Chapter 8

Water Regime

CHAPTER 8
WATER REGIME

INTRODUCTION

Water is the elixir of life. Surface and groundwater regime constitutes an integral part of hydrologic cycles. In northwestern India the precipitation being the only input to replenish the annual incurred losses of water; the development and utilization of total water resources of any area cannot be unlimited. The study area falls within the semi-arid- sub-humid climatic domain of tropical region. The availability of precipitation input is dependent of southwestern monsoon. Highly erratic pattern of monsoon, particularly the lean monsoon phases, severely affects the availability of water and cause drought condition. Accordingly the groundwater regime is also adversely affected due to paucity of an adequate recharge. Similarly excessive utilization of canal water i. e. over irrigation and the continual returned irrigation seepage to the groundwater regime damages the soil and sub-soil horizon due to over-saturation and salt built-up. Therefore, the optimal utilization of water resources in any area through evaluation of water regime is pre-requisite. The study area, which is forming an integral part of canal irrigation system, the occurrence and distribution of water resources are under two modes i. e. the surface and groundwater resources.

SURFACE WATER RESOURCES

Surface water resources, the one of the foremost and only option available for the agriculture, irrigation, domestic and industrial practices during the non-availability and/or scarcity of groundwater. Rainfall being the only source, surface water resources occur naturally as a part of river channel flow and generally stored by constructing the ponds, reservoir, lakes etc. In the study area, which constitutes a part of the canal irrigation, the surface water is channelized through the canal network. However, the area has considerable numbers of rainfed ponds and reservoirs; which have been serving as important source of water for domestic and irrigation needs, prior to the canal inception. Ponds at Tranja and Traj are now linked with the canal; hence they are perennial source of water supply.

RAINFALL

The precipitation being the only source, in the study area it is monitored at two locations viz., Nadiad and Matar. Rainfall hydrograph prepared for the study area is indicative of uneven pattern and restricted to the monsoon season only i.e. July-September. The average annual rainfall in the study area amounts to 825.58 mm. The study carried out by the Indian Meteorological department on rainfall pattern in the command area, considering 50 years of data has found substantial variation in rainfall pattern. It is observed that in the study area the rainfall less than 80% of the normal, occurred more than 05 times at Matar and 04 times at Nadiad. The rainfall-time-series curve (Fig. 8.1) plotted for last 20 years i.e. 1978-99 indicates that about the 11 years the area has received the rainfall above average and 9 years it was below average.

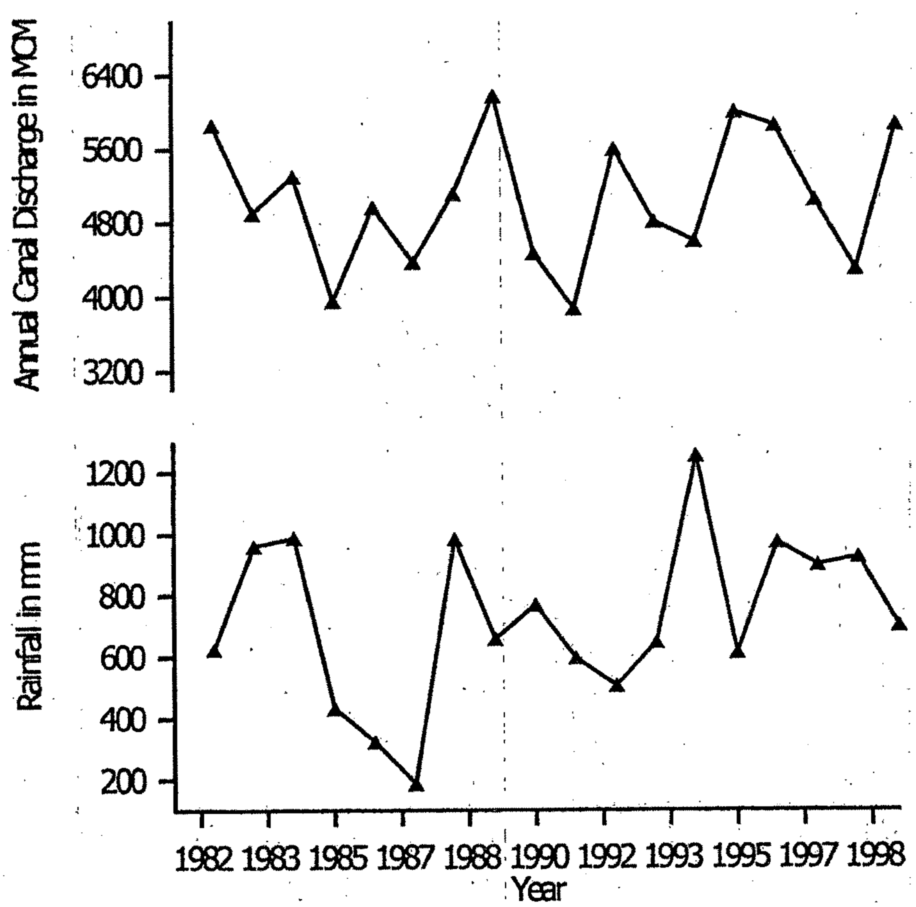

Fig. 8.1 Time Series of Canal Water Input vis-à-vis Rainfall Pattern in Matar Command Area

The plotted curve on volume of water supplied during this period also supports that the availability of rainfall and irrigation water demand fluctuates accordingly.

CANAL WATER INPUT

As it has already been described in the preceding introductory chapter that the area consists of close network of the canal system comprising Branch, Distributory, Minors, Sub-minors and field channels. The branch canal, which is 18 km long with its Traj Distributory and Matar Minor off-taking at Undhela. The branch canal in the command area is lined one with sandwich Brick-Tile lining, where as the other lower order network is unlined in nature. Also, the command area has been divided in to different land irrigability classes depending upon soil and drainage conditions. As the command area predominantly consists of class III and IV soils, the canal irrigation is specifically envisaged to cater the irrigation needs for Kharif season.

Table 8.1 Average Annual Canal Discharge Records in Matar Branch Canal Measured at Piplag.

