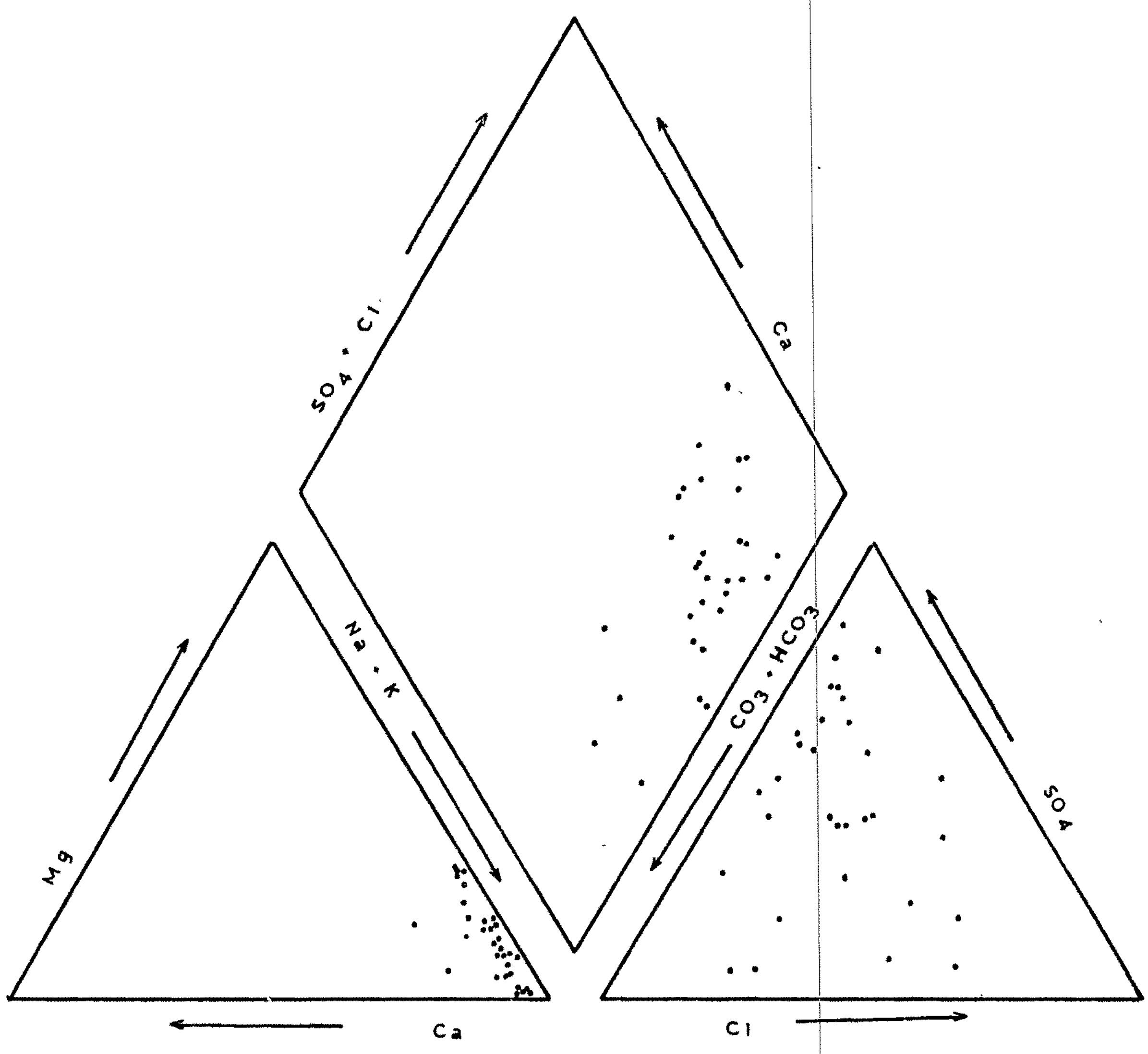
sulphate (i.e. 12-146 ppm) and low TDS (500-1200 ppm) contents. This is on account of sandy nature of the aquifer systems.

So far as the chemical quality of the water is concerned the Blocks IV & V between rivers Mahi, Narmada and Narmada-Tapi respectively show almost identical characteristics. The presence of vast tidal mud flats and intermixing of fresh and sea water has contaminated fresh groundwater. The average TDS is in the range of 256-3418 ppm, but the values for Na, K is reasonably potable. There is a rise in sulphate content, but this appears to be due to the bacterial reduction of organic material in the tidal muds. The high sulphate content in the Narmada, Tapi block might also be due to waterlogging and use of chemical fertilizers. The concentration of plots in the diamond field of Piper Trilinear diagram (Fig.VII.6 & 7) shows moderately saline characteristics of the groundwater.

