Chapter 4
Water Resources Characterization

CHAPTER 4

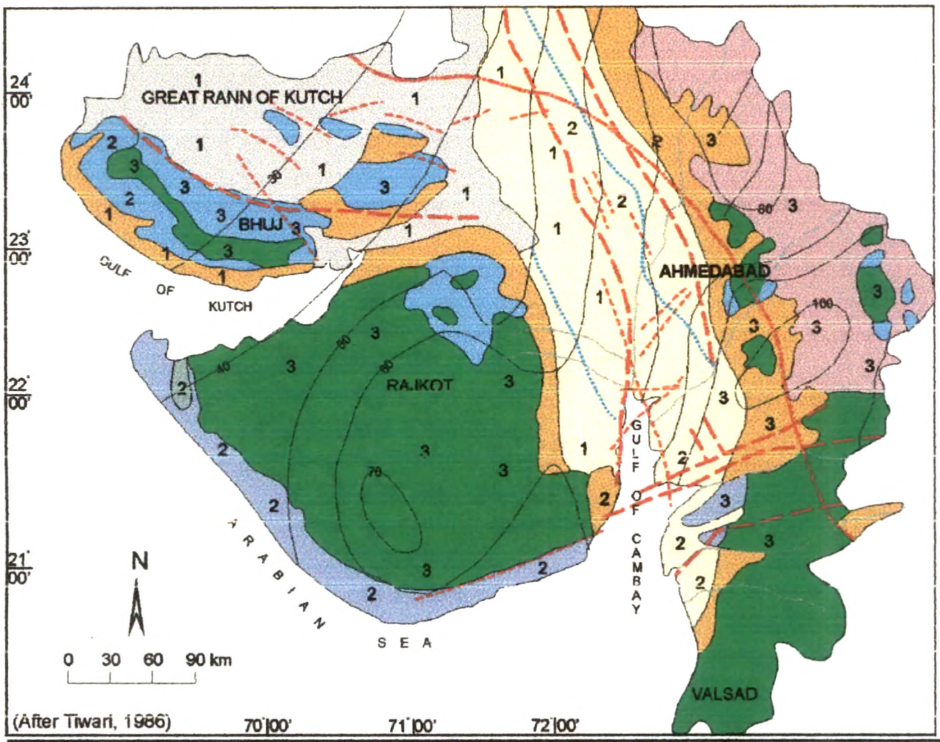
WATER RESOURCES CHARACTERIZATION

Occurrence, distribution and quality of water resources are closely interrelated with the geological characteristics of area. Geological parameters viz. lithology, structure and geomorphology, independently and/or combinedly influence the distribution of surface run-off and groundwater recharge. Hence, for quantitative and qualitative evaluation of water resources of any area, proper understanding and precise information on geological aspects are pre-requisites. Gujarat being predominantly agrarian state and also on the fore front of industrial development; ever increasing water demand in its various sector further necessitates to obtain precise information on hydrogeological characteristics; to envisage an appropriate strategy for resources management and its optimal utilization.

REGIONAL HYDROGEOLOGICAL SET-UP

On a regional context the Gujarat State has been bestowed with some important groundwater provinces of moderate to high potential, viz. (i) Gujarat Alluvium Plains, (ii) Deccan Trap of South Gujarat and Saurashtra and (iii) Mesozoic Sandstone of Saurashtra and Kutchh (Karanth, 1987).

The Gujarat Alluvium constituting an aggregate thickness of more than 600 m of Quaternary sediments has been one of the high potential groundwater provinces in western India (Phadtare, 1988). This province is characterized by a multi-tiered aquifer system of semi-confined- confined nature. These aquifers coalesced at its northern extremity, the mountain front of Delhi-Aravalli Range, constituting the recharge zone. The study area also forms a part of its southwestern extension. Here, although the aquifers are of similar nature, the recharge zone in located in the northeastern parts of the state. A regional hydrogeological map (Fig. 4.1) encompassing entire state provides further details on other hydrogeological aspects.



Symbol	Age group	Nature of formation	Lithology	Tectonic Framework	Groundwater Conditions
	Quaternary-Upper Tertiary	Unconsolidated formation	Clay, Silt, Sand, Gravel, Pebbles, Boulders, Calcareous concretions	Groundwater basin occurring in platform area and fordeep 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 area of groundwater basins having aquifers within 100m. with limited extension due to boundary conditions.
	Quaternary and Tertiary	Semi-consolidated formation	Limestones (Milliolite, Guj, Kirthar)	Coastal areas of Saurashtra and between Tapi and Narmada Mouths	Karstic limestone (Milliolite and Guj) in coastal area having groundwater in cavern and solution channels within 50 m.
	Tertiary and Mesozoic		Grit, Sandstontes, Siltstones, Shales, Conglomerate, Limestone	Platform area in Kutch and NW Saurashtra outlier and inliers in East Gujarat an dNarmada Valley	Tertiary and Mesozoic sedimentary rocks with restricted confined aquifers in platform areas.
	Cretaceo-Eocene	Consolidated formation	Basalt (with intertrappean beds)	Terrestrial volcanic effusiions on platforms.	Groundwater occurrence restricted to weathered zone, joint planes, zones of shearing and faulting and vesicals. Phreatic unconfined conditions prevail in weathered zone and piestic condtions in deep fractures.
	Pre-Cambrian		Sandstontes, Shales, Phylites, Slates, Wuartzites, Dolomite, Marbles, Schists, Granites, Basic Igneous Rocks.	Ancient platform area of Archean Folding.	Groundwater occurrence restricted to soil and regolith cover and weathered and fissured zones under phreatic unconfined conditions.

BOUNDARY AREAS WITH ARTESIAN FLOWING CONDITIONS
ISOHYTES ANNUAL AVG. RAINFALL
MAJOR FAULTS
MINOR FAULTS
TECTONIC ZONAL BOUNDARY

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

Fig. 4.1 Hydrogeological Map of Gujarat

HYDROGEOLOGY OF THE STUDY AREA

SURFACE WATER RESOURCES

Utilization of the surface water resources depends more on the conservation of water during monsoon season and its utilization during the non-monsoon period. Owing to erratic monsoon pattern limited groundwater resources; continual deteriorating conditions of the natural drainage system, influencing the recharge; increasing demand of the agricultural products; have necessitated the need for artificial irrigation system. Irrigation tanks conjuctively with the canal network function as reservoir.

Tanks and Ponds

Tanks and Ponds, which constitutes an integral part of Mahi Right Bank Canal (MRBC) area, are considered to be the earliest system of irrigation. The MRBC area has large number of ponds/tanks constructed at suitable places, by taking the benefit of abandoned palaeo-channel segments with the restricted catchments. Prior to the canal irrigation this particular terrain, which in fact form a part of vast coastal plains, subsists its irrigation as well as the domestic requirements through these ponds. As these ponds have been constructed on a palaeochannel courses; they are of variable shapes and dimensions (Fig. 4.2). Normal functioning of these ponds used to be of two folds (i) To create sufficient storage to be utilized for a very restricted irrigation and major domestic purposes, and (ii) an important mode of groundwater recharge thereby, preventing the shallow phreatic aquifers from contamination due to saline water intrusion. It has been observed that the down ward percolation of potable water through the tanks, generally creates, a subsurface mound (Fig. 4.3) Owing to density contrast this mound suppressed the saline water from upward movements. Also, during lean monsoon periods, even the pond gets dried up; the local inhabitants have an assure source of potable groundwater; through a system of wells sunleed in, the midst of pond itself as well as on the ponds' periphery (Islam, 1986).

Latter, when the canal irrigation commenced, these ponds have been linked through the feeder canals thereby making them a sort of perennial storage. The details on existing important ponds, maintained by the State Irrigation Department are given in Table 4.1.

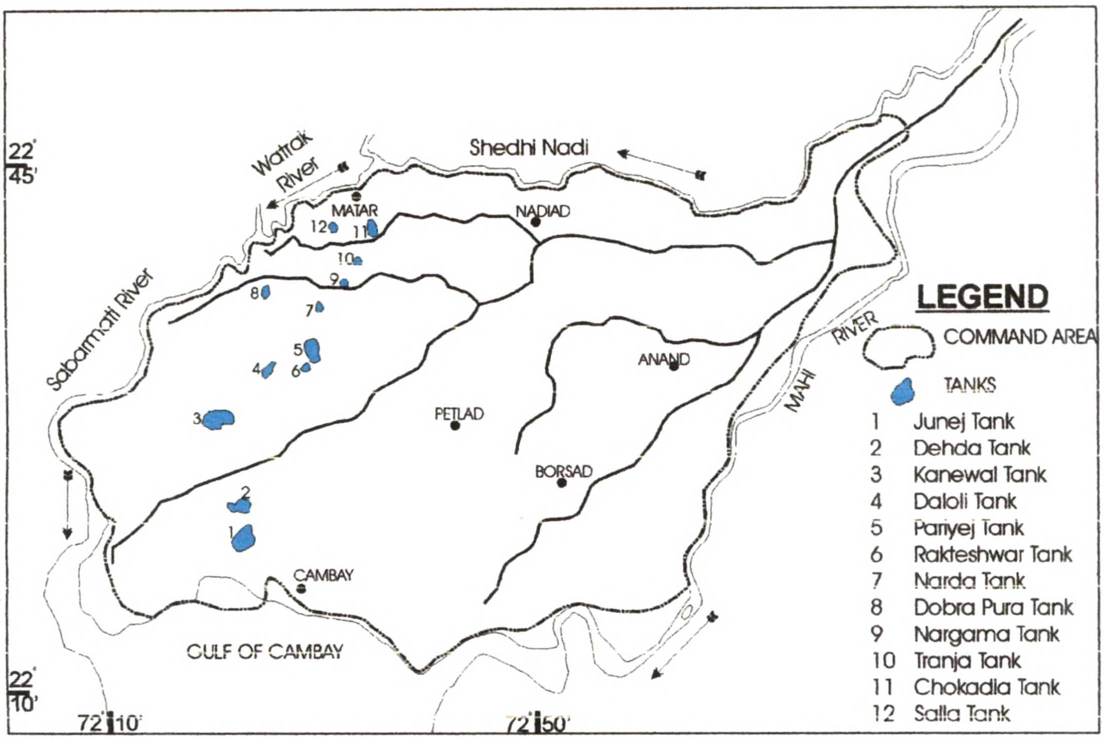


Fig. 4.2 Location of Irrigation Tanks in MRBC Command Area.

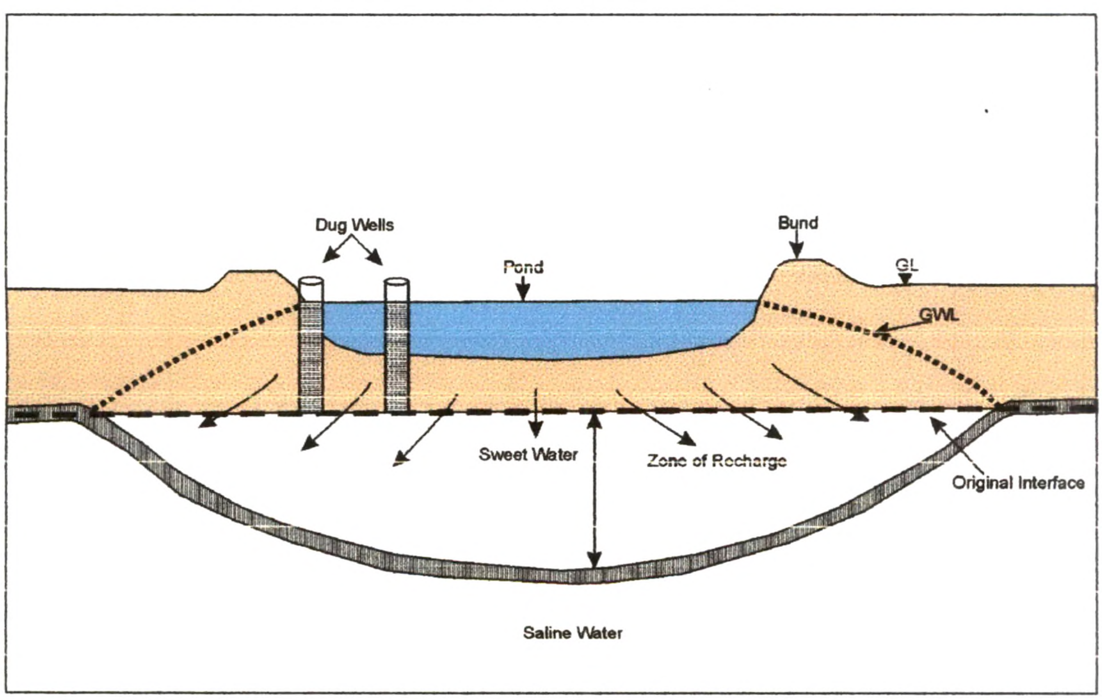


Fig. 4.3 Groundwater Recharge and Development of Sweet Water Mound on Account of Surface Water Body (Pond and Tank)

Table 4.1 Salient Features of the Irrigation Tanks in MRBC Area

Sr. No.	Name of Tank	GCA ha	CCA Ha	Irrigation Command Area ha	Capacity MCM	FSL M	Land Irrigability Class
1	Pariyej	457	378	354	10.889	8.99	V
2	Daloli	598	504	404	1.694	15.54	V
3	Salla	191	191	124	0.972	21.95	V
4	Kanewal	1866	1764	1411	16.500	13.72	V
5	Tranja	280	276	-	-	23.47	V
6	Narda	-	-	118	0.574	18.14	IV
7	Bhandrej	-	-	138	1.142	16.50	III

(Source: Govt. of Gujarat)

Irrigation Canal System

The pick-up weir has constructed on the Mahi River with a primary objective to augment the irrigation in non-monsoon season. The Mahi River has a fairly dependable discharge upto the October, of which more than 95 % discharge occurs during the monsoon season. The irrigation system comprises a network of Main Canal, Branch Canal, Distributaries, Minors, Sub-minors, Field Channels and Outlets of different dimensions and capacity (Fig. 1.3) with the designed irrigation intensity of 70.77 %. The main canal and branch canals have been lined where as other network unlined. The status of canal network in terms of their extent, effective period of water supply and aspects of water quantity vis-a-vis seepage losses in MRBC area is given in Table 4.2.

Table 4.2 Status of Canal Water Supply in MRBC Area.

Canal	Length of Canal Km	CCA ha	Average No of Running Days	Average Discharge MCM	Seepage Factor MCM/km	Average Wetted Perimeter 'm'	Total Seepage MCM/km/ year	Actual Seepage* MCM
Main	74.00	31,191	180	2483.00	0.338	25.90	25.04	10.02
Branch Canals								
Nadiad	37.60	23,573	180	940.09	0.326	25.00	12.27	4.91
Matar	19.00	13,272	180	171.78	0.179	13.72	3.39	1.34
Cambay	48.50	53,811	180	594.11	0.298	22.86	14.49	5.80
Limbasi	35.20	31,073	180	189.23	0.179	13.72	6.30	2.52
Petlad	58.60	41,683	180	419.60	0.219	16.76	12.82	5.13
Borsad	23.60	37,155	180	170.31	0.239	18.28	5.64	2.26
Total	296.5	231,758		2483.00			79.95	31.98

*** 40% of Total Seepage** (Source: GWRDC)

It can be seen from the data that an average annual discharge from Wanakbori Weir is about 3583 MCM, out of which 900 MCM is utilized to fill up various irrigation tanks and initial filling of the branch canals. Therefore, the total water utilized for irrigation stands at 2483 MCM out of which 1252 MCM water remains within the canal network. Owing to major network being unlined, the seepage losses from canal system are bound to recharge the groundwater regime.

The canal seepage losses is calculated by taking the basis of Average Wetted Perimeter and number of running days. The losses that occurred through seepage from Main & Canal networks accounts to 32 MCM i.e. 2.6 % of total water delivered in the canal system (Anonymous, 1975). Studies carried out by the State Irrigation Department had also pointed out that in MRBC command area about 7 % of water is simply lost as seepage directly from distributaries and 30 % through the outlets. Therefore the annual seepage losses stand at 87.64 MCM and 375.6 MCM through the distributaries and field outlets respectively. The total annual loss in turn through canal network is 495.24 MCM, i.e., 39 % of the total water in the canal system. Amongst the Branch Canal System, the Nadiad branch with an aggregate culturable command area of 23,573 ha is responsible for maximum seepage i.e. 4.91 MCM.

Pond and Canal Water Chemistry

As the ponds and canal water constitutes an important perennial mode of recharge to the groundwater regime; information on its chemical contents is equally important for evaluation of an overall chemistry.

The chemical contents of the canal and pond water samples (Table 4.3) and their treatment to the standard evaluation techniques for potability and Irrigability suggests:

(i) By and large the chemical contents are within the permissible limits, except the Na^{2+} which is moderately high.

(ii) From the potability point of view, majority of the samples fall under field 9 in the diamond of Piper Tri-linear Diagram, indicating balanced chemical contents i.e. acids and alkalis (Fig. 4.4).

(iii) Irrigation quality under U. S. Salinity chart, the water fall under the C_1-S_1, S_2 classes; Wilcox pattern diagram under A-B classes (Fig. 4.5 a & b) provides their suitability in irrigation.

Table 4.3 Analytical Details of Surface Water in MRBC Area.