Year	Monthly canal Discharge (MCM)												Annual
	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	Jun.	Jul.	Aug.	Sept.	Oct.	
	Rabi and Hot							Kharif					
1982	240	0	262	301	361	449	174	0	997	822	1366	888	5861
1983	6	0	172	368	439	521	660	105	315	651	1052	616	4904
1984	66	0	243	201	516	647	605	0	778	311	1126	818	5311
1985	78	0	108	166	211	450	472	7	323	1181	123	836	3956
1986	176	103	0	0	0	298	70	0	740	1285	1213	1090	4974
1987	323	245	0	388	376	440	414	0	265	118	998	813	4381
1988	101	148	430	329	386	571	747	44	33	844	719	773	5124
1989	44	110	469	532	633	623	774	9	412	810	1010	759	6186
1990	177	195	261	471	303	666	438	0	819	518	274	358	4480
1991	93	123	180	342	410	0	0	0	97	860	969	809	3881
1992	135	241	356	304	664	641	721	0	86	731	903	834	5615
1993	29	142	323	475	428	100	0	55	586	1122	1010	561	4830
1994	48	198	459	456	627	865	423	0	288	432	63	762	4621
1995	13	139	415	511	702	643	653	0	623	895	869	562	6026
1996	18	29	347	638	963	861	200	0	680	743	730	672	5881
1997	0	0	423	698	530	869	159	40	733	397	711	511	5070
1998	0	117	0	236	689	702	534	18	683	777	206	362	4323
1999	41	0	370	663	500	879	332	0	731	1128	1084	167	5896
Avg	88	99	268	393	485	568	410	15	511	757	801	677	5073
Total Irrigated Area Kharif = 23022 ha., Rabi and Hot = 9975 ha., Total 32,997 ha													

However, at the latter stage the irrigation has been extended to Rabi and Hot weather crops also, but for very limited command area. Taking in to account monthly canal discharge as recorded by the command authority for the period of 1982-1999 (Table

8.1) the annual average water input stands at 5073 MCM; this encompasses an irrigation area 23,022 ha. (Kharif) and 995 ha (Rabi and Hot weather).

In order to study the rainfall pattern vis-a-vis canal water input a monthly time series curve has been drawn (Fig. 8.2). This also suggests the crop water requirement is in conformation with the rainfall input.

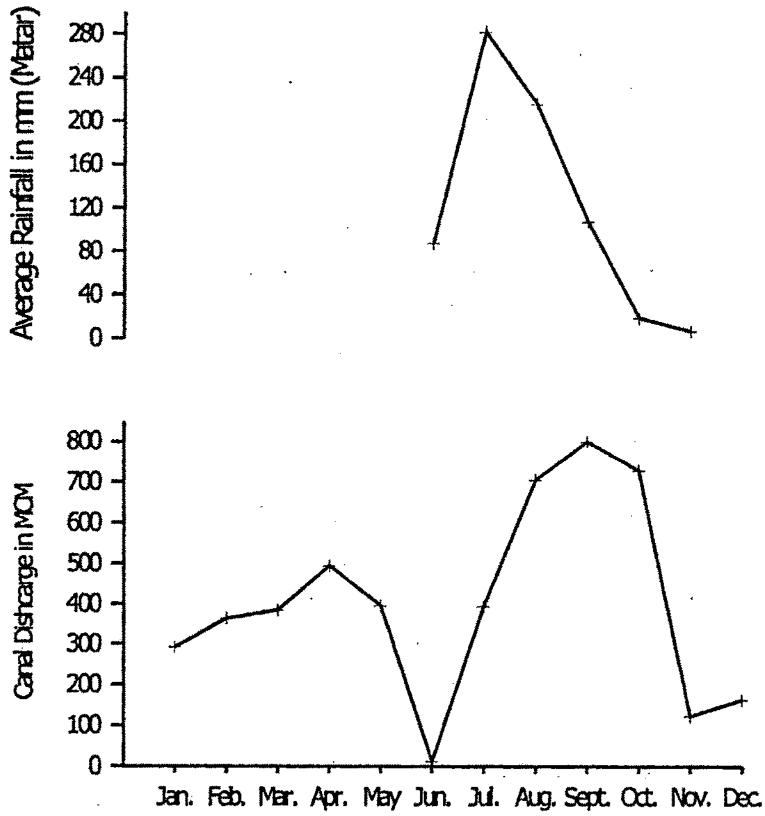

Fig. 8.2 Time Series Plots Depicting Mean Monthly Canal Water Input and Rainfall in Matar Command.

GROUNDWATER RESOURCES

The Matar Command area forms part of the MRBC, which possess the excellent groundwater potential associated within the thick quaternary sediments. A critical appraisal on the hydrogeology of the Matar Branch command area based on available information and authors own collected field observations is enumerated as under:

AQUIFER NATURE AND EXTENT

As it has been already discussed in the previous chapter that the entire MRBC area comprises the multi-tired sandy aquifers of confined nature. The various sub-surface hydrogeological profiles, prepared with the help of available bore well longs corroborate this fact beyond any doubt. Saline features of some of the important profiles are as follows:

*1. **Kosiyal-Maliyataj-Palana Profile:***

The profile drawn on NNW-SSE azimuth (Fig. 8.3) is characterised by the alternate layers of the clay and sand sequences, with an intermittent lenses of gravels (at Maliyataj) and Kanker (at Kosiyal). The sand layers ranging between fine and coarse size. The thickness of these sands tends to decrease downwards. These sandy layers as moves are separated by the clay layers acting as aquiclude.

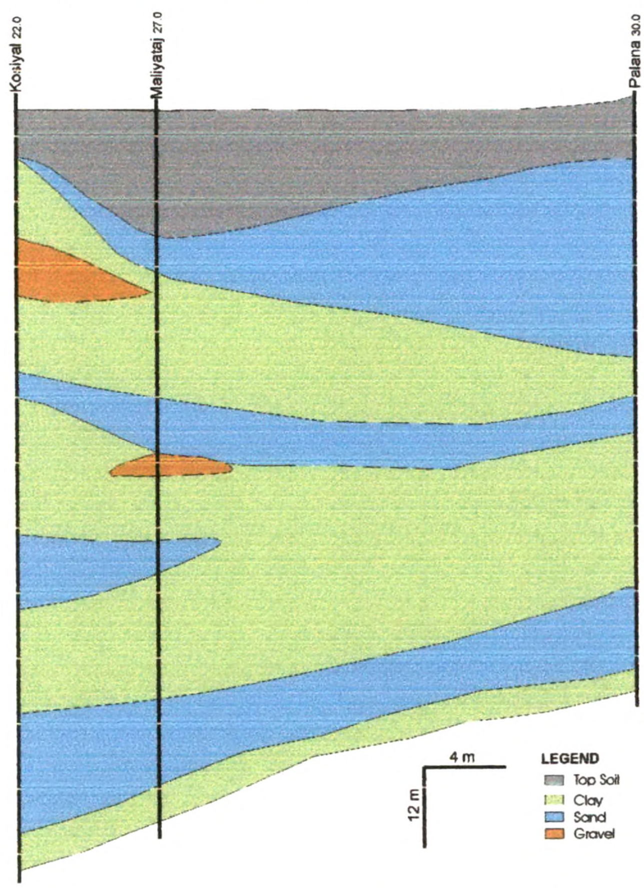

Fig. 8.3 Sub-surface Section of Matar Command Area.