SOME ASPECTS OF MANAGEMENT

Obviously, the present freshwater supplies along the Gulf coast through dug wells and surface storage are not such that they can keep pace with the rapid economic development activities along the coastal areas. On one hand, it is most essential that the quality of life of the

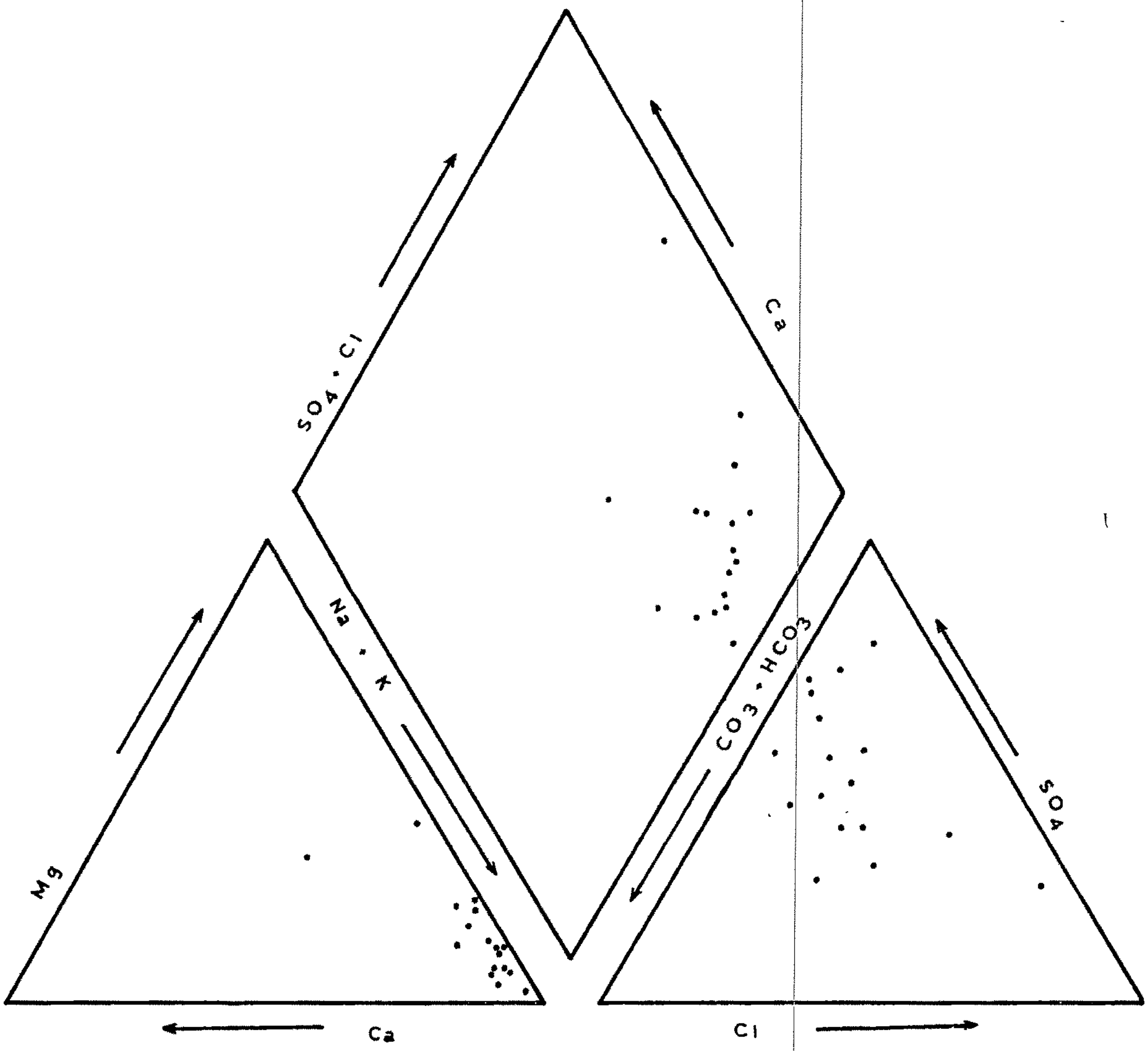
FIG. VII.6



PIPER'S DIAGRAM SHOWING THE CHEMICAL QUALITY OF GROUNDWATER

BLOCK - IV

FIG. VII.7



PIPER'S DIAGRAM SHOWING THE CHEMICAL QUALITY OF GROUNDWATER

BLOCK - V

coastal inhabitants has to improve through a variety of developmental activities, but on the other hand, it is equally important to keep in mind the constraints of the availability of potable water. It is not only the question of providing other infrastructural facilities for various economic upliftment, but the increased activities in the coastal areas would involve greater influx of people from outside and also considerable need of augmented water supply.