Tank	Depth	pH	EC mmohs/cm	Cations in mg/l			Anions in mg/l			TDS mg/l	SAR
				Na+K	Ca	Mg	CO_3+HCO 3	Cl	SO_4		
Kanewal	6.5	7.10	246.40	56.00	11.00	132.00	89.82	82.91	26.27	385	3.11
Kanewal	4.0	7.80	226.56	52.00	8.00	31.00	48.55	23.04	19.41	354	6.15
Dehda	3.9	7.50	195.20	49.00	9.00	28.00	41.58	31.68	12.74	305	11.10
Junej	5.8	7.10	243.20	58.00	9.00	44.00	56.22	46.85	7.93	380	13.48
Junej	4.5	7.20	249.60	59.00	30.00	28.00	49.80	59.29	7.91	390	11.46
	15.8	7.20	182.40	48.50	12.00	91.00	51.24	92.09	8.17	285	9.01
	17.0	7.30	204.80	52.60	16.00	61.00	58.59	68.31	2.69	320	7.33
	9.5	7.30	212.48	54.00	14.00	42.00	59.75	48.60	1.64	332	8.70
	22.5	7.50	189.44	47.00	9.00	44.00	61.38	37.46	1.15	296	8.88
Daloli	7.8	7.00	257.28	53.00	9.00	36.00	41.91	43.28	12.80	402	10.30
Pariyej	8.3	7.00	212.48	49.00	8.00	46.00	56.90	34.33	11.77	332	10.33
Canal		7.30	182.40	21.00	15.00	21.00	28.22	23.14	5.64	285	4.04

(Source: Govt. of Gujarat)

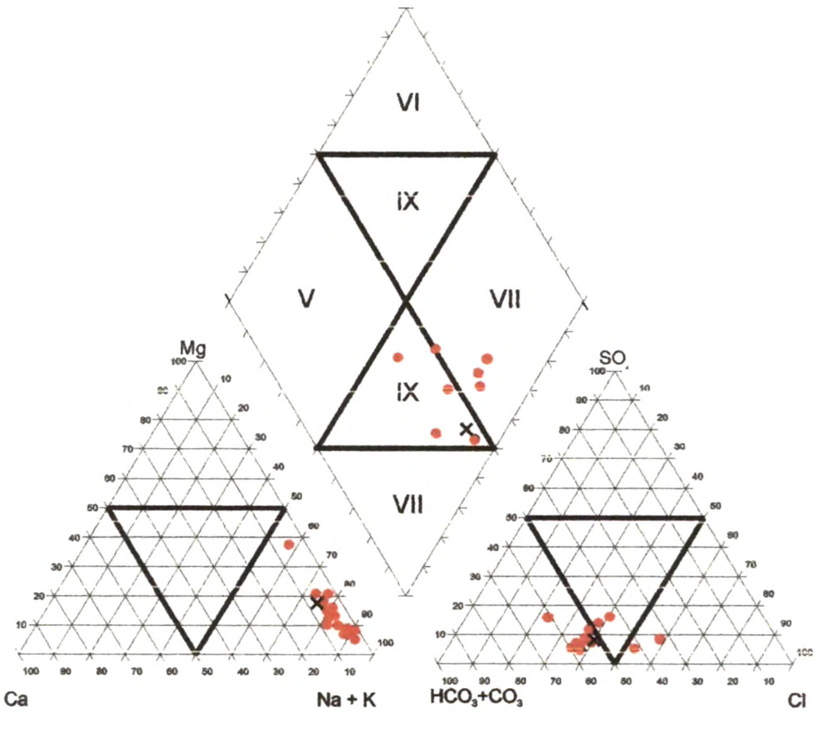


Fig. 4.4 Piper Tri-linear Diagram for Suitability of Canal and Surface Water Quality in MRBC Area for Drinking Purpose

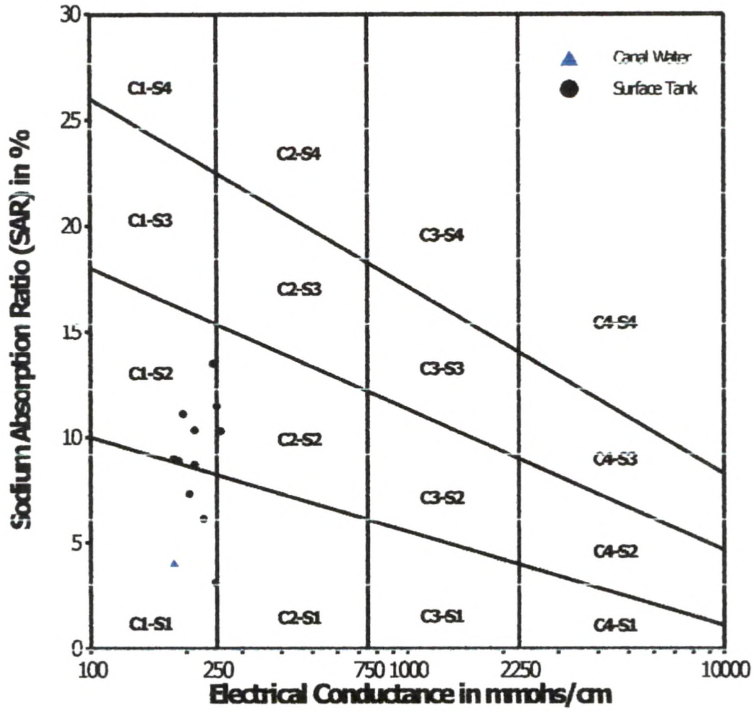


Fig. 4.5 a U. S. Salinity Diagram of Surface and Canal Water in MRBC area

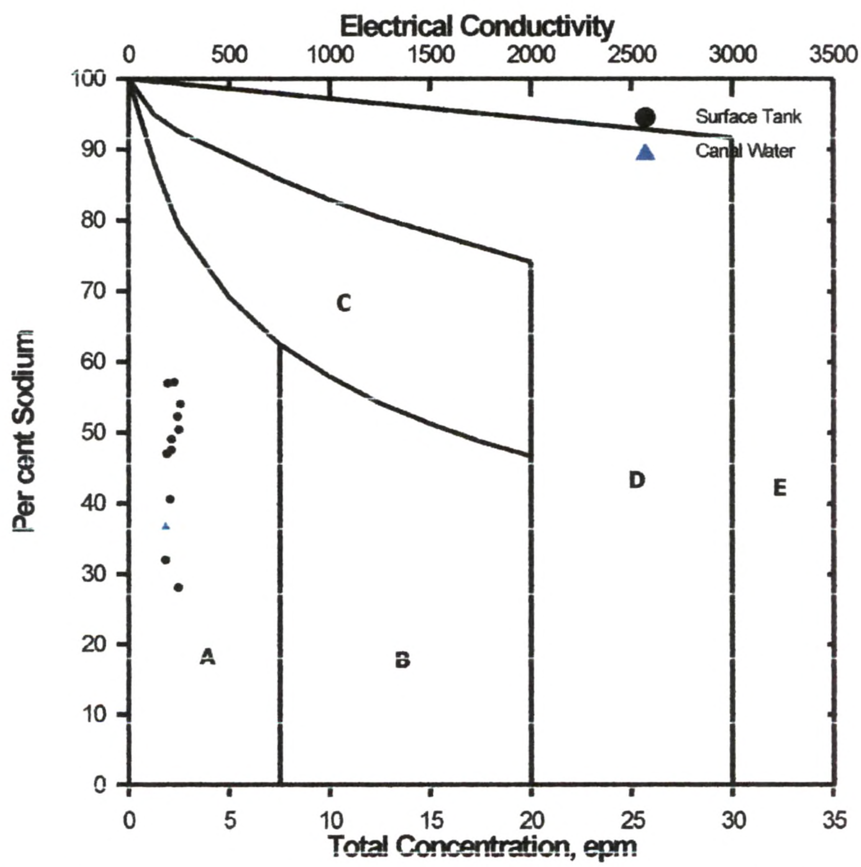


Fig. 4.5 b Suitability of Surface and Canal Water for Irrigation in MRBC area

GROUNDWATER RESOURCES

The Mahi Right Bank Irrigation Command area constitutes a part of Central Gujarat Alluvium Plain, which ultimately merges with the coastal plains of Gulf of Cambay in its southwestern parts. As it has already been eluded in preceding chapter on geological set-up that the study area forms a part of Tarapur-Cambay block of Cambay Graben, which is characterized by an extensive thickness of sediments pile ranging from Eocene-Recent in age. The occurrence of potable groundwater in this part is restricted up to the Quaternary sediment of fluviatile nature. Although the sediments display an intercalated sequence of thin sands and thick clayey layers, while on approaching towards the coastal plains the sediments are predominated by the clayey fractions. Similarly the quality of the groundwater is also accordingly influenced. The overall quality of groundwater exhibits enrichment in their chemistry as traced towards the coastal tracts of the Gulf of Cambay, which is attributed to inherent salinity in the sediments deposited under fluvio-marine conditions (Islam, 1986).

The hydrogeological studies of the MRBC area has been carried out with a view to understand (i) Nature of Aquifers, (ii) Water Level Fluctuations, (iii) Hydraulic Characteristics of the Aquifers, and (iv) Groundwater Chemistry and its Behavioral Patterns with time. For this, the author has carried out a critical review of available data for the entire command area. A brief account on the various facets of the study area hydrogeology is discussed as under:

Aquifer Nature and Extent

The dimensional aspects of the various aquifers can be better studied through the borehole lithologs. The author has collected the available bore hole data from the various government and MRBC authorities and prepared various subsurface hydrogeological profiles. The salient features on the dimensional parameters of aquifers and their nature are discussed on an individual profile basis.

(i) ***Kapadwanj-Ode Profile:*** A NNW-SSE profile exhibiting sub-surface deposition pattern of the sediments in the upper reaches of the command area (Fig. 4.6 a). This valley filled deposits represents an aggregated thickness of 80 m and has been deposited over the erosional surface of Deccan Traps. The sediments are

predominantly characterised by clayey compositions with a single lensoidal 30-60 m thick layer of sand, the aquifer. The thickness of sediments increases as one moves from NNW to SSE, which is a normal trend observed in any watershed basin configuration. Occurrence of very thin aquiclude layers over the aquifer characterized them to be of unconfined nature.

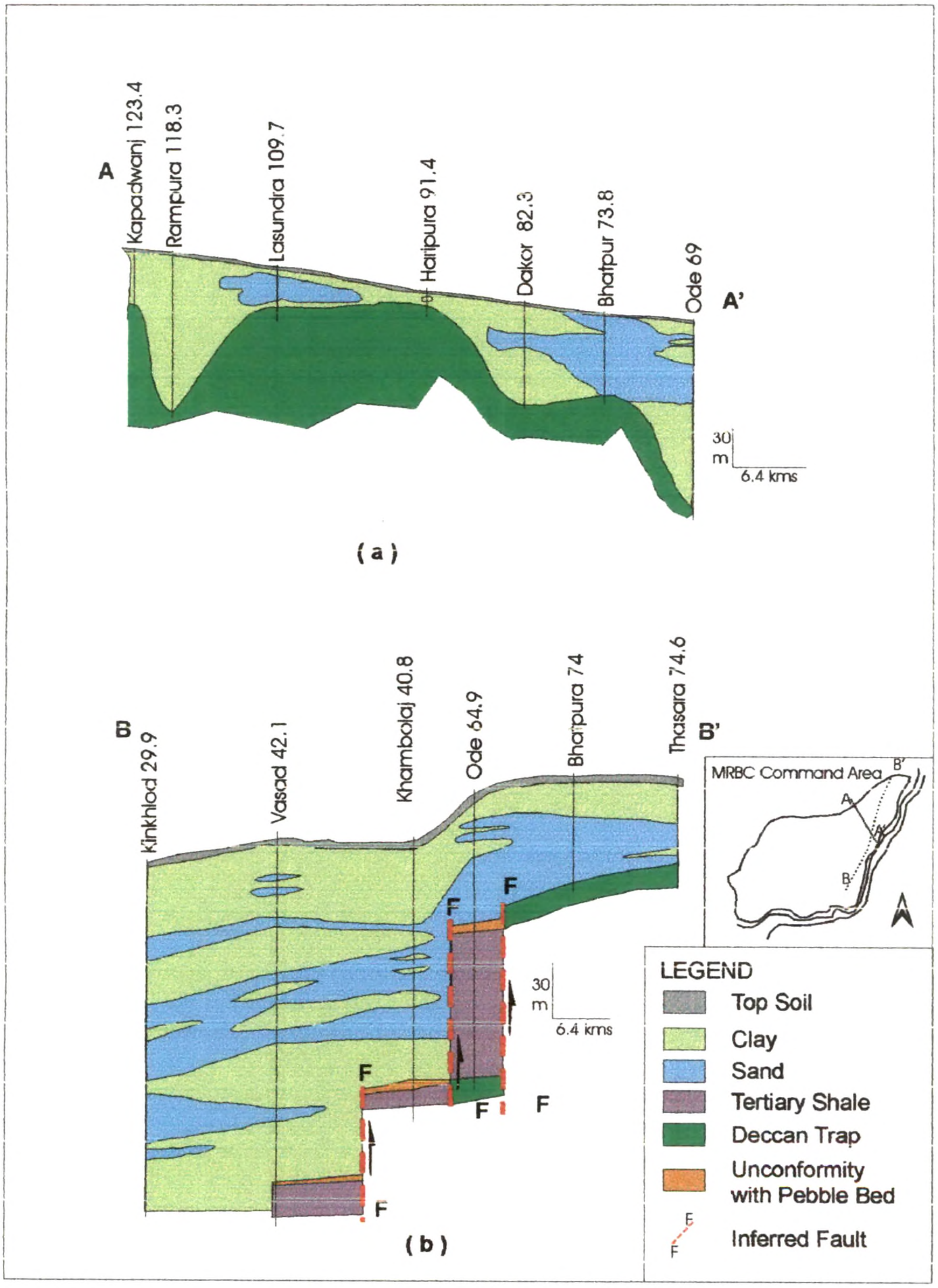


Fig. 4.6 a & b Hydrogeological Profile of MRBC Command Area

(ii) ***Thasra-Kinkhlod Profile:*** This profile which is on NNE-SSW azimuth exhibits strong influence of tectonism. Perhaps it is representing the Eastern Cambay Margin Fault system. Here, the basement (Deccan Trap) rock shows step faulting under the differential block movement. As one movement. As one views the profile, the basement rock has been encountered at Thasra-Bhatpur-Ode at variable depths i.e. 50 m, 60 m and 140 m respectively (Fig. 4.6 b). Since the basement had consistently gone down westward, accordingly the above lying sediments show increase in their thickness. Similarly the displacement of Pliocene shales i.e. the Broach formation; as seen at Ode, Khambholaj and Vasad; along the above lying gravelly horizon (Jambusar formation) of Pleistocene age (Pandey et. al., 1993), corroborates that the faulting must have taken place during early to middle Quaternary period, the neotectonic activity.

The Sub-surface cross-section depicts the predominance of clayey sediments. The coarse horizons are developed as an aquifers and are of confined in nature. These granular horizons are developed occurs at both shallow and deeper depths. Looking to their lateral continuity showing swelling and pinching patterns, the aquifers lacks uniformity in their characteristics. Also, these aquifers are of coalesced nature i.e. near Thasra, but as one move towards westward it shows bifurcation in to three or four multi-tiered aquifers

(iii) ***Cambay-Thasra Profile:*** Perhaps this profile (Fig. 4.7 a) shows the maximum and consistent thickness of Quaternary-Recent sediments to the order of 120 m or so. The basement configuration on the northeastern parts provides more or less similar pattern of displacement as seen in other profiles.

However, on comparing with other profiles, here the section between Ajarpura and Cambay displays considerable thickness of Tertiary shales, which may be attributed to latter faulting, during Quaternary times and perhaps demarcating the southern limits of the Tarapur-Cambay block of Cambay Graben. The aquifer are thin, multi-layered, confined and shows coalesced nature near Ajarpura. Contrary to this, the clayey aquiclude layers are of considerable thickness.

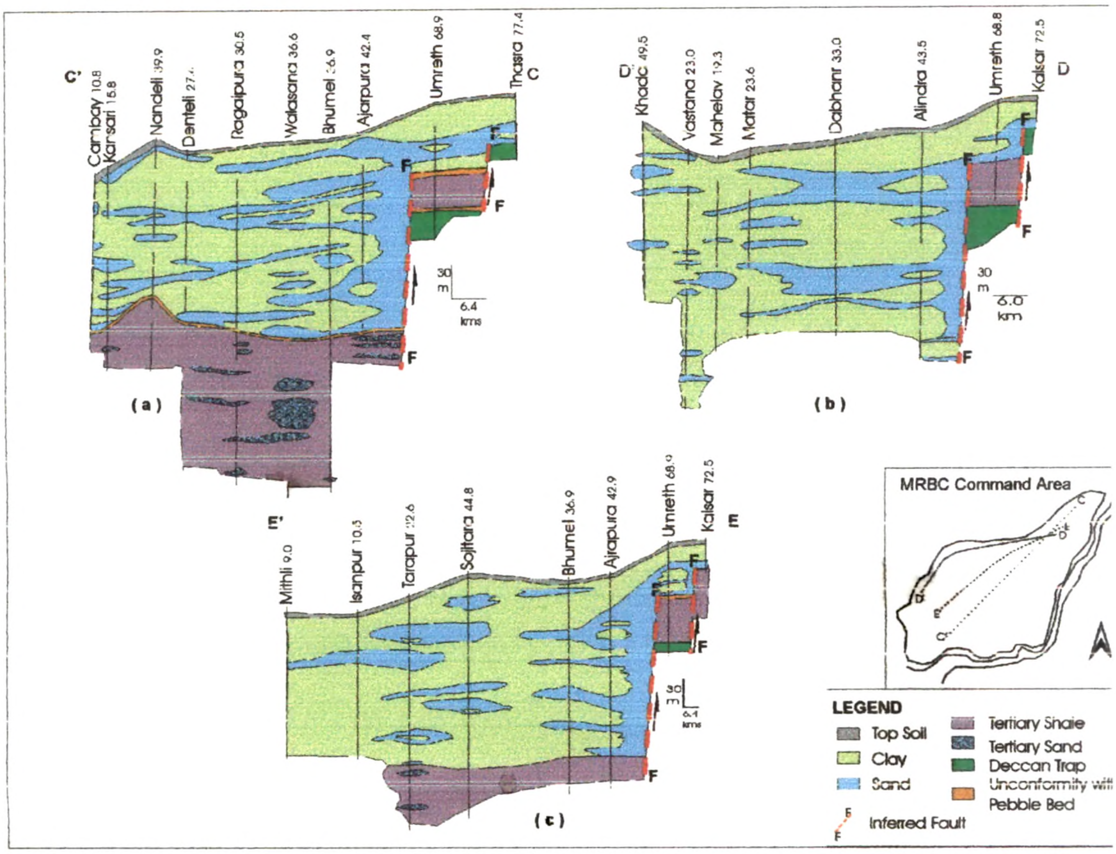


Fig. 4.7 a, b & c Hydrogeological Profile of MRBC Command Area

(iv) ***Khada-Kalsar Profile:*** This WSW-ENE profile (Fig. 4.7 b) shows discrete occurrence of well developed two layers confined aquifers between Alindra and Matar, further, the southwestward these sands reduced to tiny pinches with considerable thickness of clayey sediments. These clayey sediments are forming a part and parcel of Cambay Gulf coastal plains and the groundwater shows deterioration in quality owing to inherent salinity within the sediments.