*2. **Machhiyel-Palana-Dabhan Profile:***

The NNE-SSW profile is also marked by the presence of the alternate sequence of the clay and sand layers (Fig. 8.4). The disposition pattern indicates that the area possess the sandy layers to the limited depth and of varying in grain size from fine to coarse grained. As one moves due west the sandy layer is dominated by the clay layers and sandy layers pinches out.

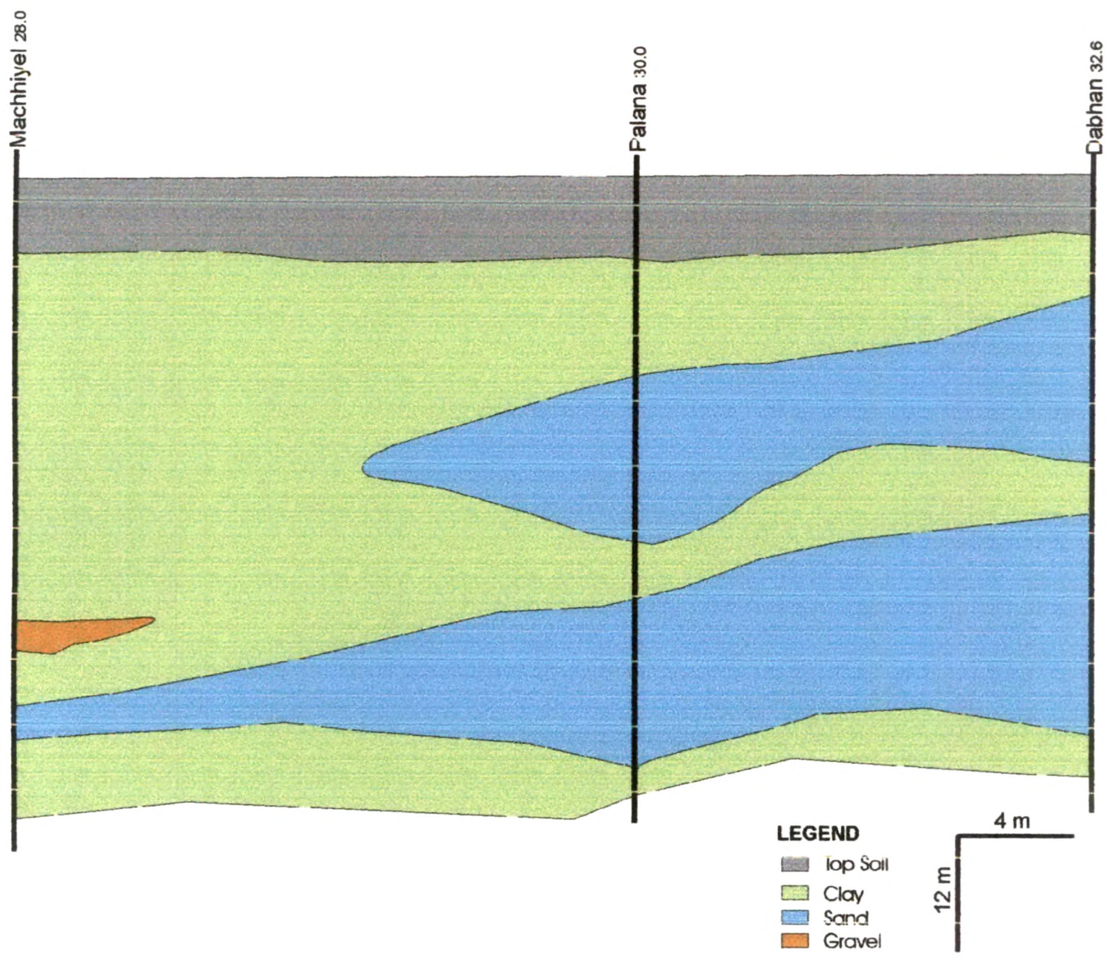

Fig. 8.4 Sub-surface Section of Matar Command Area.

Inventory of various lithologs indicate maximum 05 aquifers exists within the depth range between 25 and 135 m. The area around villages viz., Silod, Siholdi, Ratanpur, and Sandhana are characterised by the present of 05 aquifers. The various observed hydraulic characteristics (Table 8.2) shows wide range i.e. Discharge (677-3045 LPM); Transmissibility (82-2477 m^2/day); Hydraulic Conductivity (10-72 m/day).

GROUND WATER CHARACTERISTICS

The Matar branch command area has close network of the observation wells for monitoring the behavioral pattern of groundwater levels, since the inception of the canal. For the purpose of precise evaluation of groundwater characteristics, the author has divided the study area in to equal area grids of 10 sq. km. each and the best-suited observation well has been selected at each nodal center for further monitoring. The author has monitored each well during the present studies for three different seasons with the point of view of seasonal water table fluctuation and the behavioral changes in groundwater chemistry.

Table 8.2 Aquifers' Hydraulic Characteristics in Matar Branch Command Area.

Taluka	Village	Aquifer Depth M	Thickness m	Aquifer Tapped Depth Range M	DD m	Discharge LPM	T m^2/day	K m/day	Specific Capacity L/sec
Nadiad	Nadiad	134-152	21-60		5.03	2889	1946	56.67	9.50
	Piplag			72.45-89.72	8.50	2989	1961	21.64	5.80
				124.02-141.08					
	Piplag			73.95-96.92	631.00	3405	2477	67.77	8.90
				103.93-111.91					
				131.56-137.17					
	Silod			48.80-53.30	8.80	2071	397.2	10.42	3.90
				64.00-73.20					
				88.40-96.00					
				114.30-118.90					
				123.40-135.60					
Matar	Matar	152-155	18-40		8.13	2744	1160	29.71	5.60
	Alindra				9.14	3020	885	17.73	5.50
	Shiholdi			51.97-6.97	6.68	2986	672	13.17	7.4
				73.97-86.01					
				96.00-113.97					
				116.97-125.94					
	Sokhda			88.12-94.32	8.50	2250	950	51.56	4.40
				99.95-106.66					
				108.0-114.12					
	Ratanpur			48.76-55.00	3.50	1136	874	21.77	5.40
				62.06-67.00					
				70.3075.25					
				85.95-88.97					
				91.82-105.73					
				122.90-129.97	16.6	1136	118	4.99	1.2
	Untai			89.39-99.22					
				102.92-107.47					
				111.77-128.00					
	Kosiyal			85.07-105.09			82	2.84	
				107.39-116.10					
	Sadhana			43.00-49.16	3.15	1516	635	14.8	8.12
				65.00-67.86					
				77.15-82.82					
				90.18-101.50					
				105.47-116.75					
				120.41-126.05					
	Heranj			25.74-31.50	6.05	2274	1449	72.2	6.26
				37.71-52.01					

(Source: GWRDC, Ahmedabad)

WATER LEVEL FLUCTUATION

The fluctuation in groundwater level is manifested by the factors relevant to meteorological, geomorphic and lithological characteristics of the area coupled with pace of abstraction. It is also an established fact that in any canal irrigation command recharge to the groundwater regime apart from rainfall received major contribution from canal seepage ad the returned irrigation seepage. Therefore, behavioral pattern in groundwater level fluctuation has to be viewed, considering individual recharge factors as well as the cumulative effects. As it has already been eluded that the command area has been monitored for observing the behavioral pattern in water level fluctuations since the canal inception. For the purpose of evaluation of water level fluctuations and change in groundwater storage the author has carefully scrutinized the available data. Then, the seasonal and secular changes in the groundwater regime have been studied by adopting the conventional approaches viz., well hydrographs, static and reduced water level contours and temporal hydrographic profiles. For this author has taken the basis of last 25 years of pre-monsoon data at the interval of 05 yearly changes in the groundwater regime i. e. 1976-80-85-90-95- and 1999. As water table information during pre-canal irrigation period is very scanty, same has been adopted for a well specific hydrographs only.