The present author, has on the basis of his observations and evaluation of the existing resources and future potential has come to following two main conclusions which have to be kept in mind while planning the proper management of groundwater resources along the Gulf coast:

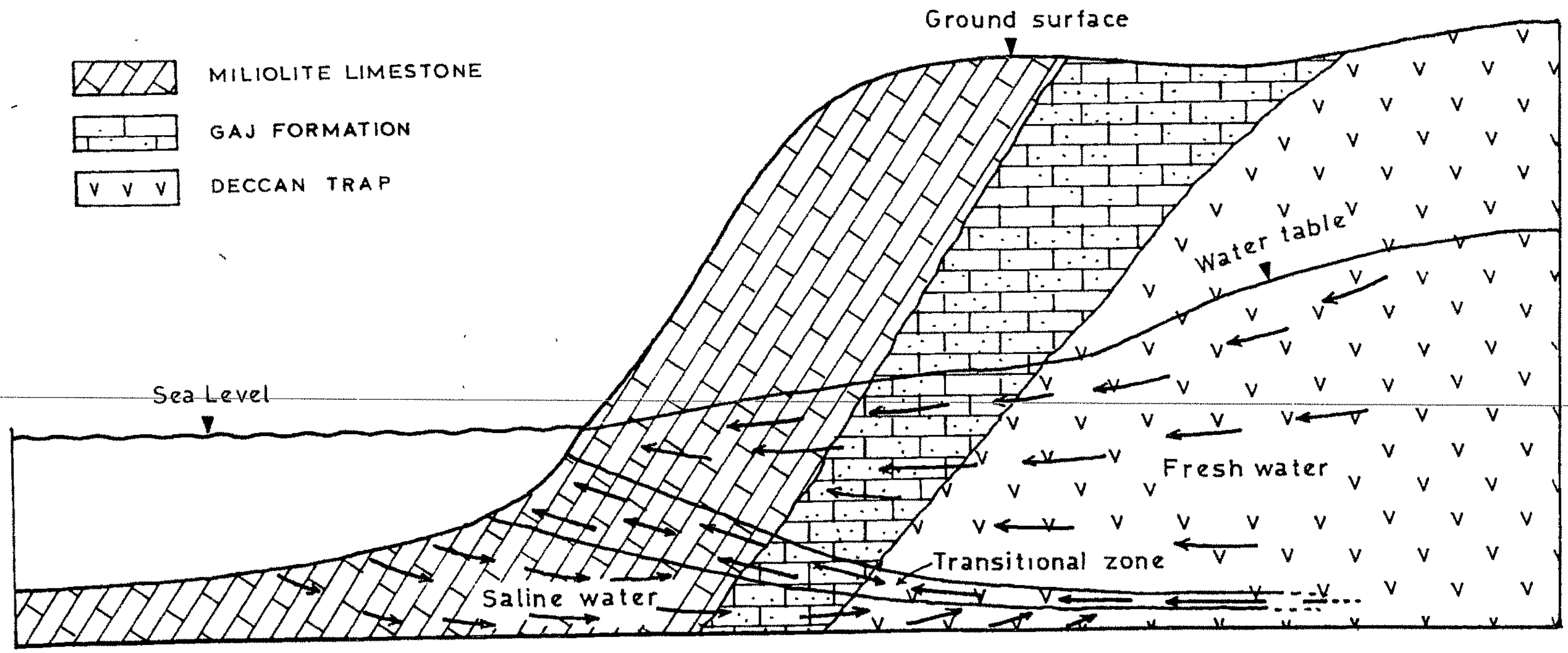
(1) No single strategy could be adopted for the entire coast, because its various segments pose their own distinct geohydrological conditions and need individual strategies for management.

(2) There is an optimum beyond which the coastal terrain cannot sustain the interference with the natural conditions of freshwater availability.