(v) ***Mithli-Kalsar Profile:*** The sub-surface picture along this NE-SW trending profile (Fig. 4.7 c) is very much similar to Kinkhlod-Thasra profile. Here also the basement had moved down under the block movement. This profile recording an average sediment thickness of more than 170 m or so. The entire sediments pile is predominated by clays with intermittent sandy lenses. Interestingly after Bhumel, these clays with intermittent sand units (aquifers) abruptly pinches out and lacks further continuity. Although the aquifers are multi-layered but, in absence of their lateral continuity from Sojitra and further down; the groundwater potential is meagre with higher enrichment of salts.

WATER LEVEL FLUCTUATIONS

In any irrigation command area, the study of the groundwater levels and their fluctuations both vector and secular, are pre-requisites for the evaluation of groundwater recharge as well as to envisage strategy for an efficient water management.

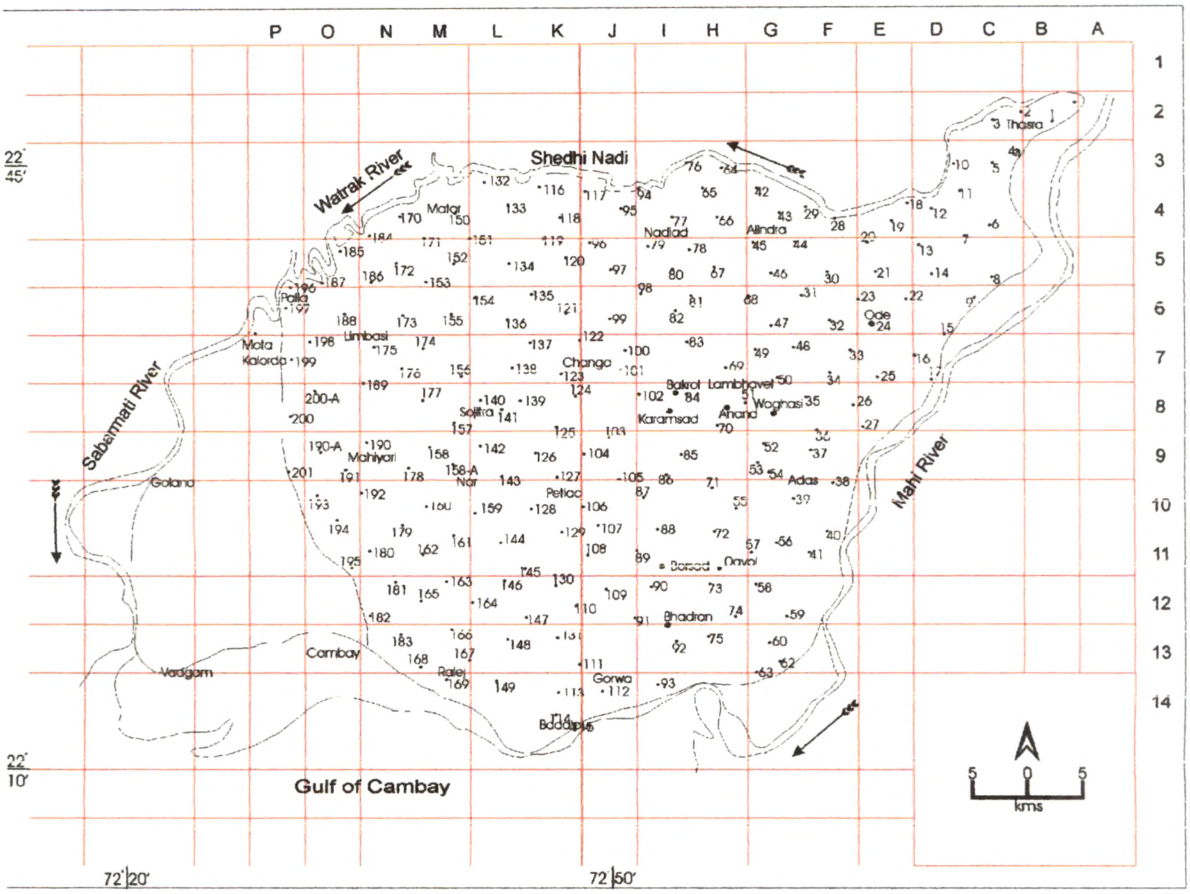


Fig. 4.8 Location Plan of Observation Wells in MRBC Area

The MRBC area has close network of almost 2340 observation wells for monitoring the water table which existing since the inception of canal system i.e. 1959. Evaluation of such a voluminous data is not only a herculean task but also difficult in bringing out inference within a limited time framework. In view of such obvious limitations, where major emphasis of this present study has been laid on a small portion of the command; the author had selectively utilized the mammoth database generously made available by the project authority.

For this author has divided the entire command area in to 25 sq. km area grids (Fig. 4.8). On each node of the grids, the nearest and best responding observation wells data have been taken in to account for evaluating the water level fluctuations. Similarly, to study the secular variation in the water level last 25 years of monitoring records have been considered at decinal intervals, beginning from 1975 to 1999. In order to observe the effect of canal irrigation on groundwater regime, the pre-irrigation water table data have been also been taken in to account. Accordingly, the author had constructed the Reduced Water Level contour maps have been prepared. Also, in order to obtain effects of rainfall recharge as well as the returned irrigation seepage the pre-monsoon data has been accounted to draw the inferences.

a) PRE CANAL IRRIGATION SCENARIO

Prior to the canal water made available for irrigation, the area used to subsists for irrigation requirements through the groundwater extraction. In order to evaluate the changes in groundwater regime from pre canal irrigation to present day scenario; the author had prepared Reduce Water Level contour (RWL) map. The influence of topography and sub-surface features along with surface drainage can be seen in RWL contour plan (Fig. 4.9).

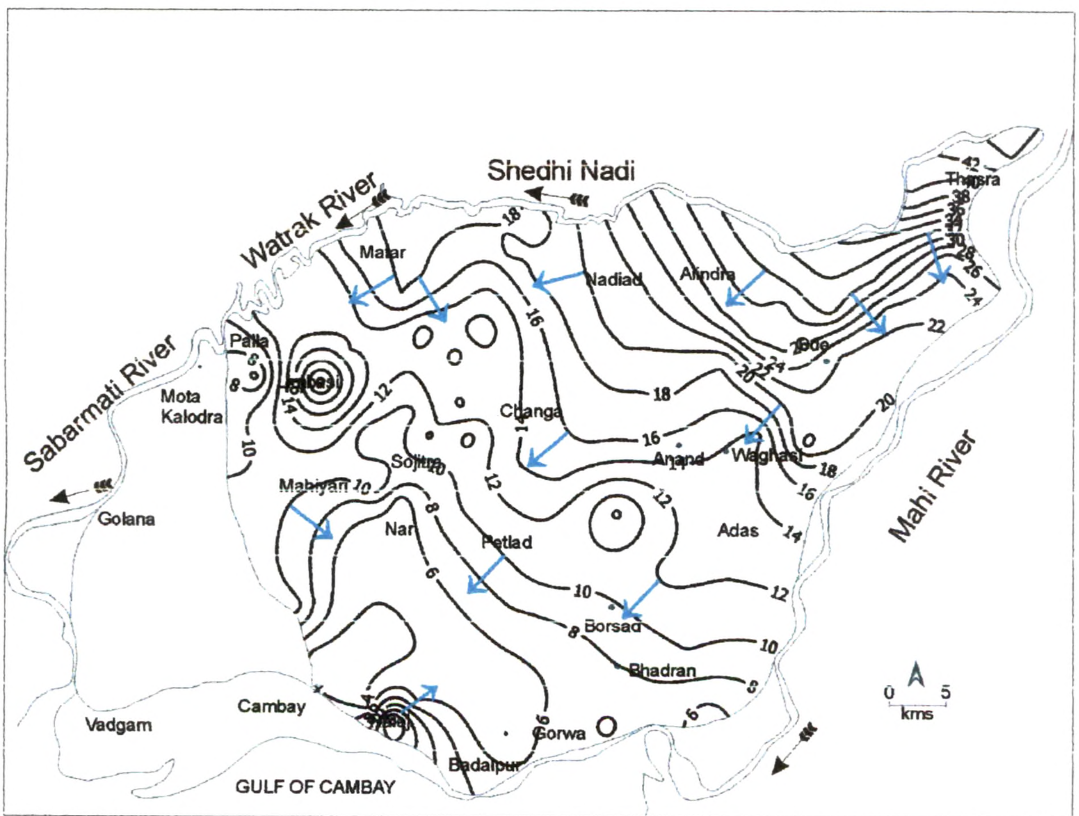


Fig. 4.9 Reduced Water Level Contour Plan of MRBC Area. (Year: 1958)

In the upper reaches of the command from Thasra to down south the groundwater movement direction and the gradient is southerly and steep i.e. 1:555. The Mahi river channel in this part shows the characteristics of influent channel. But, on approaching further down stream the channel has become affluent. Incidentally the groundwater gradient and movement direction, immediately after Ode is flattened to 1:2390 with almost southwesterly direction. This shift may be attributed to steep Eastern Cambay Basin Marginal Fault and the abrupt truncation of alluvium plains at the coastal plains, having contrasting material behaviour and lacking the hydraulic continuity. Also, the area in its western limits shows two maximas viz. near Limbasi and Badalpur with the RWL of 20 m and 12 m respectively which may be attributed to increase in saturated thickness of aquifer and/or change in lateral gradient of aquifer due to neo-tectonism. Further, the prepared hydro-isobath map for the pre-monsoon 1958 (Fig. 4.10) of the MRBC area suggests extreme variation in water table depth.

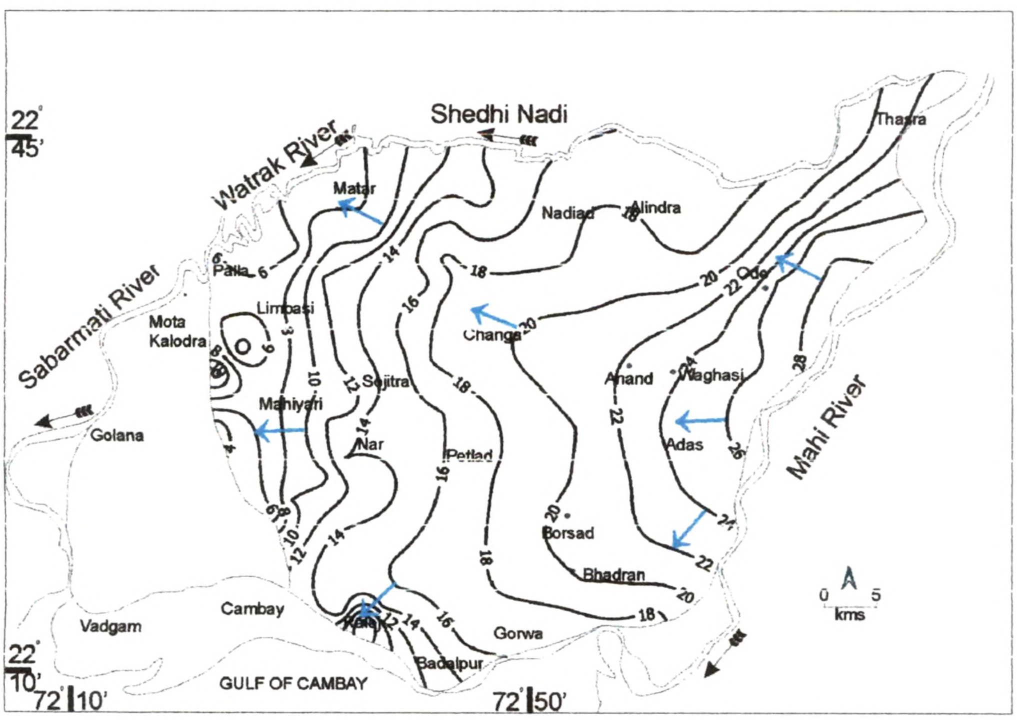


Fig. 4.10 Hydro Iso-bath Contour Plan of MRBC Area. (Year: 1958)

The depth to water table attains its maximum level of about 30 m (RWL 20 m) in upper command area near Khambholaj and Vasad and tend to decrease northwest ward to almost 3 m (RWL 6 m) around Asamli and Chanor villages in lower command. In the middle parts of the MRBC area viz. Petlad, Anand, Sojitra etc.; the depth to water table is in the range of 22-15 m. Further, it is interesting to note that prior to canal inception there was no area having the water table depth less than 3 m and also, merely about 0.9 % of the command area was under 3-6 m depth range of water table.

b) POST CANAL IRRIGATION SCENARIO

It is an established fact that after the canal water supply; the command area is vulnerable to the problems of the water table rise; this may be attributed to increase in groundwater recharge. The factors responsible for this, like excess use of water in irrigation hence, return irrigation seepage to the groundwater regime and non-utilization of groundwater resources. In order to study the long term and absolute effects of groundwater recharge, abstraction and canal irrigation on the groundwater regime; the author had carefully scrutinized the available monitoring records, collected from various governmental organization and his own field investigations during last three years time. Accordingly, the pre-monsoon Reduced Water Level maps for the years 1975-85-95-99 have been constructed and evaluated (Fig. 4.11 and 4.12).

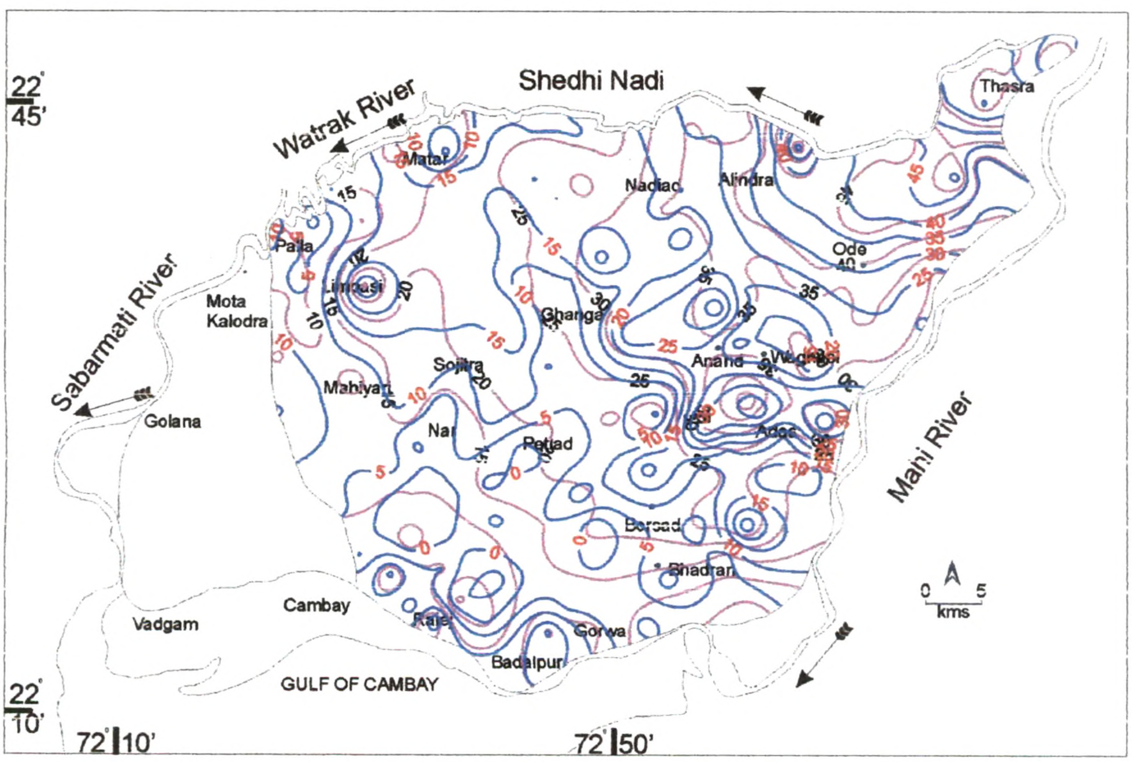


Fig. 4.11 Reduced Water Level Contour Plan of MRBC Area. (Year: 1975-1985)

In contrast to pre canal irrigation scenario (1958), where the water level have been observed within the depth range of 44.00 - 4.00 m. The reduced water level for the year 1975 shows considerable change. In groundwater mounds, which generally influence the local variation in groundwater flow are ubiquitously seen developed in the area around Dhundi, Sansiya and Hadmatiya in the middle command and Akholnani in the lower command (southwestern).