SEASONAL BEHAVIOUR

The seasonal water fluctuation is of utmost importance in studying the annual change in groundwater regime. This change in groundwater storage is influenced by recharge, accentuated by the quantum of rainfall and the canal water input, substantiating recharge as returned irrigation seepage. In order to obtain such seasonal changes and the spatial distribution pattern, the author has prepared static and reduced water level contour maps of both pre- and post-monsoon seasons. The pre and post monsoon RWL contour maps (Fig. 8.5) developed for the year 1976 (i. e. the year when 100 % irrigation potential has been created by the command authority) has divulged following details:

1. Movement of groundwater illustrates strong influence of aquifers' lateral and vertical distribution pattern. In the upper half command area there exists two minimas i. e. near Hathnoli and Sandhana, indicating the groundwater movement centrally. While the developed maximas around Machhiyel (Lower half command area) the groundwater flow is radial which further tend to move westerly.

2. The observed change in groundwater storage through these contour diagrams is uniform nature, except those areas falling under the influence of minima. The command area in general displays 2-3 m rise. While those around the minima, the rise in groundwater storage is 6 m around Hathnoli and 4 m around Sandhana-Vaso localities. This observed rise might be attributed to the significant thickness of the aquifers, which is pinching out as one moves laterally i. e. the aquifer morphology.

The reduced water level contours drawn for 1999 seasons (Fig. 8.6) does not show much change sin groundwater storage pattern as well as the movement. However, there is significant change observed in pre and post monsoon level fluctuation. This fluctuation is to the order of <0.5 -2.5 m.

SPATIAL HYDROGRAPHIC PROFILES

In order to delineate and quantify the net change in the pre- and post monsoon fluctuation, the author has plotted the spatial hydrographic profiles (Fig. 8.7) along A-A' i. e. Asamli-Dabhan transact. It is noteworthy to see sharp decline in pre and post monsoon level changes. The 1976 profile show 2-10 m seasonal fluctuation in groundwater storage. However, the curve plotted for 1999, the seasonal fluctuation in groundwater storage has drastically reduced to <0.5 - 2.5 m. The observed sharp changes in seasonal levels, clearly point to increase in the pace of recharge attributed to excessive canal irrigation and returned irrigation seepage to the groundwater storage.

SECULAR BEHAVIOUR

Evolution of water level fluctuation in canal irrigation command from the point of view its long-term behaviour is vital in understanding the problems of waterlogging and adopting corrective measures to manage the water resources.

The Matar Branch command area has also been monitored by the MRBC authority for this purpose. Long-term seasonal water level records since the canal inception exists for this purpose. The author has utilised this data to evaluate the secular changes in water level. For this the pre-monsoon reduced and static water level contours and spatial hydrographic profiles were prepared and evaluated; incorporating the available data as well as authors' own observation, for the period between 1976 and 1999 at five years interval scenarios.

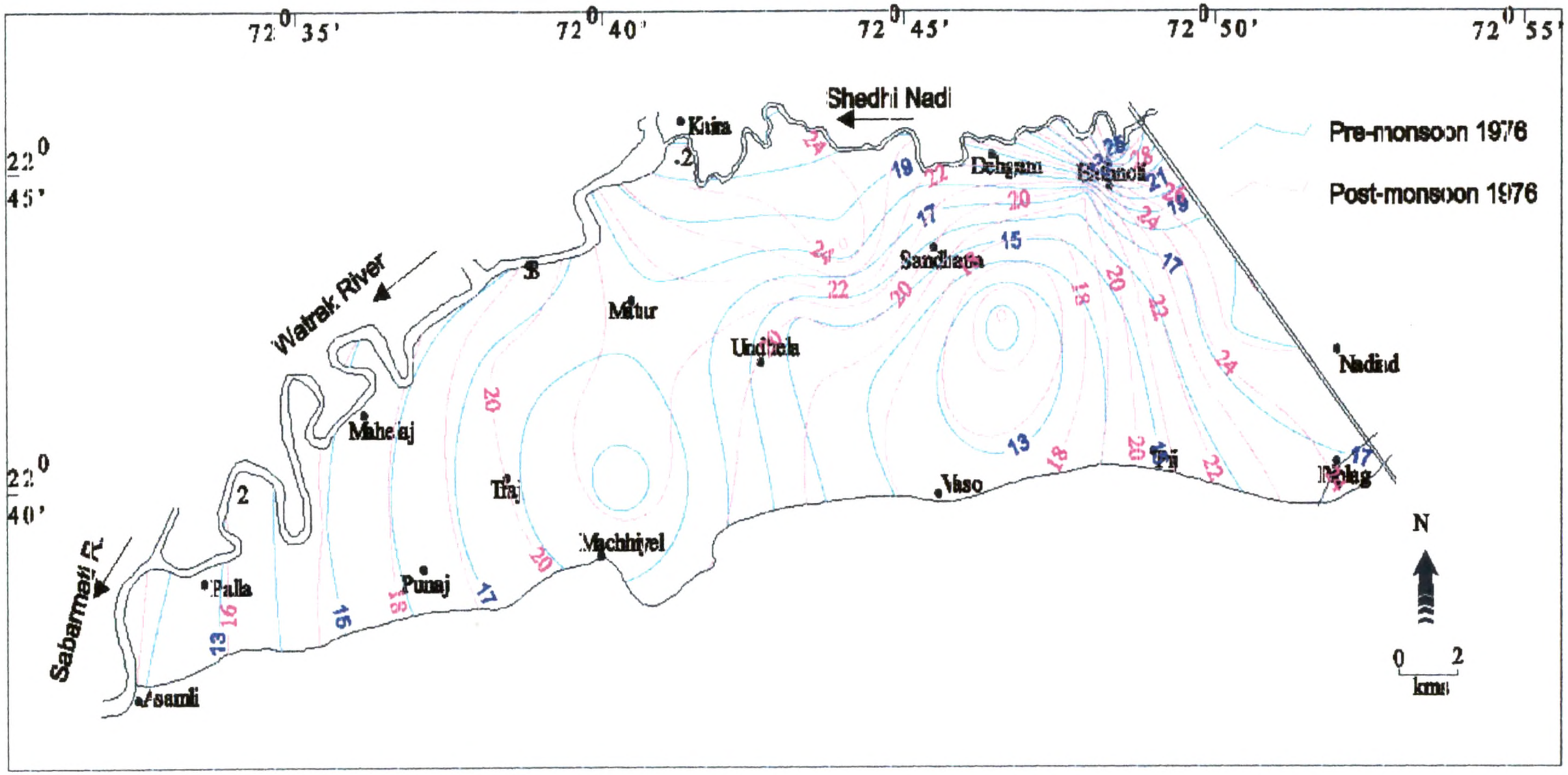

Fig. 8.5 Seasonal Reduced Water Level Contour of Matar Command Area. (Year: 1976)