The management of groundwater in Saurashtra coast involves an entirely different strategy from that for the Mainland coast. On Saurashtra side, the rocky areas to the south of Bhavnagar do provide sweet water in reasonable quantity; but the supply is such that it cannot be exploited beyond its present stage of utilisation. The problems arising out of over exploitation would be identical to those faced by the rest of the rocky coast of Saurashtra, (Fig.VII.8) where it has been experienced that once the salinity ingress has taken place, it has been found very difficult to push it back (Ahluwalia,1983). The coastal terrain to the north of Bhavnagar, poses an entirely different management problem. Here, there are no wells and the water is availed of by storing the rain water in dug ponds. Some bigger ponds support a few shallow wells around the pond fringes. This area is chronically deficient in sweet water and needs a special strategy involving augmentation of surface storage facilities and prevention of loss of impounded water through downward seepage and evaporation. Experiments at Rahtalav near Dholera have been conducted on a very limited scale by a voluntary organisation (Mahiti Project) to line the ponds with polyethylene sheets and spraying certain chemicals to inhibit seepage and evaporation losses respectively (Plate VII.6). As the area has a low and erratic rainfall, the present author is of strong opinion that the sweet water availability can be suitably augmented by digging many more ponds, lining them by impervious material and cutting down the evaporation.

On the Mainland coast, the hydrogeological conditions in the Mahi right bank area are ideal in the sense that it

FIG. VII.8



SCHEMATIC CROSS SECTION SHOWING SALINITY ENCROACHMENT ALONG COASTAL SAURASHTRA

Plate VII.6. An artificial polypropylene lined pond for sweet water storage at Rahtalav.

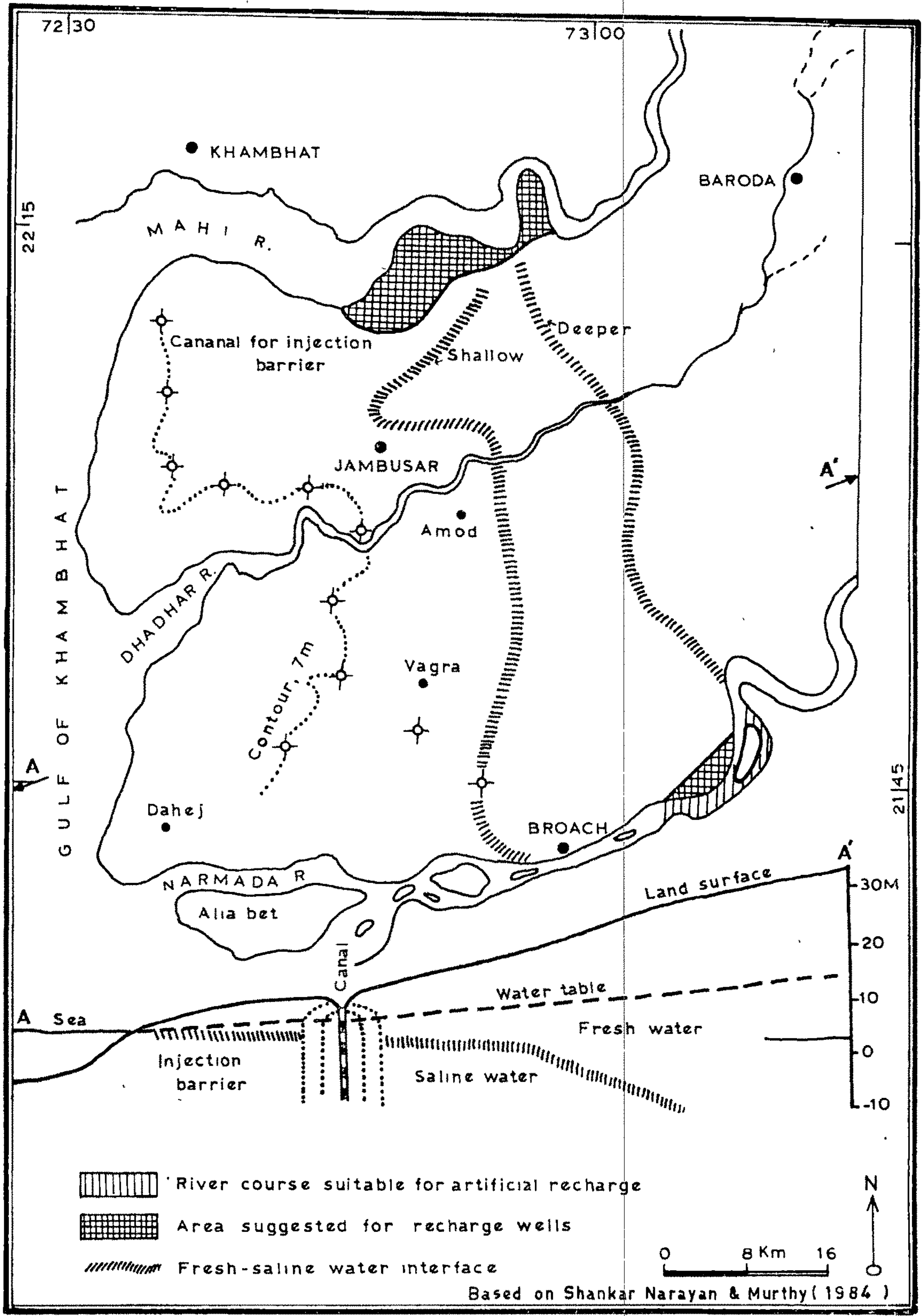
Plate VII.7. View of a tobacco field reflecting the excellent agricultural conditions at Bhadran.