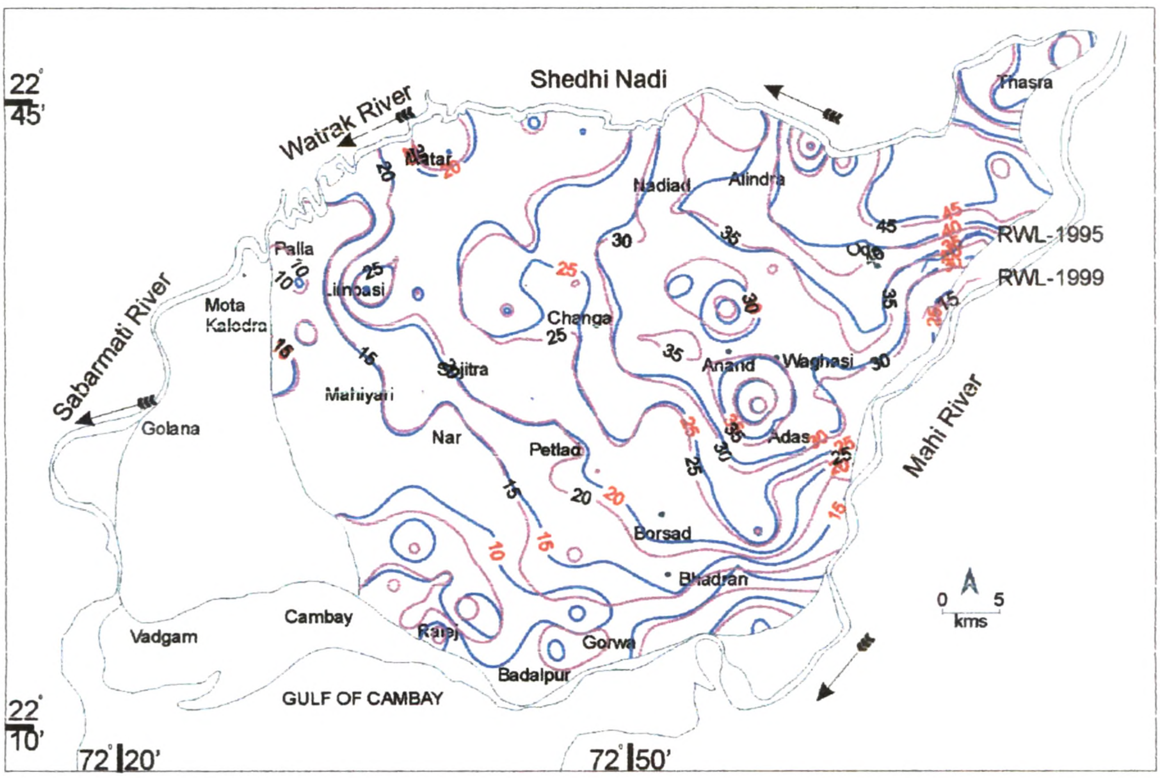
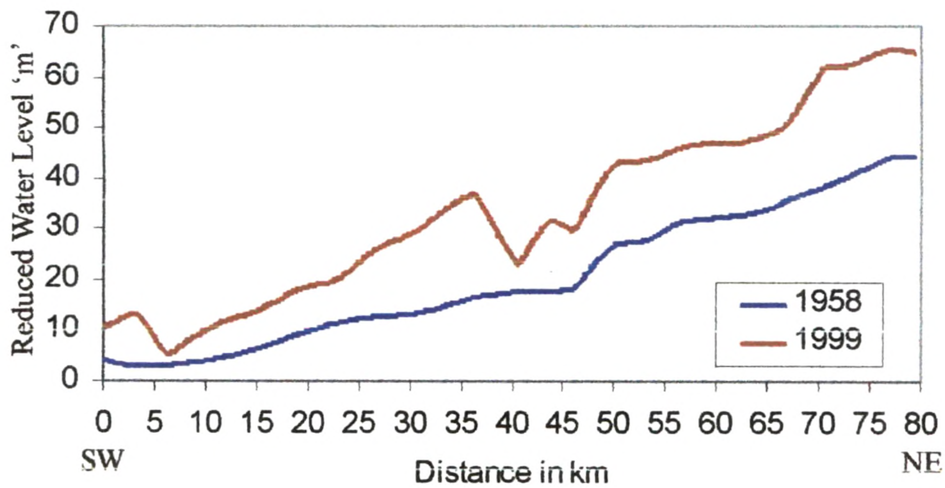


Fig. 4.12 Reduced Water Level Contour Plan of MRBC Area. (Year: 1995-1999)

From the subsequent RWL maps for the years 1985, 1995 and 1999 it is clearly seen that there is not much change in the direction of groundwater flow, however there is considerable change in the gradient of groundwater flow. The area beyond the Ajarpura-Ode line i.e. upper command limits has undergone considerable change in water table depth. The contours beyond this line have become more wider as traced westward and entire command area has RWL within the range of 35-15 m which is higher as compared to that in the year 1975. In order to assess the temporal behaviour of water level rise, the author had prepared the hydrographic profiles (Fig. 4.13 a & b) along SW-NE transact of MRBC. The profiles show significant change in groundwater storage since 1958. On comparing the 1958 water level data with 1999, it could be seen that there is an overall rise in the water level there by storage. The maximum rise has been seen in the upper command and the minimum in the lower command area i.e. 25 and 7 m respectively. Taking in to account the net change observed in groundwater level for the last 40 years; the average annual rate of water level rise stands at 33.24 cm/year. However, the anomalous all time low water level especially in the lower command area, as recorded in the year 1975 is on account of non-creation of irrigation potential in the lower command. The same has been developed after 1976. To study the impact of irrigation on sub-soil and groundwater regimes within the command area, Depth to Water Table i.e. SWL is considered to be an important parameter. Looking to the fact author has prepared depth to water table contour maps for the years 1985-95-99 pre-monsoon periods (Fig. 4.14 - 4.16) and evaluated the behavioral pattern of water table for the last 15 years.



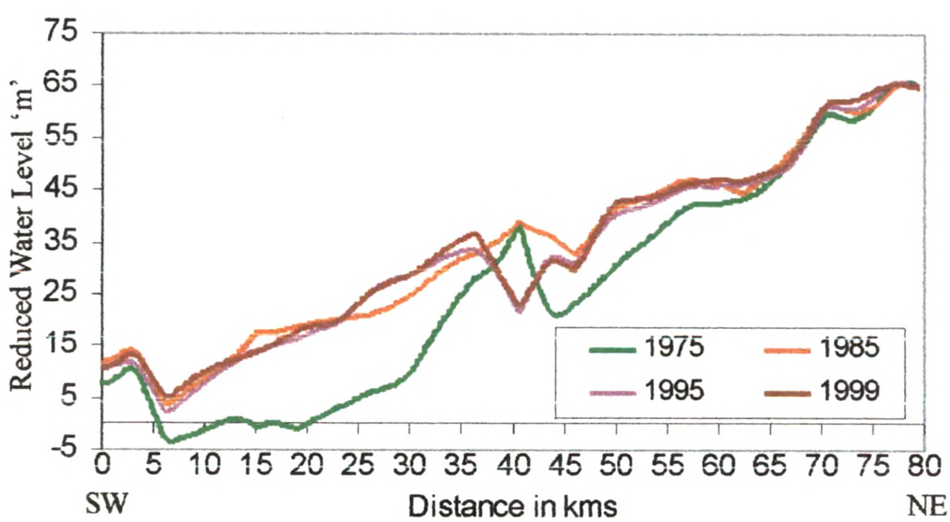


Fig. 4.13 Hydrographic Profiles of MRBC Area (a) 1975-99 and (b) 1975-85-95-99

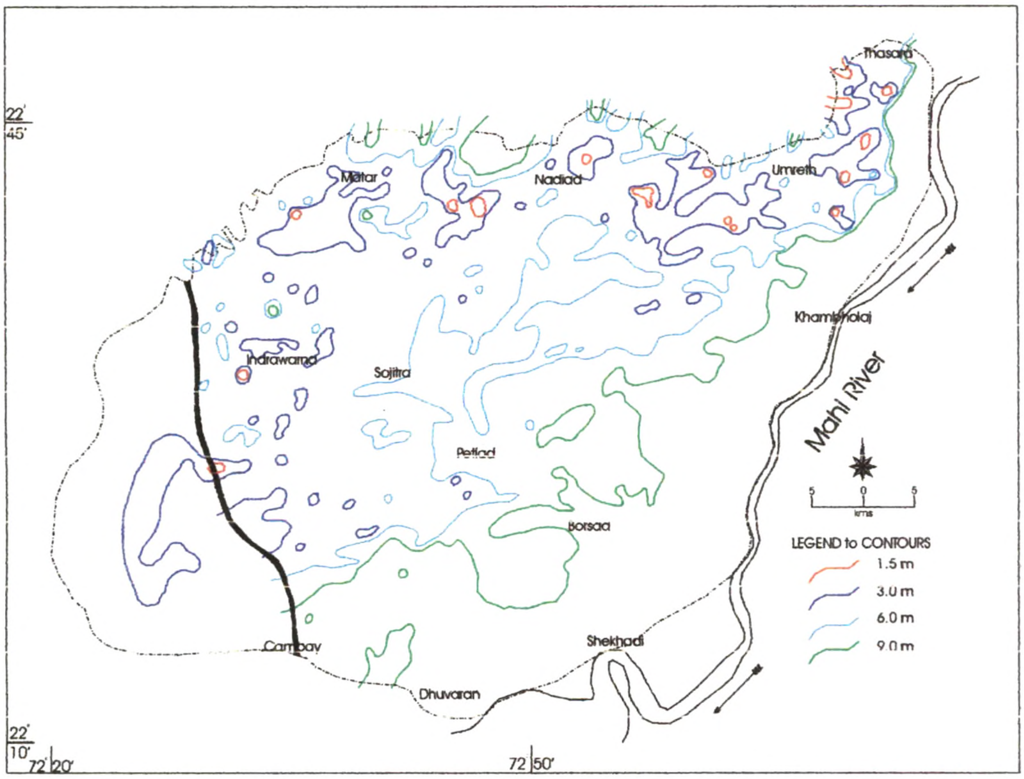


Fig. 4.14 Hydro Iso-bath Contour Plan of MRBC Area. (Year: 1985)

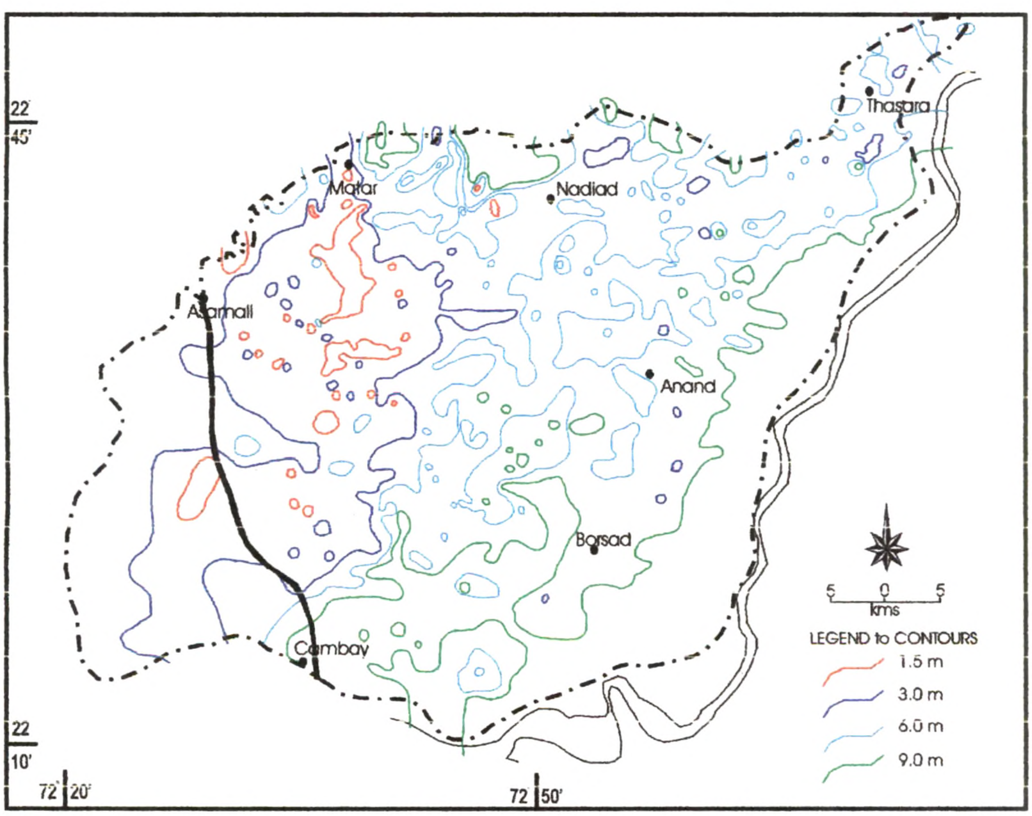


Fig. 4.15 Hydro Iso-bath Contour Plan of MRBC Area. (Year: 1995)

On comparing the SWL contours plan of the year 1985 with that of 1995 and 1999, it is clearly discernible that in the southern parts of the command area i.e. along Mahi River; the depth to water table which was more than 9 m had progressively and considerably reduced southward i.e. between Thasra-Cambay.

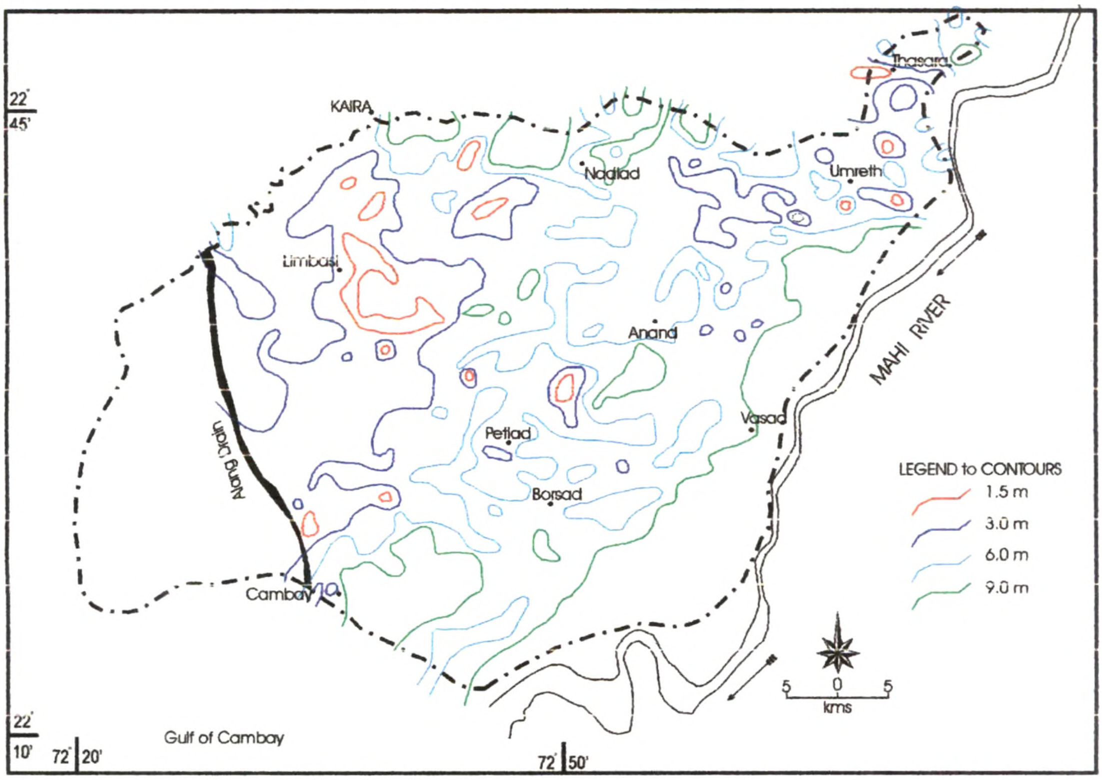


Fig. 4.16 Hydro Iso-bath Contour Plan of MRBC Area. (Year: 1999)

Contrary to this, in the northern parts of the command area, the rise in the water level on Nadiad-Sojitra-Cambay transact has witnessed significant and progressive shift. Here the area falling within the limits of 6.00 m water table depth had considerably shrunk northward. Also, the contours delimiting the area having SWL depths of 3.00 m and 1.50 m i.e. Matar-Limbasi-Mahiyari transact had turned from sporadic and localized pattern to a continuous with large aerial coverage.

SECULAR CHANGES IN GROUNDWATER REGIME

MRBC area has a close network of observation wells for monitoring the behavioral pattern of water table. For the evaluation of temporal and secular changes in groundwater storage hydrographs have their proven credentials. For this, the author has prepared water level hydrographs by selecting an exemplary and representative observation wells, distributed in the entire command. It can be observed (Figure 4.17) that irrespective of area locations, the observation wells displays sharp and significant rise. The rise is particularly more in the middle parts of the command area. The hydrographs had recorded an overall decline during the period 1988-91; which may be attributed to below average rainfall, delimiting the groundwater recharge.