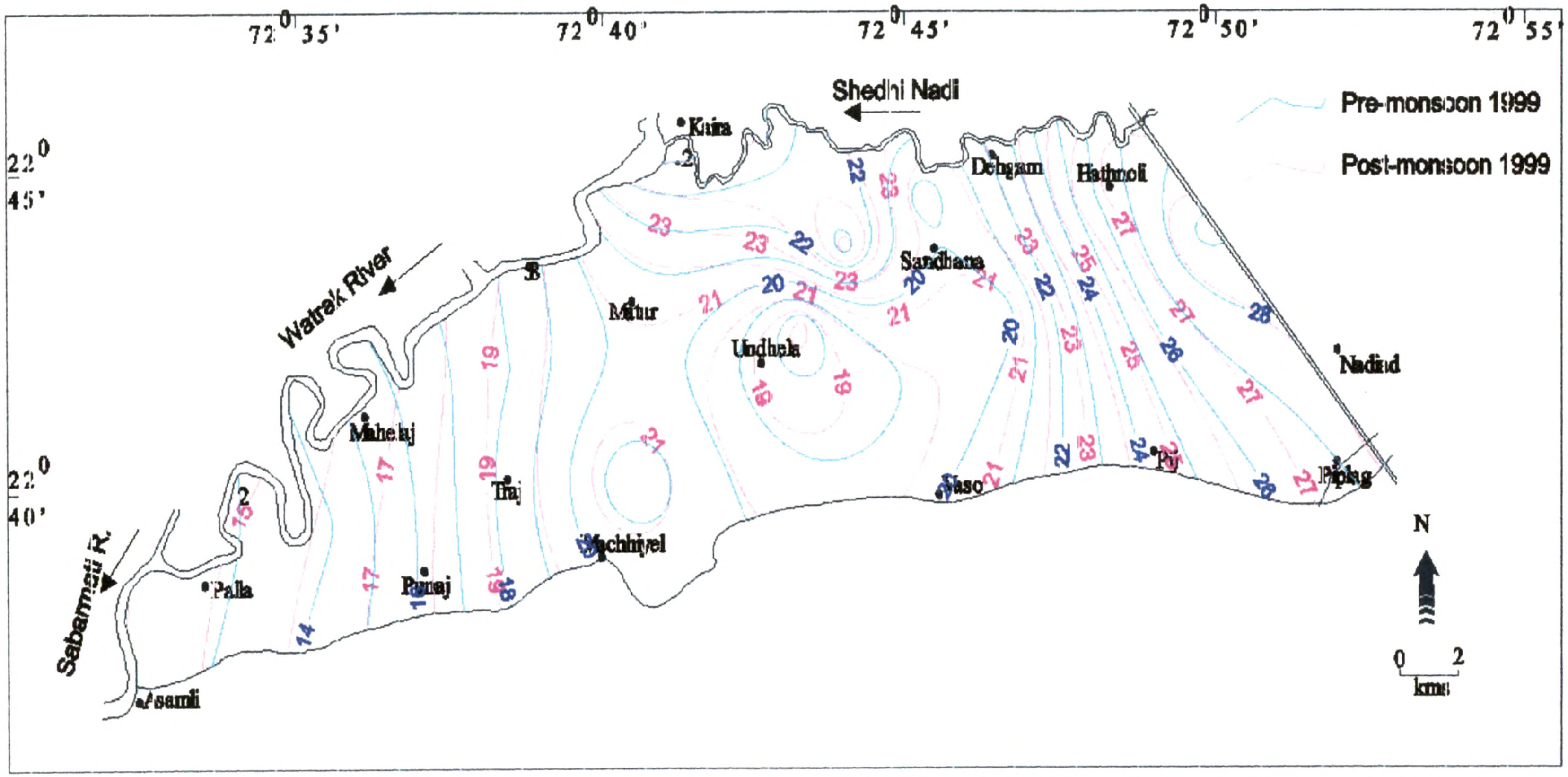

Fig. 8.6 Seasonal Reduced Water Level Contour of Matar Command Area. (year 1999)