provides ample water both for domestic consumption as well as for irrigation (Plate VII.7). There is no scarcity of water availability. On the other hand, some areas on account of over-irrigation and seepage from unlined canals have created problems of waterlogging and salinity of soils. This hazard before it spreads, has to be tackled by appropriate measures to utilise and divert the surplus water to other areas which are in need of this resource. It is also very necessary to restrict the rise of groundwater table further up by adopting suitable measures.

The coastal segment between Mahi and Narmada, in many ways, is identical to the Saurashtra northern coast, except that here the rainfall is higher and the alluvial cover supports shallow dug wells, which have sweet water mounds resting over saline water. Most of these wells are located in and around ponds, which act as the sources of recharge. So long as a balance is maintained between the withdrawal and recharge, the saline water level does not contaminate the wells. But in future, if these areas have to be developed, it is essential to bring water through a canal system and allow controlled percolation through surface storage and drains, to create effective sweet water barrier (Shankarnarayan & Murthy, 1984), thereby preventing the ingress of salinity (Fig. VII. 9).

South of Narmada, the geohydrology is mainly dependent on heavy rainfall that is stored in surface ponds type of

FIG VII.9



GROUND WATER RESOURCES MANAGEMENT IN MAHI-NARMADA BLOCK reservours. By and large, the water supply is ample and this segment is most rich in groundwater availability and accordingly higher prosperity of the area. As already stated earlier, the construction of ponds along numerous paleochannels has been an effective man-made technique of groundwater enrichment. If the existing water resources are properly managed, there is ample scope of removing the chronic shortage and planning for proper development. But the author would like to strike a note of warning that the hazards of waterlogging and soil salinity in some areas cannot be ruled out and the planners have to very carefully attend to this problem while planning the canal network in these areas. Table - 7.7 summarizes the overall aspect of management for all the five blocks around the Gulf.

Finally, the author would like to emphasize that the factor of sweet water availability specially the groundwater has to be critically evaluated in all its aspects before embarking upon ambitious developmental activities. After all the coastal resources should **not** be strained beyond a limit otherwise it may generate unexpected environmental problems and hazards.

TABLE 7.7 ASPECTS OF WATER RESOURCES MANAGEMENT

Block Number	Area	Problem	Hazards	Preventive Measures
I	Methla-Bhavnagar (Kalubhar)	Early stages of salinity ingress	Contamination of fresh water aquifers, socio-economic imbalance	Optimal utilization of groundwater resources. Delimiting the draft
II	Bhavnagar-Sabarmati	Chronic scarcity of sweet water. Fresh water turning saline at shallow depth. Inundation and stagnation of monsoonal water on account of flat and low topography.	High salinity and soil degradation.	Prevention of inundation and tidal ingress by adopting suitable measures
III	Sabarmati-Mahi	Salinity ingress in the coastal area	Contamination of sweet water aquifers.	Delimiting the draft
		Waterlogging in the inland areas	Rising of water table, concentration of salts near the surface Land degradation. Eco-system imbalance	Restricting the rise of groundwater table by conjuctive use. Draining out the excess water.

TABLE 7.7 (contd)

Block Number	Area	Problem	Hazards	Preventive Measures
IV	Mahi-Narmada	Limited groundwater potential, further subjected to salinity encroachment	Land degradation Socio-economic imbalance	By means of artificial recharge
V	Narmada-Tapi	Over-irrigation and salinity	Water logging Land degradation	Draining out the surplus water. Conjunctive use of water resources