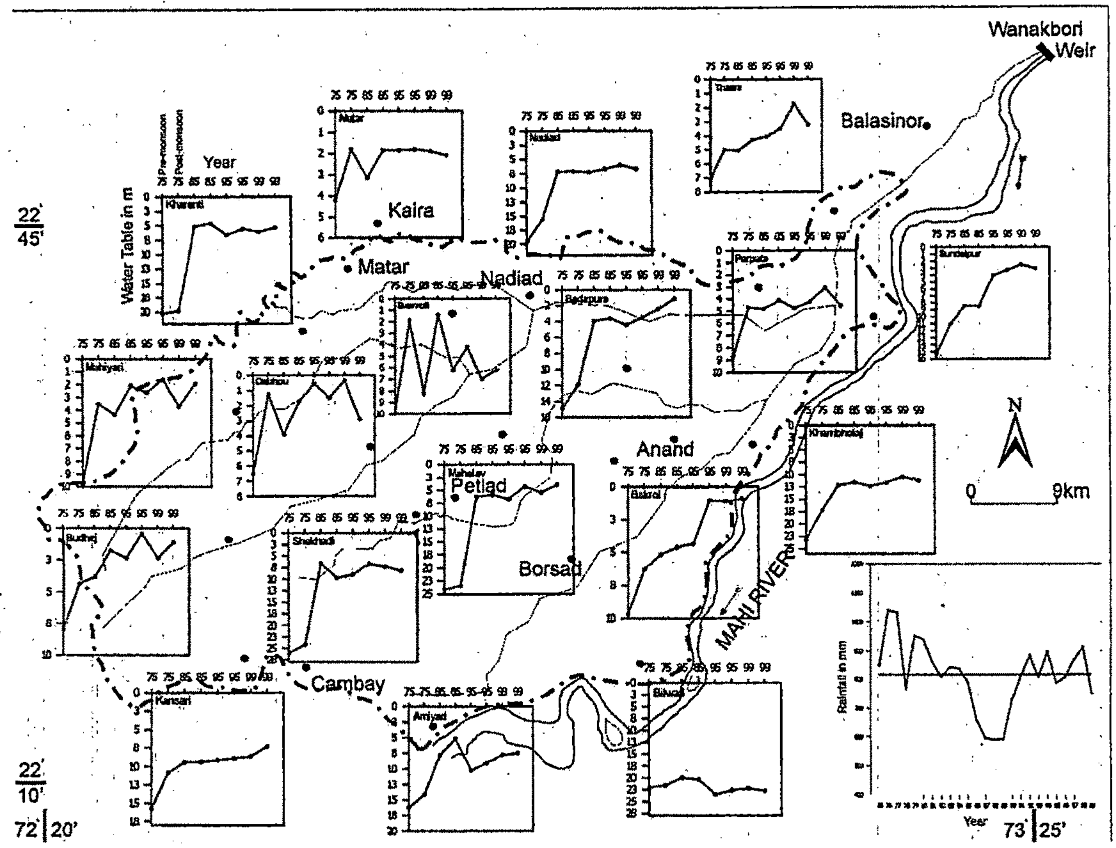


Fig. 4.17 Secular Variation in Water Table Situation in the MRBC Area (Year: 1975-1999)

Also, the past data suggests that the water table has attained its maximum rise during 1971 and 1998. During this years, the area had received maximum rainfall thereby, increased recharge to the groundwater. However, the hydrographs of the observation wells, located on the periphery of command had witnessed an overall rise during 1988-91. This may be attributed to the recharge from returned irrigation seepage to the groundwater regime and sub-surface dynamic flow of the groundwater from the higher central part of the command to the lower peripheral part of the command. Taking in to account the pre canal irrigation water table scenario and its subsequent response to the incipient recharge from returned irrigation seepage i.e. the post canal irrigation (1975-99); the author has made the quantitative estimate for the variable range of the rise and fall in water level and its aerial coverage. This has been attempted with a view to categorise the command area viz. (i) Area already attained the critical level i.e. 1.5 m, a waterlogging condition; (ii) Area may attain critical level in near future i.e. 1.5-3.0 m and so on, (iii) 3.0 to 5.0 m impact of water table rise (iv) > 5.0 m deeper water table and its impact on soil and water quality.

Accordingly in all four categories have been worked out on pre- and Post-monsoon water table scenarios (Table 4.4).

Table 4.4 Secular Changes in Groundwater Regime in MRBC Area.

YEAR OF OBSERVATION	Ground Water Table Depth (m) — Depth Range & Aerial Coverage (ha & %)							
	0 to 1.5		1.5 to 3.0		3.0 to 5.0		More than 5.0	
	Ha.	%	Ha.	%	Ha.	%	Ha.	%
	Pre-monsoon							
1975	0	0.0	1109	0.4	11850	4.0	280901	95.6
1985	1720	0.6	9200	6.5	131440	44.7	141500	48.2
1995	5358	1.7	55138	17.5	95664	30.3	159630	50.5
1999	4859	1.5	87054	27.5	102697	32.6	121180	38.4
	Post-monsoon							
1975	5493	1.9	20285	6.9	43364	14.8	224718	76.4
1985	8910	3.0	53770	18.3	77858	26.5	153325	52.2
1995	20477	6.5	86994	27.6	88874	28.1	119445	37.8
1999	13768	4.0	78249	25.0	114913	37.0	108860	34.0

* Pre Canal Irrigation Scenario

It is interesting to observe that during pre-monsoon season almost entire command area (99.2%) was having the water table below 5 m depth prior to canal irrigation made operational i.e. 1958. Subsequently, in the span of 40 years more than 50 % of the command area (1,21,180 ha) had witnessed rise in water table and had moved to the upper categories of less than 5.0 m depth. Till 1999 almost 4860 ha area had rendered waterlogged and 87,054 ha command area prone to become waterlogged. The plotted histogram (Fig. 4.18) gives the details on the progressive rise in the water table and the affected command area.

In order to assess complete picture on water table rise and fall and area specific changes in the groundwater regime; the author has taken in to account the pre-monsoon water level contour maps of 1958 and 1999. Net change in groundwater regime has been worked out by overlaying 1999-1958 contour maps. The obtained map reflecting relative rise and fall in water level for the last 40 years of time span (Fig. 4.19) has brought out the following inferences:

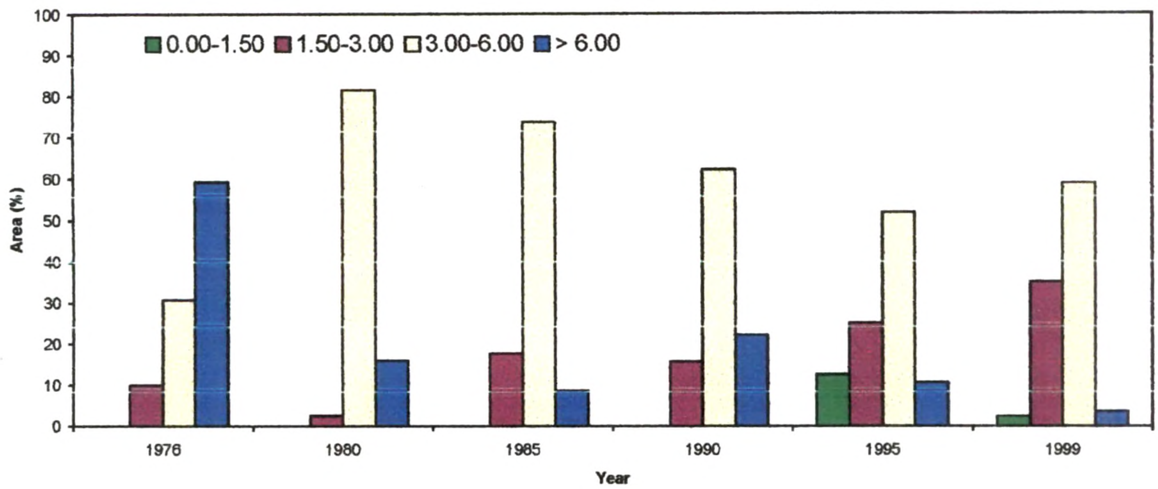


Fig. 4.18 Secular Changes in Groundwater Regime in MRBC Area

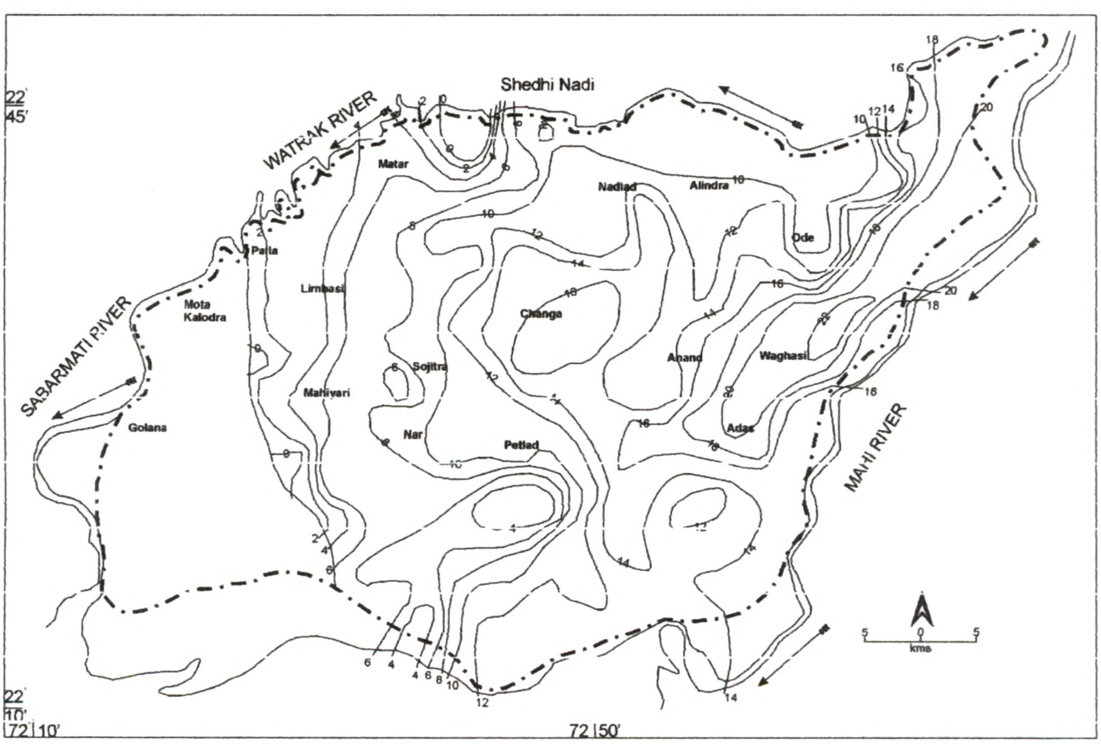


Fig. 4.19 Net Change in Groundwater Storage in MRBC Area (Year:1958-99)

(i) The entire MRBC area displays an overall rise in the groundwater level, except the northwestern and western periphery, recording neither rise nor fall i.e. northeast of Matar and west of Mahiyari respectively.

(ii) These localities where the water levels remained stationary may be attributed to sub-surface outflow to the river Shedhi and manual drain provided to collect returned irrigation seepage.

(iii) As far as rise in water level is concerned; the southeastern parts of the command area around Waghasi had recorded the maximum rise of 22 m followed by Borsad 12 m, both adjacent to Mahi River; in the Central parts of the command area around Changa had recorded 16 m rise; lower command around Sojitra and Petlad the rise in water levels is 6 m and 4 m respectively.

(iv) The general trend in water level rise tends to decrease westerly. This may be attributed to an abrupt truncation of the aquifers and their outflow in the Shedhi/Sabarmati rivers, showing affluent characters.

HYDRAULIC CHARACTERISTICS

Aquifers' response to the groundwater recharge is dominantly governed by its hydraulic characteristics. In order to evaluate these aspects, the author has collected the available data from the MRBC project authority. Comprehensive information on these aspects is given in Table 4.5. The hydraulic characteristics as given in Table 4.5 are in conformation with the sub-surface hydrogeology as discussed earlier. The aquifers are occurring at various depths and are of variable thickness with lack of considerable aerial continuity of their particle size (0.12-2.20) and sorting coefficient (1.20-1.80). This is indicative of aquifers moderate potentiality. Only those aquifers associated with the palaeochannels of Mahi and Vatrak rivers are of higher yield.

Similarly, the groundwater gradient and its movement direction, which is essentially governed by the factors like isotropic nature of the aquifer material, its lateral continuity and the physiographic attributes, mainly slope and its direction. The groundwater gradient and its overall azimuth have been studied with the help of prepared RWL contour plans for different years (Table 4.6).

Table 4.5 Hydraulic Characteristics of Aquifers in MRBC Area

Village	Taluka	Aquifer Depth m	Thickness m	DD M	Discharge LPM	T m^2/day	K m/day	Specific Capacity l/sec
Jasapura	Thasra	40-83	26-62	2.15	2412	2895	131.70	18.70
Kotliindra				4.70	1418	954	53.24	5.00
Manjipura				3.12	3296	4182	199.62	17.60
Marghakui				3.00	2274	2375	158.79	12.63
Vadoda	Anand	52-192	13-48	2.90	3500	7086	135.27	21.50
Valasana				3.30	3032	2760	94.35	15.31
Boriavi				9.14	3170	944	20.78	5.70
Sundalpur				3.26	3218	4024	98.5	16.40
Pandoli	Petlad	97-166	28-70	3.40	3036	2185	42.07	14.80
Ashi				1.82	3500	4801	108.30	32.00
Malataj				3.80	3400	1658	41.74	14.90
Piplav				9.05	2350	655	23.44	4.30
Nadiad	Nadiad	134-152	21-60	5.03	2889	1946	56.67	9.50
Piplag				8.50	2989	961	21.64	5.80
Fatepura				8.89	2071	342	11.00	3.80
Piplata				3.55	2652	1993	41.35	12.40
Sokhda	Matar	152-155	18-40	8.50	2250	950	51.56	4.40
Matar				8.13	2744	1160	29.71	5.60
Alindra				9.14	3020	885	17.73	5.50
Ratanpur				3.50	1136	874	21.77	5.40
Bamangam	Borsad	96-167	26-62	3.75	3032	2016	61.86	13.40
Borsad				3.10	2651	2069	43.11	14.20
Barejada				3.75	3896	3297	63.90	17.30
Asodar				2.38	3500	4365	83.08	24.50
Sakkarpura	Cambay	110-154	21-60	3.40	2651	2362	108.44	12.90
Khadodhi				3.90	2274	1497	53.62	9.70
Kalamsar				2.90	2274	1660	28.64	13.00
Kanzat				2.40	3032	3370	124.31	21.00

(Source: GWRDC)

Table 4.6 Variations in Hydraulic Gradient in MRBC Area

Year	Upper Command	Middle Command	Lower Command
	Gradient (Direction)	Gradient (Direction)	Gradient (Direction)
1958	1:555 S	1:2238 SSW	1:1750 SSW
1975	1:622 SSW	1:1066 SW	1:966 SW
1985	1:866 SW	1:1333 SW	1:1066 SW
1995	1:866 SW	1:1555 SW	1:1133 SW
1999	1:866 SW	1:2066 SW	1:1200 SW

The author's observation on groundwater gradient and its direction further substantiated the prevailing view of tectonic controlled sedimentation of Cambay Basin. Although one can see that there is not much change in an overall groundwater movement direction, which had remained same i.e. southwesterly since 1958. However, there is progressive flattening in the gradient in upper, middle and lower command area from 1958 to 1999. Similarly, the gradient tends to decrease in middle parts of the command but attains steepness in the lower command, a kink pattern i.e. steep-gentle-steep. Such gradient configuration may be attributed to the factors irrelevant to sedimentation pattern, depositional environment and its neo-tectonism.

GROUNDWATER CHEMISTRY

The ground water is characterised by the higher concentration of the dissolved constituents than the surface water. This is attributed to greater interaction of groundwater with various materials in the sub-stratum. Therefore, the quality of groundwater is by an large governed by the factors like nature of sub-surface stratum, landuse pattern and physico-chemical environment. For a successful evaluation, development and utilization of water resources, permissible limits of the chemical constituents are essential pre-requisite.

Soil Survey Organization of State Government has been carrying out the extensive seasonal monitoring of groundwater quality through the network of observation wells having the Electrical Conductivity greater than 2000 mmohs/cm. The author has collected the available data for evaluation of the groundwater quality of the MRBC area. As such data on groundwater chemistry are available from pre-canal irrigation period (1958) to 1999, for both pre- and post- monsoon periods. In order to assess the impact of canal irrigation; the author had carefully scrutinized the data for 90 location; for the pre-monsoon periods of 1958, 1975 and 1999. The detail information on the chemistry for these years is as Table 4.7. However, in order to observe the seasonal changes in overall quality of groundwater, the author had referred the post-monsoon data also. Broad inferences drawn for the entire MRBC area are appropriately discussed.

PHYSICAL VARIATION

1. HYDROGEN ION CONCENTRATION (pH)

Prior to canal irrigation the groundwater is mostly alkaline in nature with pH ranging between 8.5 to 10.00. The nature of the groundwater becoming alkaline as traced westward. It is inferred from the post canal irrigation scenario that there is considerable improvement in alkalinity of groundwater and the pH had gone down between 7.5 to 8.5. An overall change in the pH ranging between 7.5 to 8.1 (upper and middle command) and 8.2 to 8.0 (lower command) indicates significant improvement in the quality of the groundwater. This progression could be attributed to the continual flushing and/or dilution of the groundwater by the canal water, contributed to the groundwater regime as returned irrigation seepage having little amount of dissolved solids (USGS, 1959).