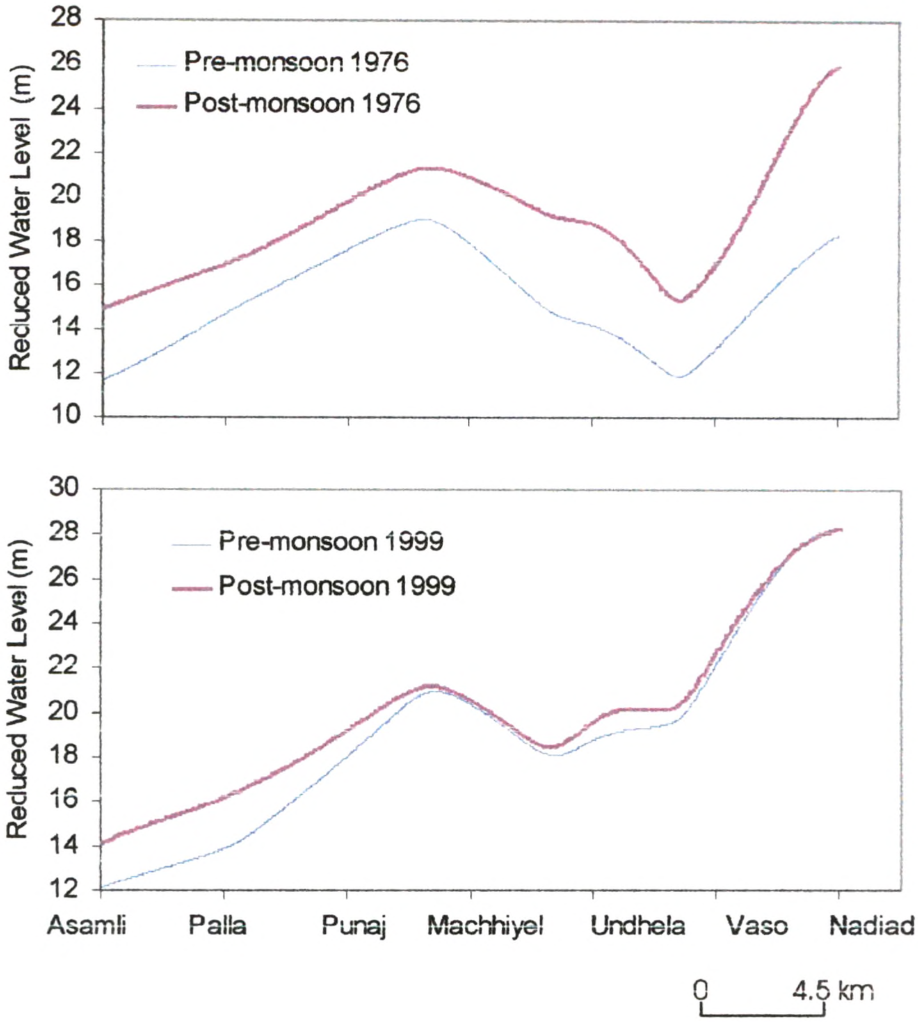

Fig. 8.7 Spatial Hydrographic Profiles Along Asamli-Nadiad (A-A') Transact Showing Seasonal Fluctuation in Groundwater Regime in Matar Command Area.

Pre-monsoon water level records have been considered to be ideal from the point of view of evaluating the secular changes in water regime (Davis and De Wiest, 1967). The details on static water level observed at various stations in Matar Branch are given in Table 8.3.

PRE-CANAL IRRIGATION SCENARIO

Prior to the inception of canal irrigation i. e. 1958, the water levels in the command area have been ranging between 5.79 and 18.29 m (Table 8.3). The upper reaches of the command used to have deeper water levels, and significant thickness of porous and permeable sandy aquifers. As one approaches to middle reaches, owing to flatness in terrain, pinching of the aquifers as well as increase in clay-silt content, the groundwater level tend to occur at shallow depth.

Table 8.3 Secular Water Table Scenario in the Matar Branch Command

Location	Annual Average SWL (m) Pre-monsoon Season						
	1958*	1976	1980	1985	1990	1995	1999
Nadiad	14.02	17.05	7.10	5.80	5.70	4.75	4.80
Haijrabad	10.06	12.80	9.45	10.30	6.35	12.65	9.10
Antroli	11.58	12.50	6.05	5.90	4.45	12.40	7.90
Ratanpur	11.28	7.95	5.35	4.20	7.60	9.75	7.00
Undhela	11.89	6.00	6.75	2.50	3.25	7.40	2.80
Raghvanaj	7.62	7.20	4.15	5.30	5.60	5.50	6.10
Heranj	6.10	0.00	4.30	3.95	4.20	2.60	2.15
Matar	6.40	6.05	5.85	2.35	3.35	2.05	1.85
Tranja	6.10	3.65	3.60	3.40	2.35	1.45	1.45
Aslali	5.79	3.85	3.70	2.30	2.00	1.25	3.50
Kosiyal	6.55	4.00	4.15	4.45	5.60	3.90	5.30
Pipriya	18.29	6.30	4.60	5.75	7.45	4.05	3.30
Punaj	7.92	3.05	5.45	2.80	4.50	2.20	2.20
Kathoda	6.10	4.90	5.95	8.00	7.00	6.70	5.30

* Pre-Canal Irrigation Scenario

The reduced water level contours (Fig. 8.8) drawn for the command area show a gentle groundwater gradient with inflow from adjoining Shedhi River. However, the groundwater flow in lower reaches of the command remained westerly and shows outflow trends to Watrak River.

POST-CANAL IRRIGATION SCENARIO

From 1976 onwards i. e. years of 100% irrigation potential created, the water level exhibits sharp rising trends. The reduced water level contour maps developed for the year of 1976, 1980, 1990, and 1999 (Fig. 8.9-8.12) display more or less uniform pattern in groundwater level rise. The contour pattern depicts a development of maxima (mound) around Machhiyel-Traj-Matar, having radial flow. While the minima (depression) developed between Sandhana and Vaso localities has internal flow, thereby sharp rise in the water table. This again shows strong controls exercised by the lateral and vertical distribution pattern of the aquifers, governed by the Cambay basin tectonic configuration and the prevailing palaeo-geographic condition of the area.

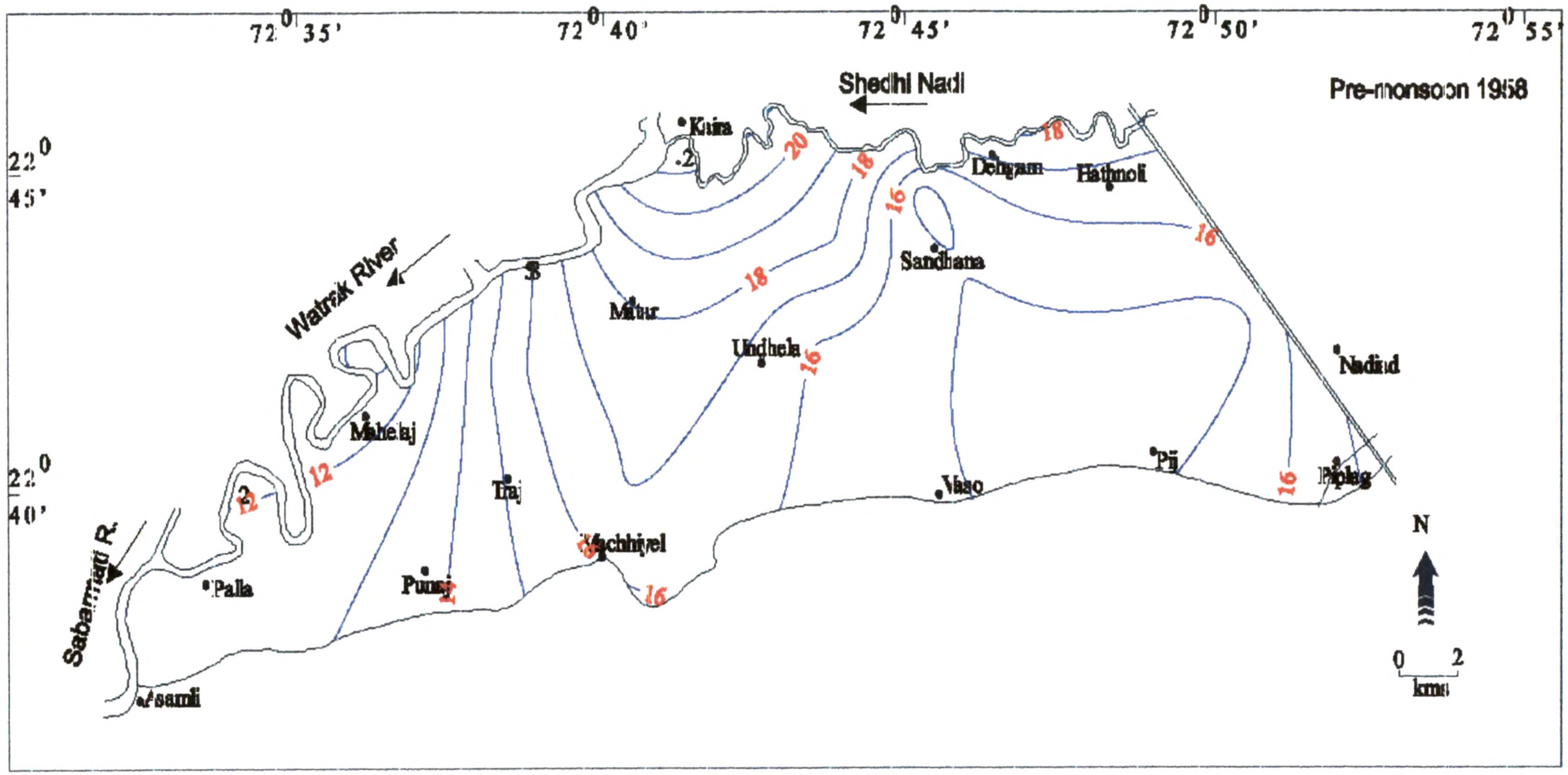

Fig. 8.8 Reduced Water Level Contour Plan of Matar Command Area. (Year: 1958)

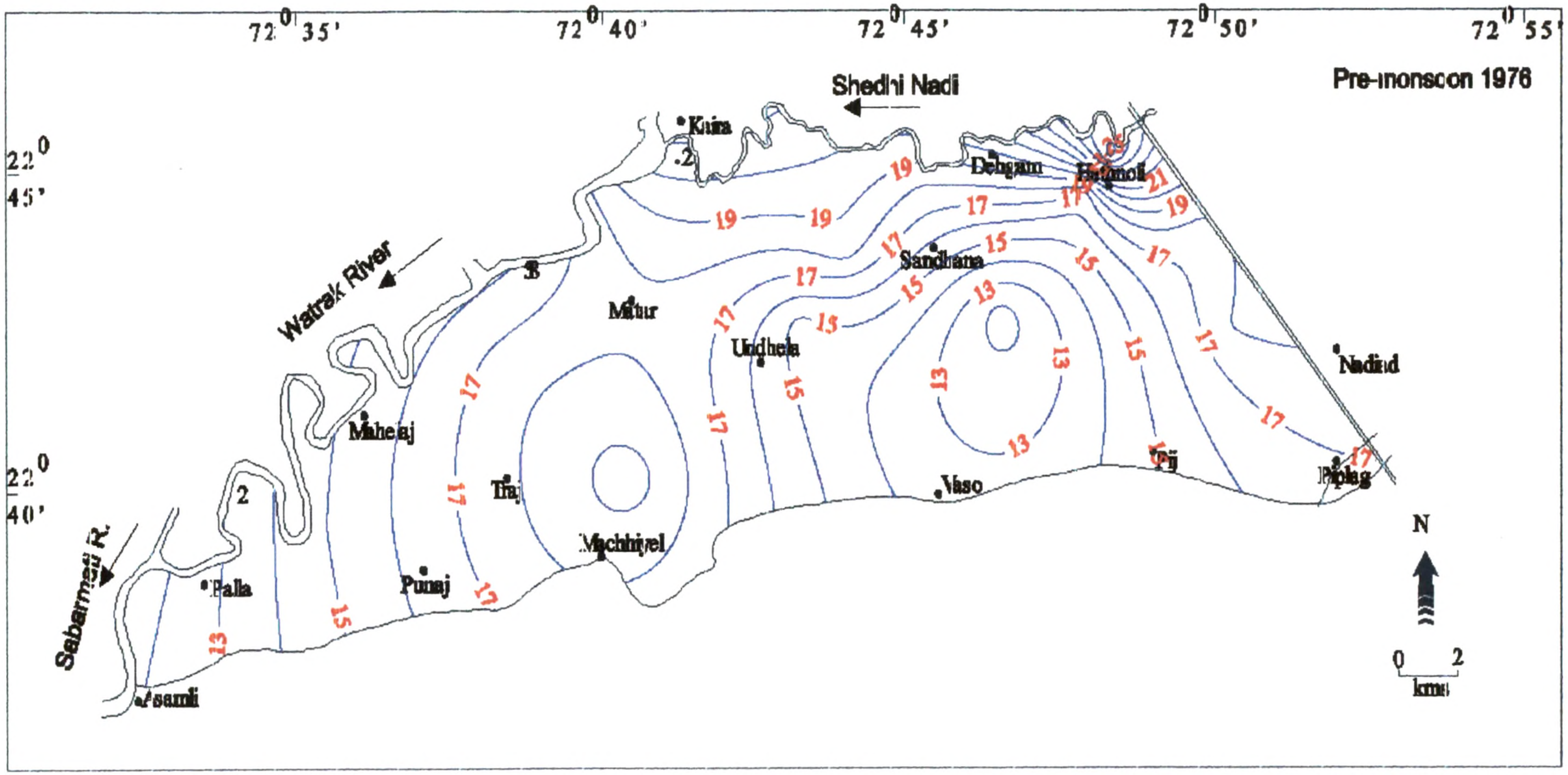

Fig. 8.9 Reduced Water Level Contour Plan of Matar Command Area. (Year: 1976)