2. ELECTRICAL CONDUCTIVITY (EC)

Electrical conductivity is a measure of ionic concentration and ionic mobility of the mineral content in solution. The electrical conductivity in MRBC area shows wide variation. Prior to canal irrigation the observed electrical conductivity was ranging between 200 and 2350 mmohs/cm at 25^{O} C. After introducing the canal irrigation the EC values have significantly increased i.e. 400-22680 mmohs/cm at 25^{O} C. Secular changes in EC values from pre canal irrigation period (1958) to 1999 and the relative aerial coverage in MRBC command area is given in Table 4.8. It is quite evident from the pre-monsoon EC data, that prior to the inception of canal water (1958) more than 70 % (2,06,495 ha) of the command area was having EC values less than 1000 mmohs/cm, which had reduced to almost one fifth i.e. 14.% % (45,685 ha) in 1999. Similarly merely 2.25 % (6,612 ha) command area was under the influence of higher EC values i.e. greater than 3000 mmohs/cm, which in turnover the period of 40 years has increased to almost 25 % of (78,539 ha) of the total command area. The plotted histogram also depicts trends for

Table 4.7 Groundwater Chemistry in MRBC Area.

Village			Ionic Concentration (epm)							
	[Year : Pre-monsoon 1975]									
	EC mmohs/cm	pH	Na + K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	TDS	SAR
Akhdol	1915	8.2	17.18	0.75	2.47	1.20	10.39	8.80	0.00	1280	13.55
Aslali	12650	8.0	166.86	15.47	37.51	0.00	9.23	155.70	2.29	8730	32.42
Balinta	8200	8.0	89.17	3.49	2.22	0.00	13.37	97.03	2.29	5110	52.75
Bamangam	410	8.0	0.00	0.00	0.00	0.00	0.00	2.26	0.00	260	
Bhatpur	512	8.4	0.00	0.00	0.00	0.00	0.00	1.35	0.00	320	
Chikhodra	1026	8.0	10.05	1.75	4.20	0.00	10.39	5.64	0.00	460	5.83
Gudel	18460	8.0	164.12	20.96	51.33	0.00	5.41	229.04	2.29	12330	27.30
Isanpur	15040	8.0	150.37	5.74	34.80	0.00	5.90	183.91	1.87	9890	33.40
Kanisa	1538	8.2	0.00	0.00	0.00	0.00	0.00	9.03	0.00	980	
Navagambura	25300	7.6	0.00	0.00	0.00	0.00	0.00	282.06	0.00	18760	
Palla	2530	8.0	22.10	1.25	4.94	0.00	8.42	18.05	2.08	1640	12.57
Pandoli	1162	8.4	10.40	0.50	1.48	1.53	5.80	4.96	0.00	760	10.45
Radhvanaj	820	8.0	0.00	0.00	0.00	0.00	0.00	4.51	0.00	530	
Thasra	2120	8.0	22.62	1.25	5.18	0.00	16.65	12.41	0.00	1500	12.61
Vadgam	60610	7.8	467.38	19.96	145.61	0.00	5.60	605.87	2.29	48700	51.37
[Year : Pre-monsoon 1999]											
Akhdol	4293	8.4	20.70	1.30	25.00	4.00	5.50	37.00	0.50	2747.52	5.71
Aslali	2157	7.5	15.40	1.30	7.30	3.00	8.00	12.50	0.50	1380.48	7.43
Balinta	5184	7.3	41.90	2.30	11.80	2.00	6.00	47.00	1.00	3317.76	15.78
Bamangam	14560	8.7	138.40	0.80	6.80	8.00	49.00	84.00	5.00	9318.4	71.00
Bhatpur	2650	7.4	8.25	4.00	14.75	2.00	15.00	9.00	1.00	1696	2.69
Chikhodra	4240	8.1	20.00	3.75	18.75	2.00	3.50	36.50	0.50	2713.6	5.96
Gudel	25520	7.8	223.00	15.00	32.00	2.00	5.00	258.00	5.00	16332.8	46.00
Isanpur	30800	7.9	328.00	12.00	20.00	3.00	10.00	340.00	7.00	19712	82.00
Kanisa	2511	7.8	19.50	1.00	5.00	6.00	5.00	12.00	2.50	1607.04	11.26
Navagambura	14080	8.2	154.00	3.00	23.00	6.00	10.00	158.00	6.00	9011.2	42.71
Palla	5670	7.5	47.40	0.80	9.80	4.00	11.50	40.50	2.00	3628.8	20.59
Pandoli	2916	8.1	22.00	1.00	9.50	2.00	4.50	22.00	4.00	1866.24	9.60
Radhvanaj	4698	7.7	23.00	8.00	26.00	1.00	4.50	51.00	0.50	3006.72	5.58
Thasra	3380	7.8	20.00	6.25	5.25	2.00	8.00	20.00	1.50	2163.2	8.34
Vadgam	33440	7.5	300.00	20.00	80.00	3.00	10.00	377.00	10.00	21401.6	42.43

40 years of progressive changes in electrical conductivity in MRBC command and their aerial converge (Fig. 4.20).

This significant increase in EC values can be attributed to dissolution phenomenon of the available salts within the Quaternary sediments i.e. inherent salinity; within the canal water returned irrigation seepage to the groundwater regime; and its subsequent upward rise to the sub-soil regime.

Table 4.8 Secular Changes in Electrical Conductance of Groundwater in MRBC Area

Year Of Observation	Range of E. C. in micromohs/cm.							
	0 to 1000		1000 to 2000		2000 to 3000		> 3000	
	Ha.	%	Ha.	%	Ha.	%	Ha.	%
	Pre-monsoon							
Pre--58*	206495	70.3	75525	27.7	8228	2.8	6612	2.25
Pre-78	28504	9.7	185720	63.2	39083	13.3	40553	13.8
Pre-85	54908	18.7	133280	45.4	61124	20.8	44548	15.1
Pre-95	57007	18.0	123147	39.0	57325	18.2	78311	24.8
Pre-99	45685	14.5	122662	38.8	68904	21.8	78539	24.9
	Post Monsoon							
Post-85	50869	17.3	142237	48.4	72729	24.8	28025	9.5
Post-95	92335	29.2	86765	27.5	50830	16.1	85860	27.2
Post-99	54908	16.0	130451	43.0	53737	17.0	76694	24.0

* Pre Canal Irrigation Scenario

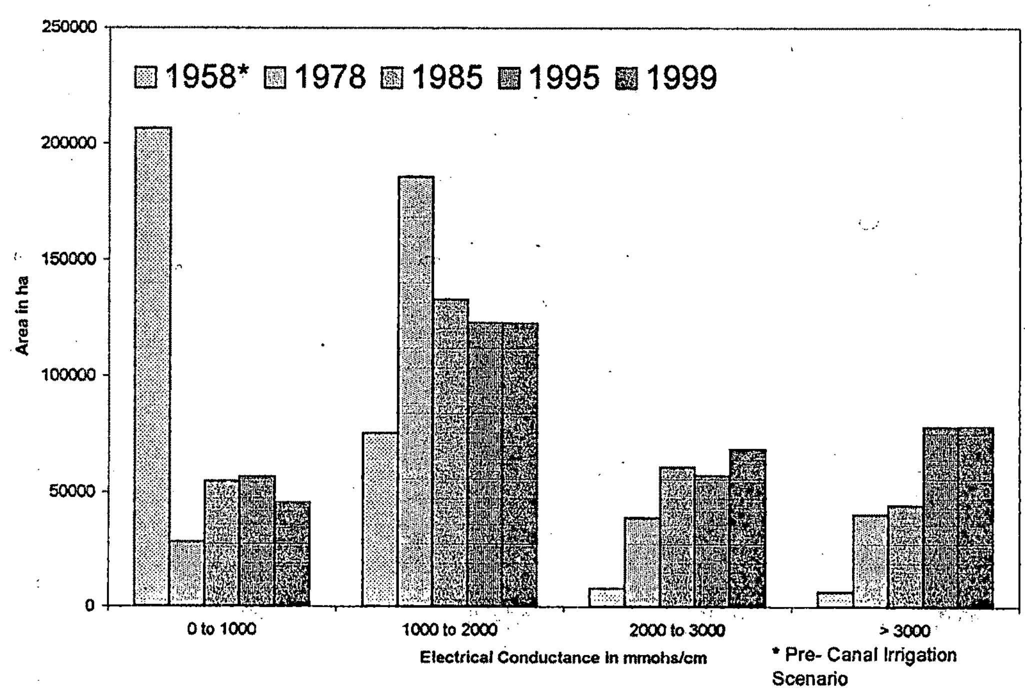


Fig. 4.20 Secular Changes in Groundwater Quality in MRBC Area

3. **TOTAL DISSOLVED SOLIDS (TDS)**

This parameter provides broad idea regarding enrichment of groundwater chemistry and thereby salinity hazards. In the MRBC area the groundwater chemistry had been monitored from 1975 on regular basis. Prior to this the data available are very scanty. Hence, after realizing these practical difficulties, the author has preferred to make a cursory remark on TDS scenario prior to the canal irrigation; further TDS content has been reviewed considering 1975 and 1999 (30 years) data.

As per the available information, the Total Dissolved Solids during pre canal irrigation period was within the range of 13 and 1500 mg/lt. indicating good quality to groundwater in entire command. Subsequently it has increased manifold. As the TDS has been considered to be the most vital parameter for evaluation of water and soil quality; the author has prepared Iso-TDS contour plans for the year 1975 and 1999. The contour trend pattern during pre-monsoon (1975) scenario (Fig. 4.21) depicts an overall TDS ranging between 500 and 2800 mg/lt.

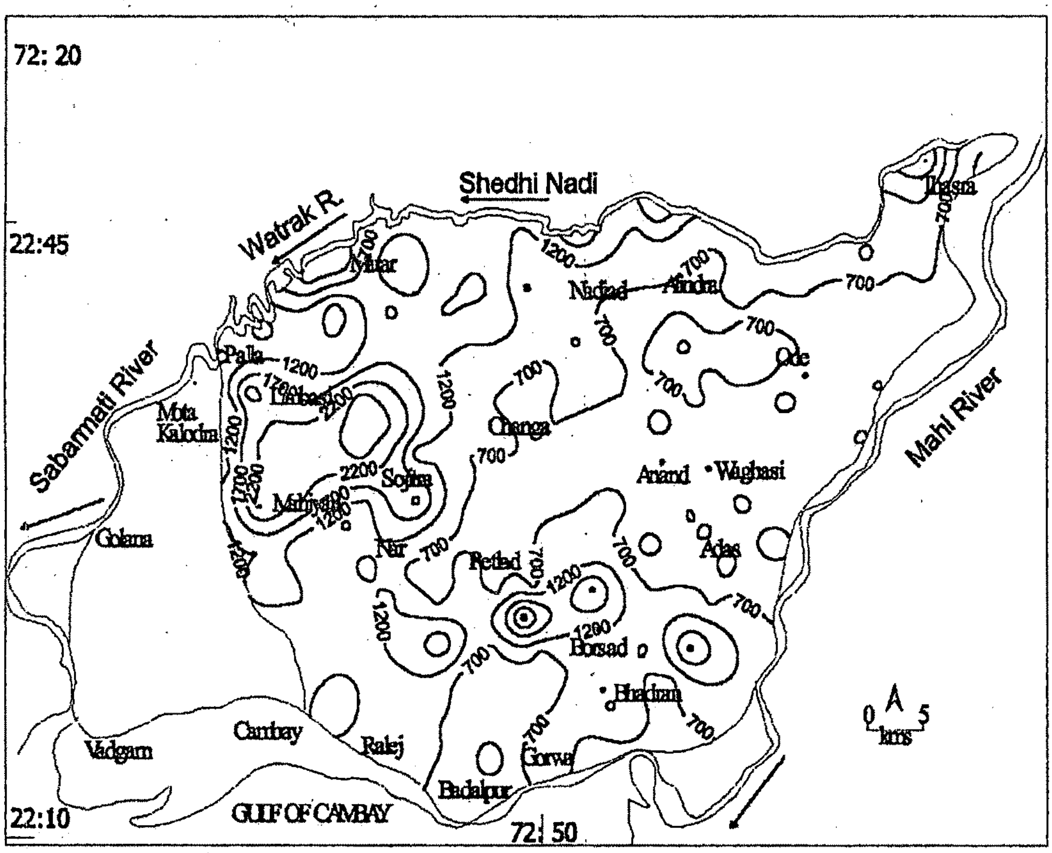


Fig. 4.21 Iso-TDS Contour Plan of MRBC Area. (Year: 1975)

In the lower command area around Limbasi-Sojitra and Matar it attains the highest values; while entire middle and the upper command area shows the TDS values within 800 mg/lt. limits. A Borsad and Bhadran town does shows maximas up to 2200 mg/lt. These values indicate fresh-Brackish nature of groundwater (Freeze and Cherry, 1979). Contour map (Fig. 4.22) for the year 1999 shows significant increase. This increase in TDS i.e. more than 7000 mg/lt. observed in northwestern parts i.e. the lower command area around Limbasi-Palla-Matar. Interestingly the upper command and parts of middle command does not show much change in TDS. This may be attributed to the groundwater flow under the available hydraulic gradient ultimately taking salts to the lower reaches, a zone serving the hydraulic boundary between fluviatile and marine sediments/aquifers (Islam, 1986).

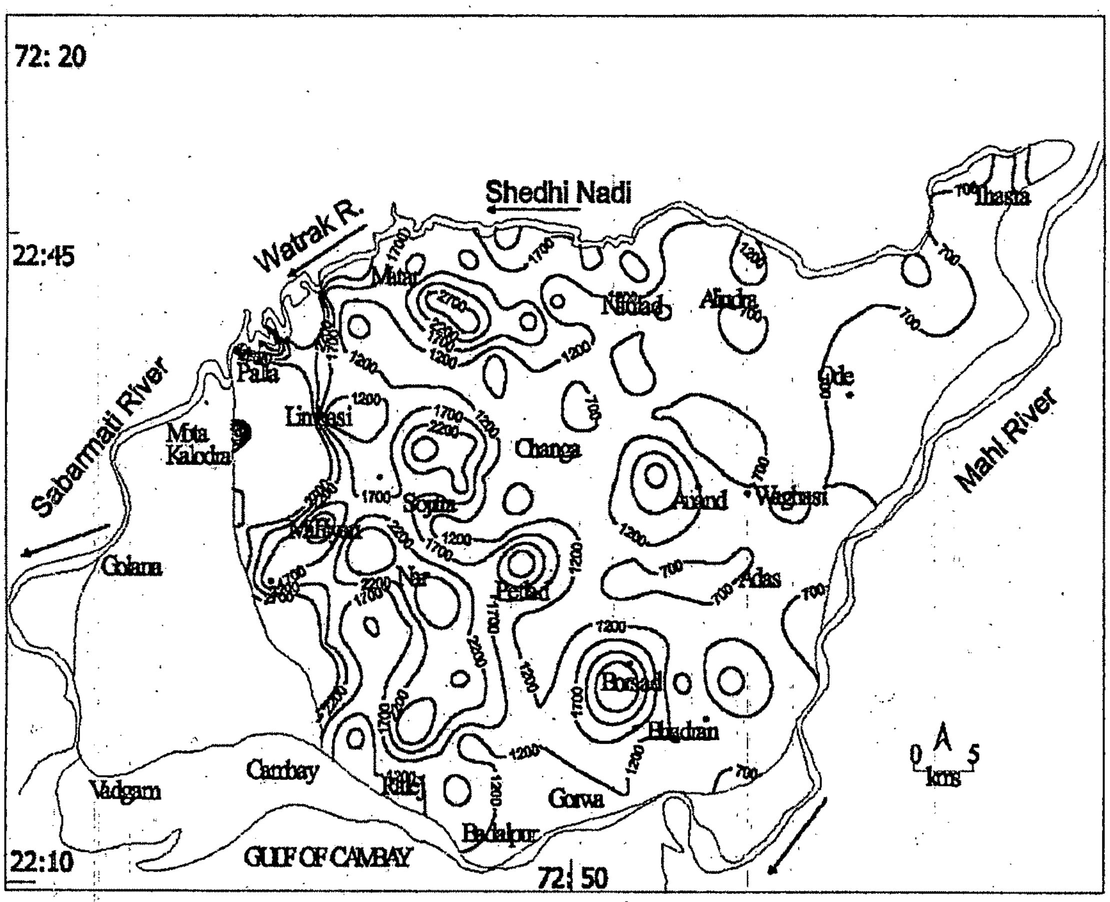


Fig. 4.22 Iso-TDS Contour Plan of MRBC Area. (Year: 1999)

IONIC VARIATION

1. Sodium And Potassium

These tow ions considered to be the most command and abundant in the groundwater. The groundwater quality data of MRBC area indicates that in most of the area these both ions dominate on the other cations. The study of 1975 data indicates that the concentration of these ions ranges between 230 mg/lt. and 3678 mg/lt. However, the highest concentration was observed i.e. 10767 mg/lt. at Vadgam, 10090 mg/lt. at Golana, the localities situated surrounding of raised tidal mudflats. On the other hand the analytical details of year 1999 records shows significant increase in Na+K concentration. Now the concentration of these ions are as high as 5080 at Indranaj. The localities, which are showing the higher concentration, are Piplag (1057 mg/lt.), Bamroli (896 mg/lt.), Punaj (2253 mg/lt.), Limbasi (2390 mg/lt.), Vastana (2620 mg/lt.). This increase in Na and K may be attributed to excessive use of potassic fertilizers and inherent sediment composition in case of sodium.

2. Calcium

The Calcium content in the command area does not show any regular pattern. In the year 1975 where in the area was having the Calcium concentration ranging between 10 mg/lt. and 300 mg/lt. Exceptionally high Calcium values 421 mg/lt. have been shown by the area around Vadgam and Golana. The data obtained for the year 1999 shows that there has been an overall increase in concentration of Calcium ion. Now the Calcium concentration varies between 10 mg/lt. to 490 mg/lt. and the lower command area shows the maximum values as well as the changes. This relative increase in Calcium content may be attributed to the rising trend in groundwater level; resulting in to the concentration of salts in the sub-soil horizon through upward salt migration.

3. Magnesium

The concentration of Magnesium in the MRBC area shows anomalous changes from 0-1672 mg/lt. (1975) to 6-747 mg/lt. (1999). This overall depleting trend in Magnesium content may be attributed to inherent characteristics of Magnesium ions; once it enters in solution state it remains in similar state for a prolonged duration (Matthess, 1988). Ultimately, the rise in water in canal command area and its continual sub-surface out flow in the adjoining basin/sea, could be possible reason for its depletion.

4. Chloride

The concentration of Chloride in the command area the most dominating amongst other anions. The chloride content is found to increase with time in the command area. The concentration of chloride as observed during the year 1975 is ranging between 46 and 5494 mg/lt. and found to increase as traced westward. The exceptionally higher values have been recorded as 21,477 mg/lt. at Vadgam, 20,134 mg/lt. at Golana and 8153 mg/lt. at Gudal in the lower command area. After 25 years it has significantly increased. The 1999 data shows the chloride content ranges between 2835 to 10810 mg/lt. The higher concentration has been recorded viz. 7444 mg/lt. at Bhat Talavad; 6664 mg/lt. Kharenti; 3792 mg/lt. at Laxmipura; 3722 mg/lt. at Punaj and Limbasi; 3580 mg/lt. at Vaso; 2570 mg/lt. at Mahelaj. This exceptional rise in Chloride content is attributed to rise in water level because of over irrigation and returned irrigation seepage; responsible in salt concentrations at shallow depth as well as the inherent sediment salinity.

5. Bicarbonates

In MRBC area the bicarbonates are second dominating anions after the chloride. The bicarbonate concentration is been as high as 1037 mg/lt. during 1975 to 50-2989 during 1999. Bicarbonate content in the groundwater found to vary in the command. However, the data for 1975 indicates overall higher values prevailed in upper and middle command areas. Later on the scenario has changed in 1999 where in higher concentration recorded 884 mg/lt. at Matar, 1037 mg/lt. at Trambovad, 1098 mg/lt. at Asamli, 976 mg/lt. at Timba, 1006 mg/lt. at Deval all are located in the lower command area.

6. Carbonates

Most of the groundwater in the command area is devoid of the carbonate concentration except few localities around Nadiad and Petlad. However, the present-day scenario has changed and its range has broaden to 30-510 mg/lt. Majority of the wells area showing the concentration of 30 mg/lt., except few locations where concentration recorded to be higher viz., Finav (240 mg/lt., Jalla (300 mg/lt.), Piplag (330 mg/lt.), Barejada and Hariyana (360 mg/lt.), Timba (420 mg/lt.) and Kalamsar (510 mg/lt.). These unexceptionally higher values of carbonate are attributed to the release of the carbon dioxide under the higher water table condition (Hem, 1970; Matthess, 1988).

7. Sulfates

The groundwater in the MRBC area is mostly lacking the sulfates concentration except localities around Cambay and Matar during the year 1975. But with the time concentration of Sulfates found to rise and fall within the range between 0 to 576 mg/lt. at Indranaj. The anamolous values of the sulfate concentration shown are 480 mg/lt. at Ambliyara, 576 mg/lt. at Laxmipura and Indranaj, 360 mg/lt. at Hadev, 312 mg/lt. at Asamli, 432 mg/lt. at Kharenti, 408 mg/lt. at Punaj and 336 mg/lt. at Bamroli. These higher values are on account of higher order of organic activity, bacterial dissociation of organic material in waterlogged area, creating eucscenic environmental condition (USGS, 1968).

GROUNDWATER QUALITY ASSESSMENT

Quality of groundwater is as important as the quantity. In the MRBC area, over the period of 25 years i.e. 1975-99, the quality of groundwater had considerable changed. In order to obtain quality scenario on temporal and specific basis; the author has attempted to evaluate the quality data using standard methods applied for drinking and irrigation water quality assessment.

A. Drinking Water Quality Assessment

Although various methods are in vogue to evaluate the drinking water quality the author has adopted the Piper Tri-linear diagram approach for evaluating the quality of groundwater (Piper 1944).

In order to obtained fairly detail assessment the chemical data have been evaluated by taking the basis of 1975 for the entire command area. the chemical content for 1999 has been grouped under three categories viz. Upper, Middle and Lower Command. Accordingly, the data for 1975 and 1999 have been plotted to get clear picture on the changes in groundwater quality. Broad inferences based on chemical plots on Piper Tri-linear diagrams are discussed as under:

(i) Piper Tri-linear diagram for the entire command area (1975 shown in the Fig. 4.23 . From the figure it is inferred that majority of the wells are falling in the field 9 and those in the lower command area falls within the field 7 i.e. primary salinity. Within the span of 40 year the scenario of the quality has changed drastically as shown in Fig. 4.24. Here the majority of wells having the quality with Na-K and Cl-CO_3-HCO_3, dominating in the middle and upper command, while those in the lower command are Na-K-Cl dominating.

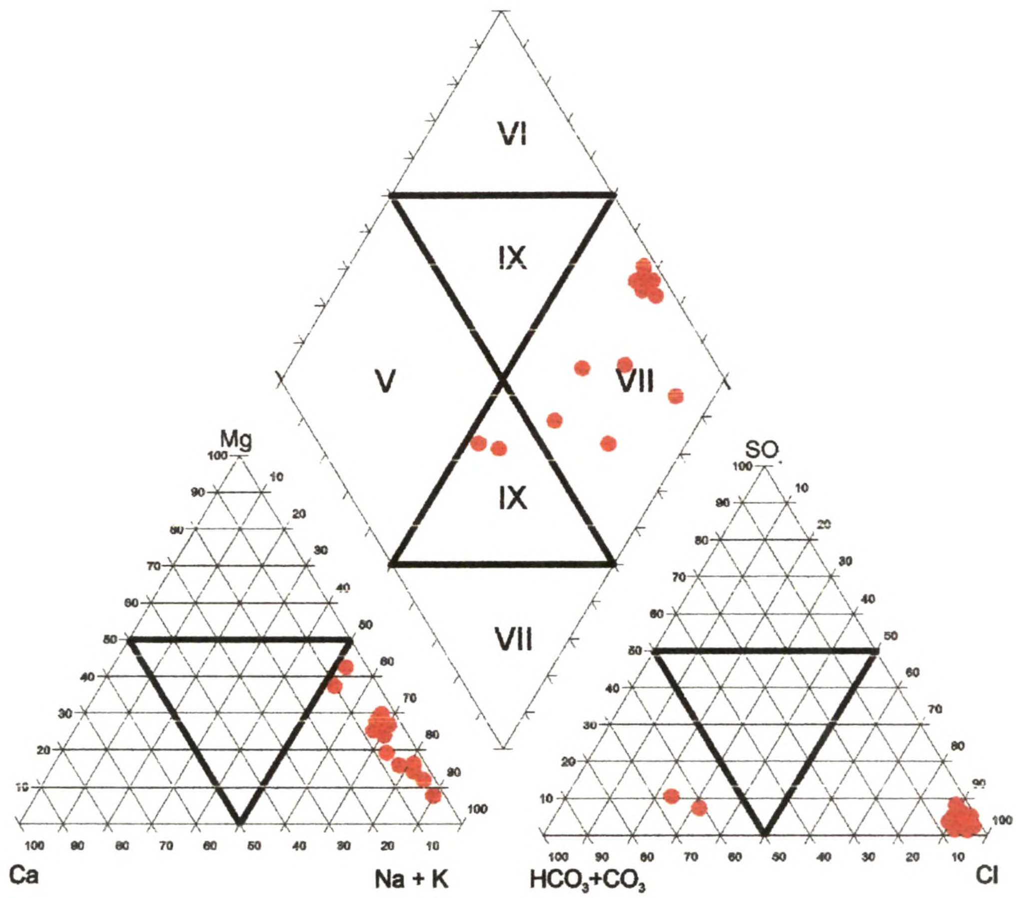


Fig. 4.23 Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose.

(i) ***Upper Command Area:*** The groundwater quality in this part doesn't show much change. Here, majority of the plots (Fig. 4.24 a) are falling in field 9, which belongs to potable water except few plots viz. Utkhandi, Navagam, Fatepura and

Gamdi, in 1999 falls under the field 6, characterised by secondary salinity. This very little change in groundwater quality may be attributed to fairly higher hydraulic gradient, responsible for sub-surface drainage of groundwater to the lower reaches.

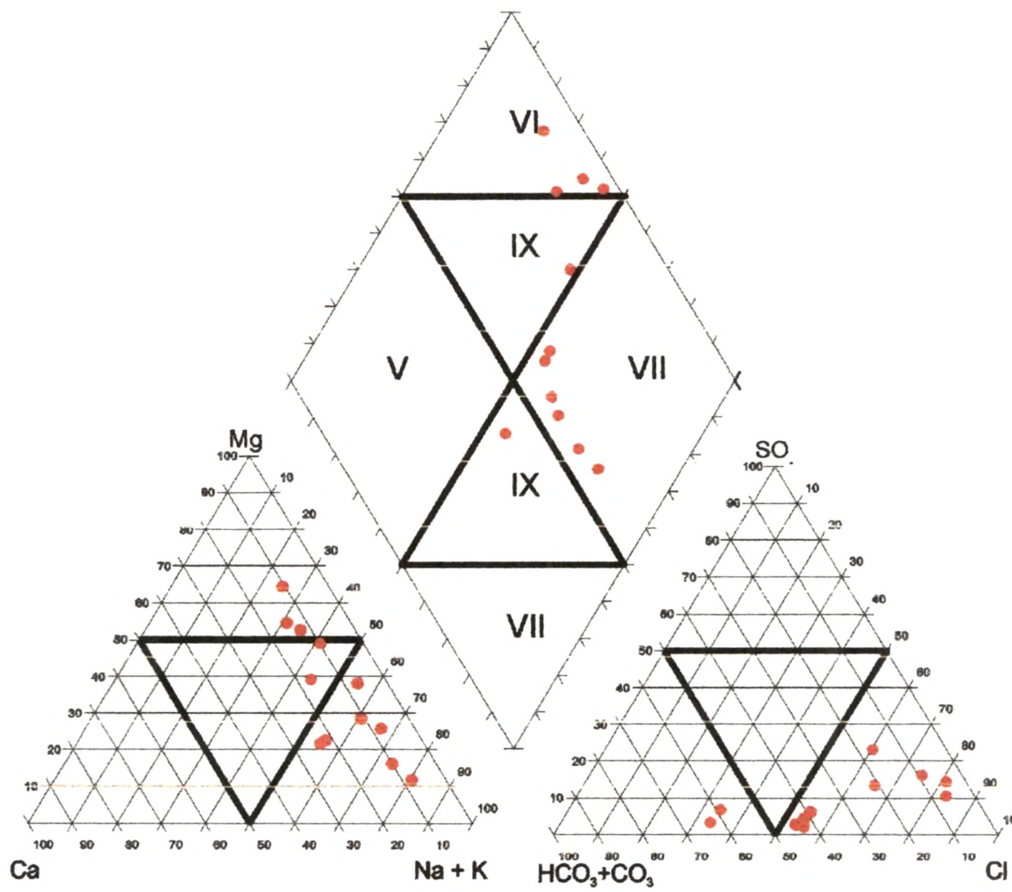


Fig. 4.24 a Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose.

(ii) ***Middle Command Area:*** Middle command area having the majority of the wells located in the central and northern part are falling in the field 9 and those in the southern part i.e. near Borsad, Petlad, Bhadran are falling in the field 7 (primary salinity). There are also wells around Alindra (Nadiad), Petli, Sandhana, Dabhou are showing the development of secondary salinity (Fig. 4.24 b). The presence of primary salinity is attributed to the inherent sediment salinity, probably deposited under the fluvio-marine conditions.

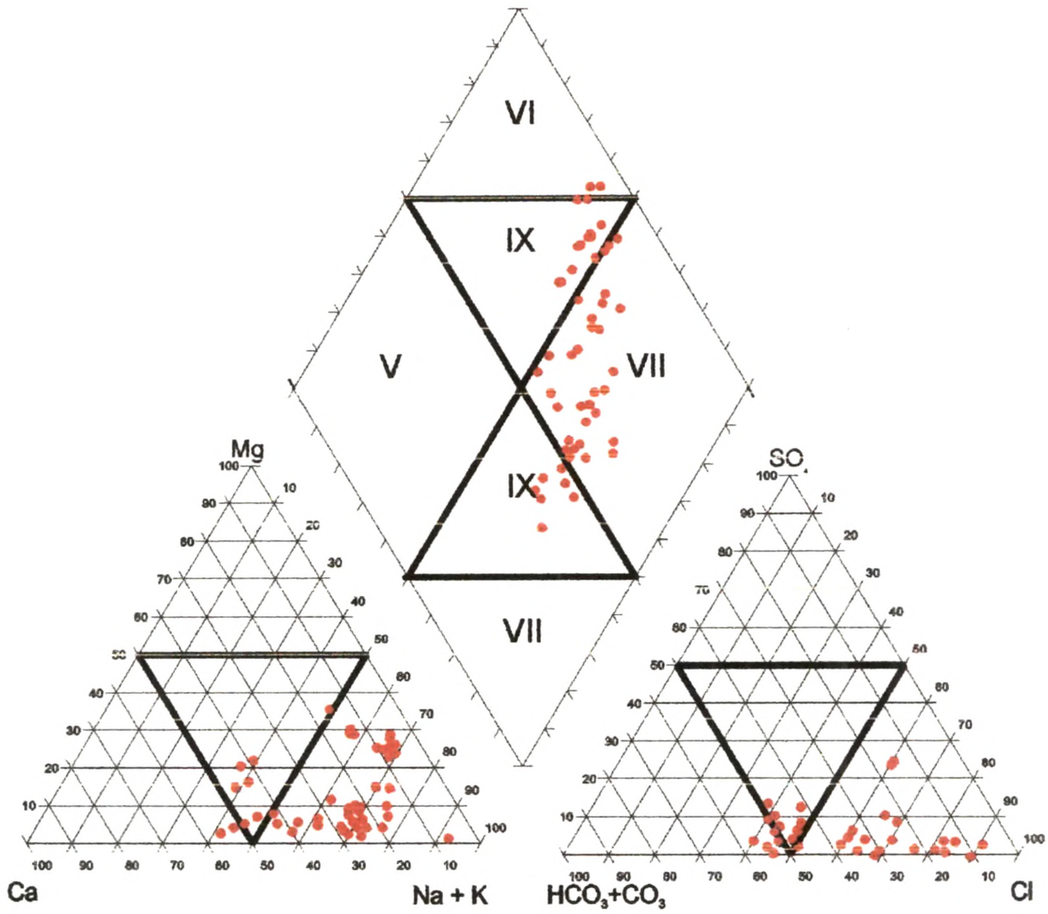


Fig. 4.24 b Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose.

(iii) ***Lower Command Area:*** The wells in the lower command area are falling in the field 7. Some of the wells around Madhavpur, Vastana, and Hadeva are falling under the field 6 of secondary salinity and those around the Hariyana are showing the development of secondary alkalinity (Fig. 4.24 c). Higher secondary alkalinity observed in the groundwater may be attributed to the predominance of bicarbonate and the sodium. This is obvious as (a) the lower area owing to receiving recharge from the upper reaches, thereby concentration of salts (b) prevailing waterlogged conditions, (c) evaporative losses, and (d) inherent sediment salinity under marine environment.

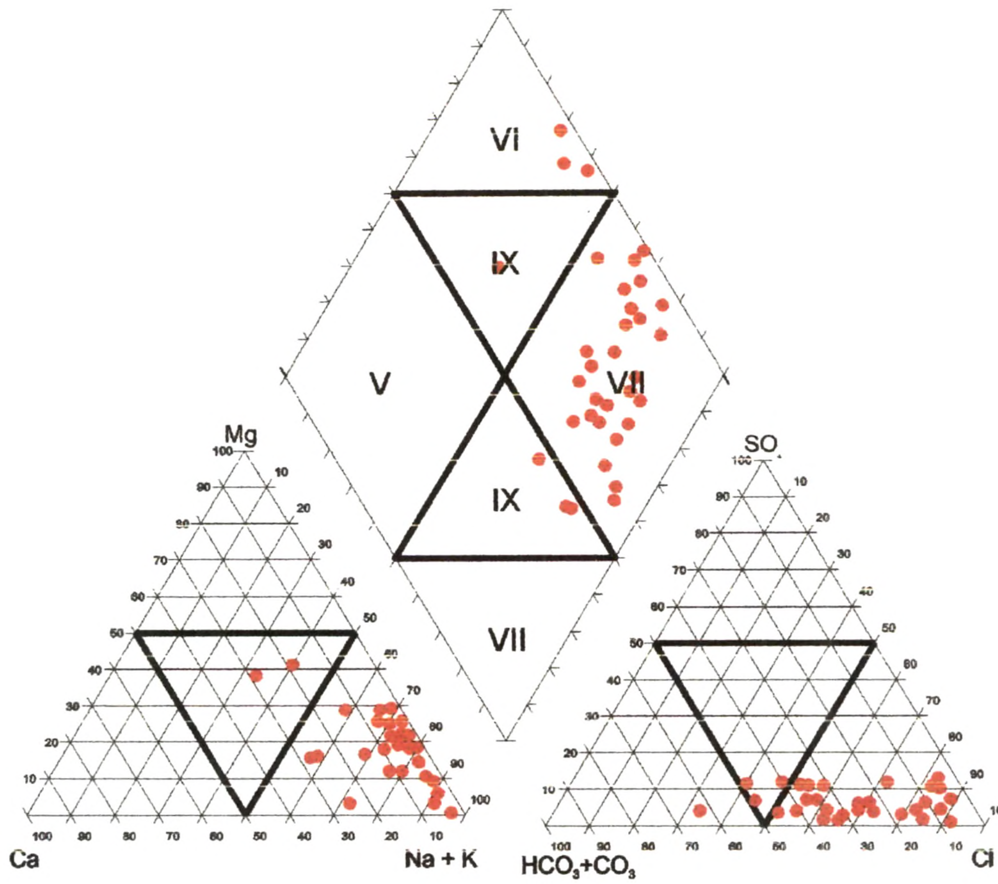


Fig. 4.24 c Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose

B. Irrigation Water Quality Assessment

Groundwater used in irrigation, its chemical quality is considered to be an important factors so far its usefulness is concern. Certain important factor related to the chemical compositions of groundwater are viz. (i) Total constituents of dissolved constituents in supply, (ii) The concentration of individual constituents and (iii) The relative proportion of some of the important constituents present in the water and affecting the soil and crops.

For any irrigation command, which lacks adequate surface drainage and sub-surface gravity water flow; the problems of deteriorating groundwater quality is very common. The MRBC area is one such case example. Further, the rising trends in water tables due to returned irrigation seepage i.e. waterlogging, recycling of groundwater for irrigation in well vicinity area are the factor responsible in an overall concentration of salts in the groundwater, ultimately affecting the soil and sub-soil horizons. For the assessment of groundwater quality in irrigation needs a number of method exists. The author has adopted the following standard approaches, widely used in classifying the groundwater for their irrigation suitability.

(i) Sodium Percentage & Electrical Conductivity Diagram (Wilcox, 1948)

Irrigation water containing high sodium content highly effects the base exchange process resulting to the displacement of exchangeable cations like Ca^{2+} an Mg^{2+} from the clay minerals available within the soil. This Base Exchange reaction, which is of irreversible one, ultimately affects the granularity of the soils; governing sub-soil aeration as well as the soil permeability.

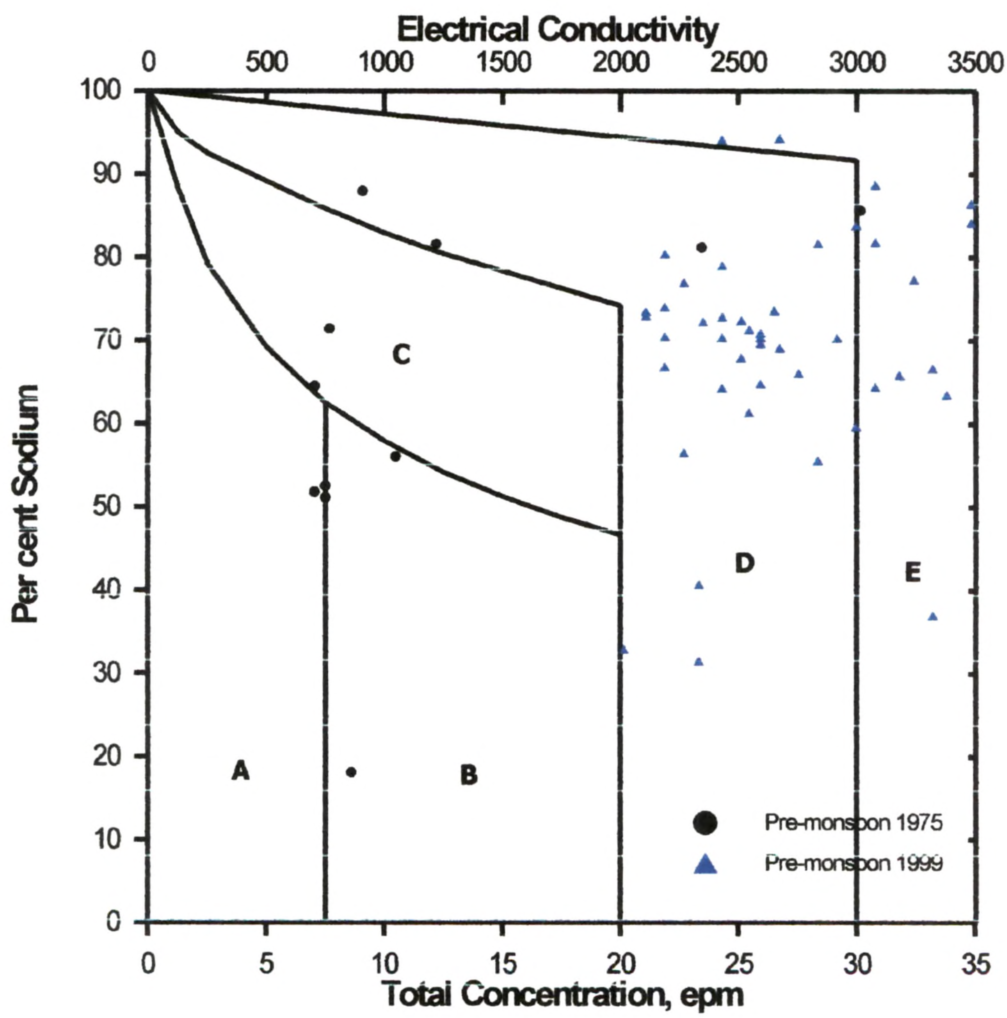


Fig. 4.25 Secular Changes in Groundwater Regime for Irrigation in MRBC area

Sodium percentage and Electrical Conductance plots for the year 1975 and 1999 (Fig. 4.25) in MRBC arca shows significant changc in groundwatcr quality. Thc groundwater quality during 1975, for majority of wells falls under the A-B-C i.e. Excellent to Usable categories. Contrary to this 1999 plots irrespective to the area, majority of the wells shows significant increase in Na % as well as Electrical Conductancc thcrcby, plots arc falling in D & E ficld i.c. Doubtful-Unusablc.

(ii) Sodium Absorption Ratio (SAR)

Popularly know as U. S. Salinity Chart takes in to account the ratio of Na^+ to other alkalis i.e. Ca^{2+}, Mg^{2+} and its combined effect with groundwater salinity. This classification is more versatile as apart from giving the extent of damage to the soils, it suggests possible remedial measures to restore the soil quality.

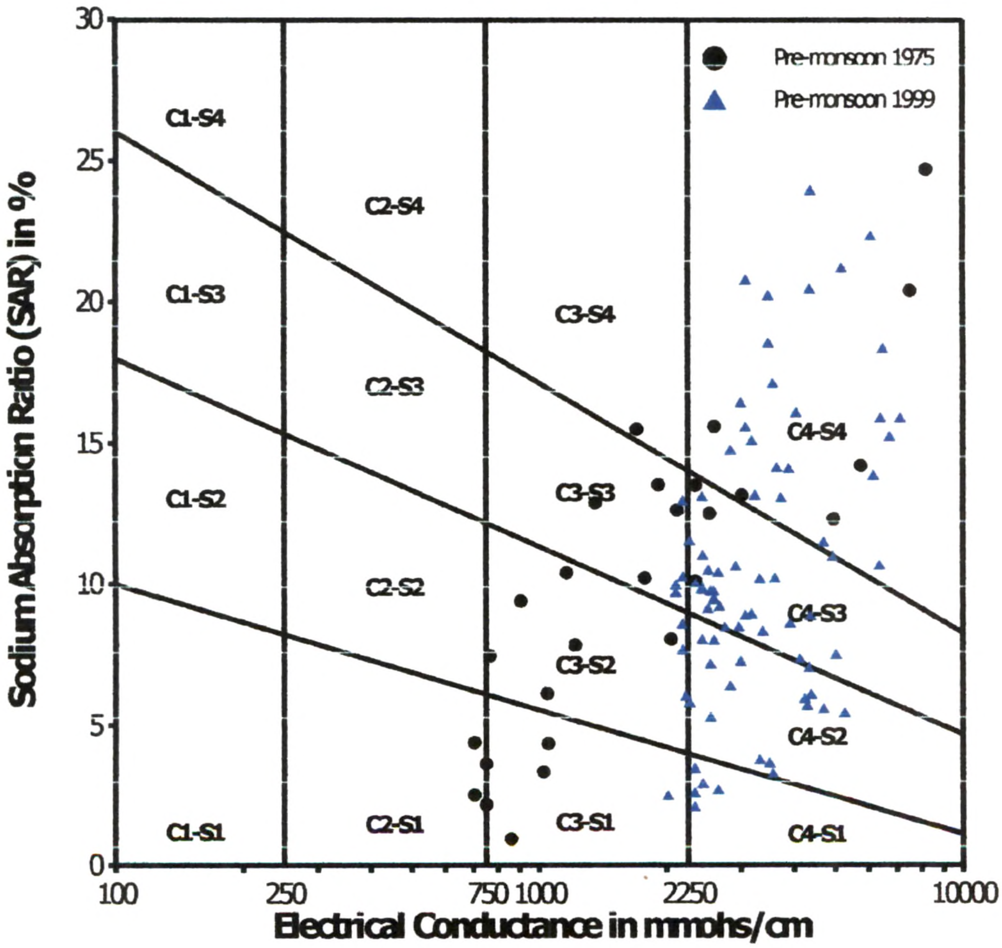


Fig. 4.26 U. S. Salinity Diagram Showing Secular Changes in Groundwater Regime of MRBC area

Like Wilcox Plot, the SAR and groundwater salinity during 1975 (Fig. 4.26) dominantly shows Good-Moderate water, falling in C_3-S_1, S_2, and S3 classes belonging to the lower command area; with average aggregate SAR values more than 50 viz. Golana, Vadgam, Isanpur and Gudel villages. The SAR values plotted for pre-monsoon 1999 season, shows drastic change, Barring a few wells water falling under C_3-S_1, S_2, S_3 classes; majority of groundwater shows overall deterioration. There is significant increase in groundwater salinity as well as the exceptionally higher SAR values. Groundwater now belongs to C_4-S_2, S_3 and S_4 classes, signifying an average quality between moderate and Very High Salinity Alkalinity.

GROUNDWATER FACIES

Taking in to consideration the ionic concentrations of major constituents the groundwater facies have been constructed. In the MRBC area the groundwater are dominated by five major facies (Back, 1960).

(i) $(Na+K)$-Mg-Ca:Cl-(HCO_3+CO_3)-SO_4

(ii) $(Na+K)$-Mg-Ca:Cl-SO_4-(HCO_3+CO_3)

(iii) Mg-$(Na+K)$-Ca:Cl-(HCO_3+CO_3)-SO_4

(iv) Mg-Ca-$(Na+K)$-:Cl-(CO_3+HCO_3)-SO_4

(v) Ca-$(Na+K)$-Mg:Cl-(HCO_3+CO_3)-SO_4

In the lower most part of MRBC i.e. near Matar and Cambay the aquifers are within the Quaternary sediments developed in marine environment (Islam, 1986; Oetting et. al., 1989) is marked by the dominance of Chloride of Carbonate of Calcium and Sodium. It has been observed that in the Middle (beyond Nadiad) and the lower command area groundwater regime is dominated by the $(Na+K)$-Mg-Ca:Cl-(HCO_3+CO_3)-SO_4 and $(Na+K)$-Mg-Ca:Cl-SO_4-(HCO_3+CO_3) i.e. groundwater is dominated by Chloride and Bicarbonate and Sulfate of Sodium. This may be attributed to the fluvio-marine deposits (Agrawal et.al. 1996, Oetting et. al., 1989). In the upper command where in the aquifers are developed within the continental deposits, the groundwater facies is marked by the dominance of Chloride of Magnesium and Calcium (USDA, 1959; Oetting et. al., 1989).

HYDROGEOLOGICAL INFERENCES

Hydrogeology of any area is characterised by the mode of occurrence, distribution and chemical content of groundwater resources in geological environment (Davis and DeWiest 1966). From the foregoing account, dealing with the various facets of groundwater regime of the study area; the following inferences can be made:

(i) The study area constitutes a part of structurally controlled sediment filled basin, the Cambay Graben.

(ii) The aquifers developed within the study area are solely belongs to non-indurated sediments.

(iii) The study area shows considerable lateral variation in nature of sediments characteristics. In the lower parts of the study area sediments are silt-clay dominated and are of fluvio-marine in nature. The middle and upper parts, sand and clay exhibit intercalated relationship and deposited under continental environment.

(iv) The aquifers owing to the nature and distribution pattern of sediments, broadly categorized in to (a) shallow phreatic aquifer and (b) deeper confined-semi-confined aquifers, and are of multi-layered nature.

(v) The area comparatively lacks surface drainage system. However, the defunct palaeo-channels are ubiquitously seen in the study area; representing proto-courses of Mahi and Shedhi and Watrak Rivers.

(vi) The rainfall, which constitutes an important input as recharge to the groundwater regime; tends to decrease northeasterly.

(vii) Owing to incipient seepage directly from canal network, surface water ponds and the returned irrigation seepage; the water level shows minimum fluctuations.

(viii) The water levels are deepest in southeastern parts and overall tend to decrease northwesterly.

(ix) The groundwater flow, with relation to the bordering Shedhi-Sabarmati and Mahi rivers is of affluent in nature. However, the overall flow direction is westerly.

(x) The groundwater quality shows considerable variation. By and large the quality is deteriorated duet upward migration of the salts, under rising trend of groundwater level as well as the inherent sediments salinity.

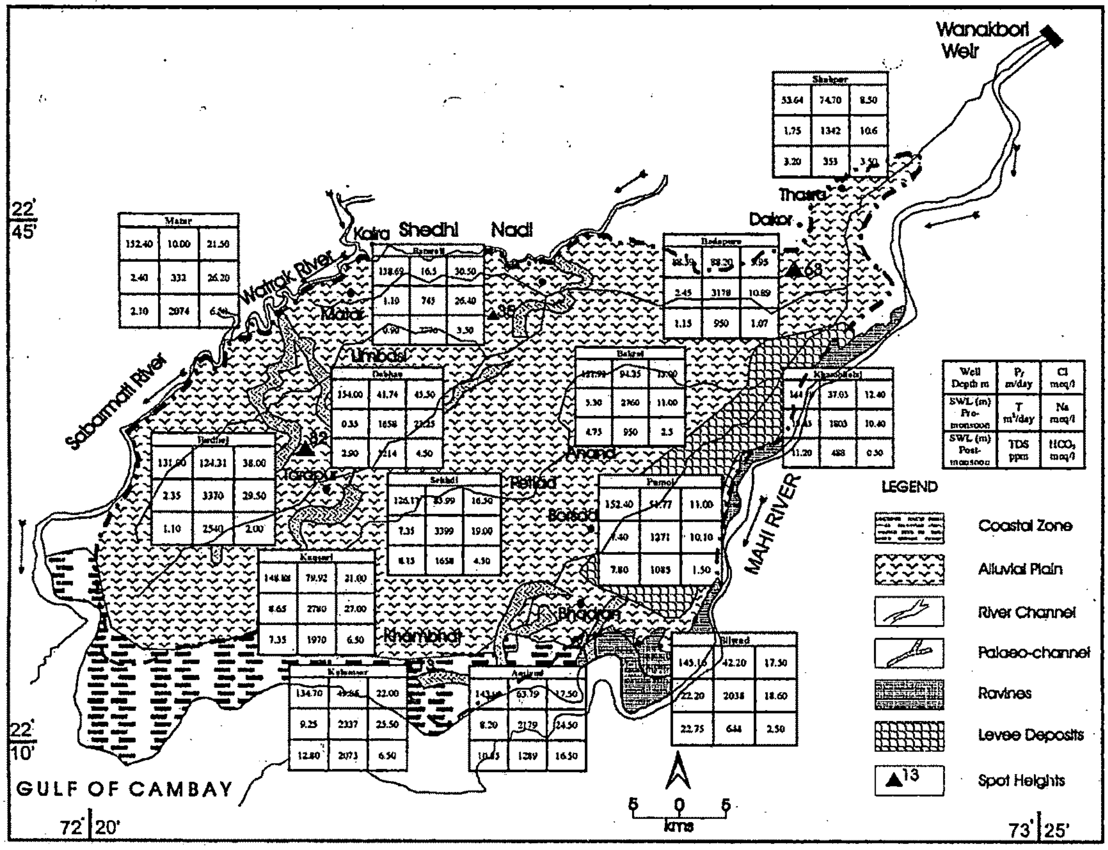


Fig. 4.27 Hydrogeological Map of MRBC Command Area

Based on above salient characteristics the author had prepared the hydrogeological map of the MRBC area (Fig. 4.27). The parameters considered for this are geology, geomorphology, post- and pre- monsoon water level, hydraulic conductivity, Transmissibility and Chemical Content i.e. TDS, Cl, Na, and HCO_3.