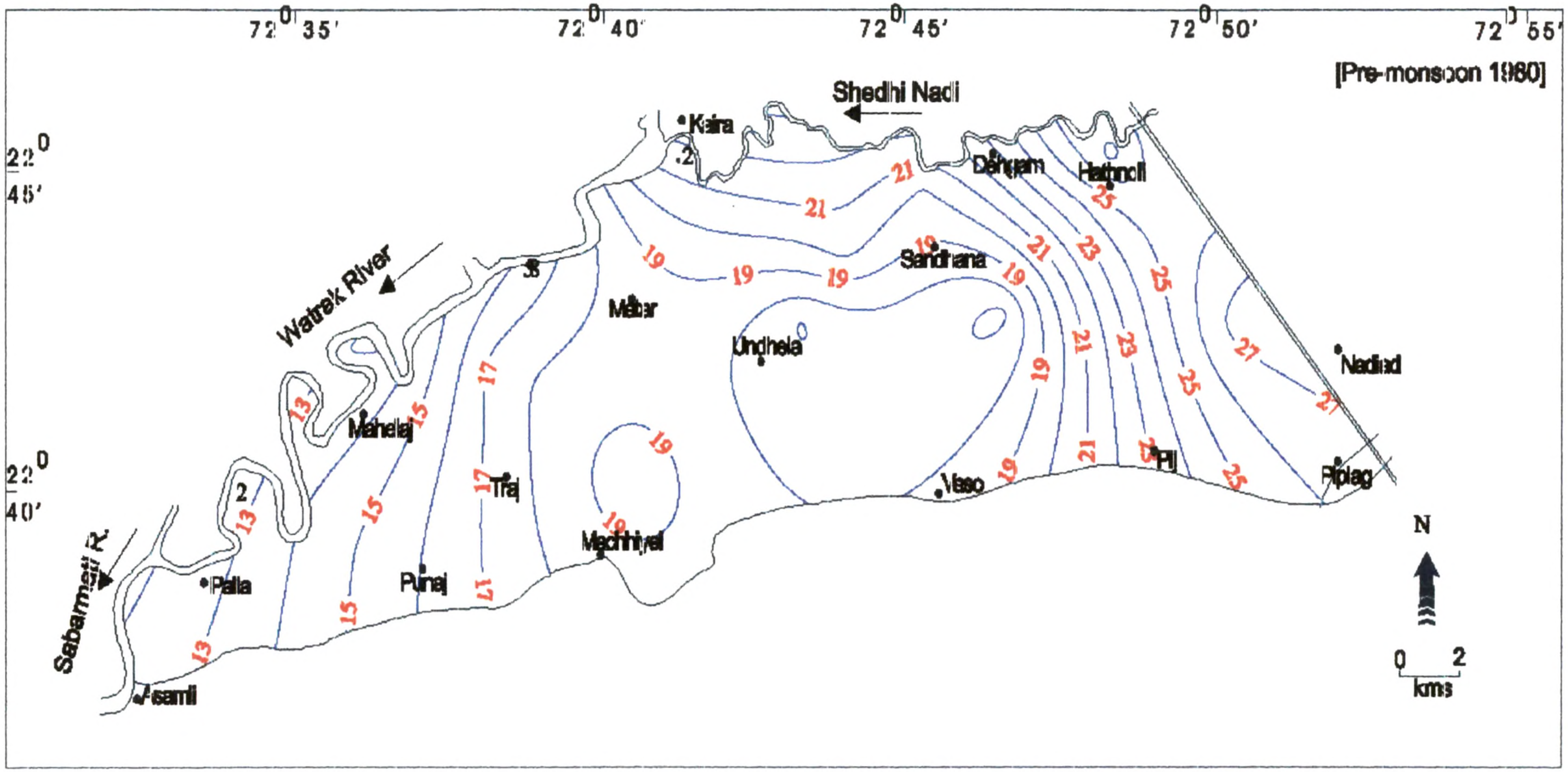

Fig. 8.10 Reduced Water Level Contour Plan of Matar Command Area. (Year: 1980)

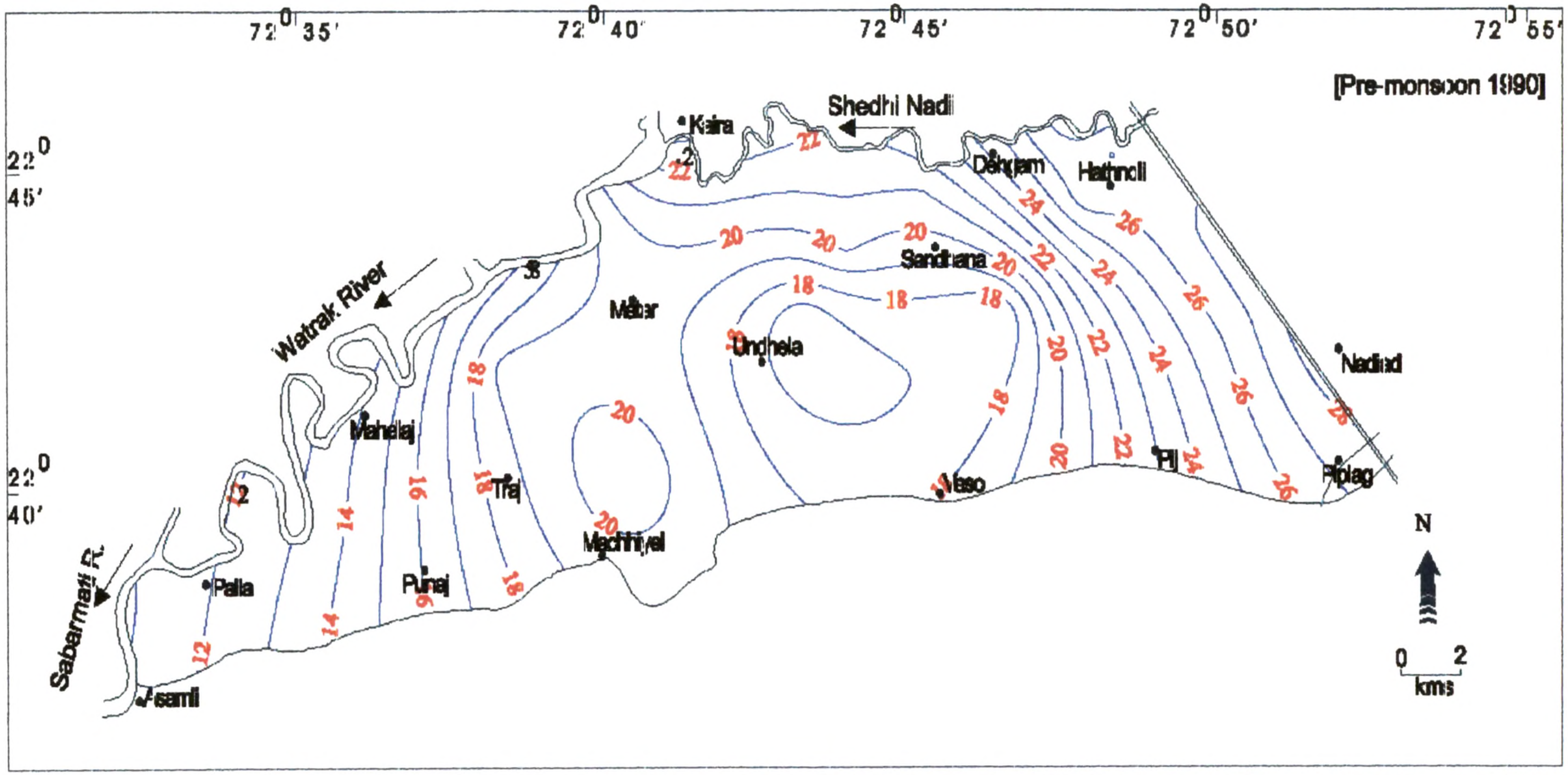

Fig. 8.11 Reduced Water Level Contour Plan of Matar Command Area. (Year: 1990)

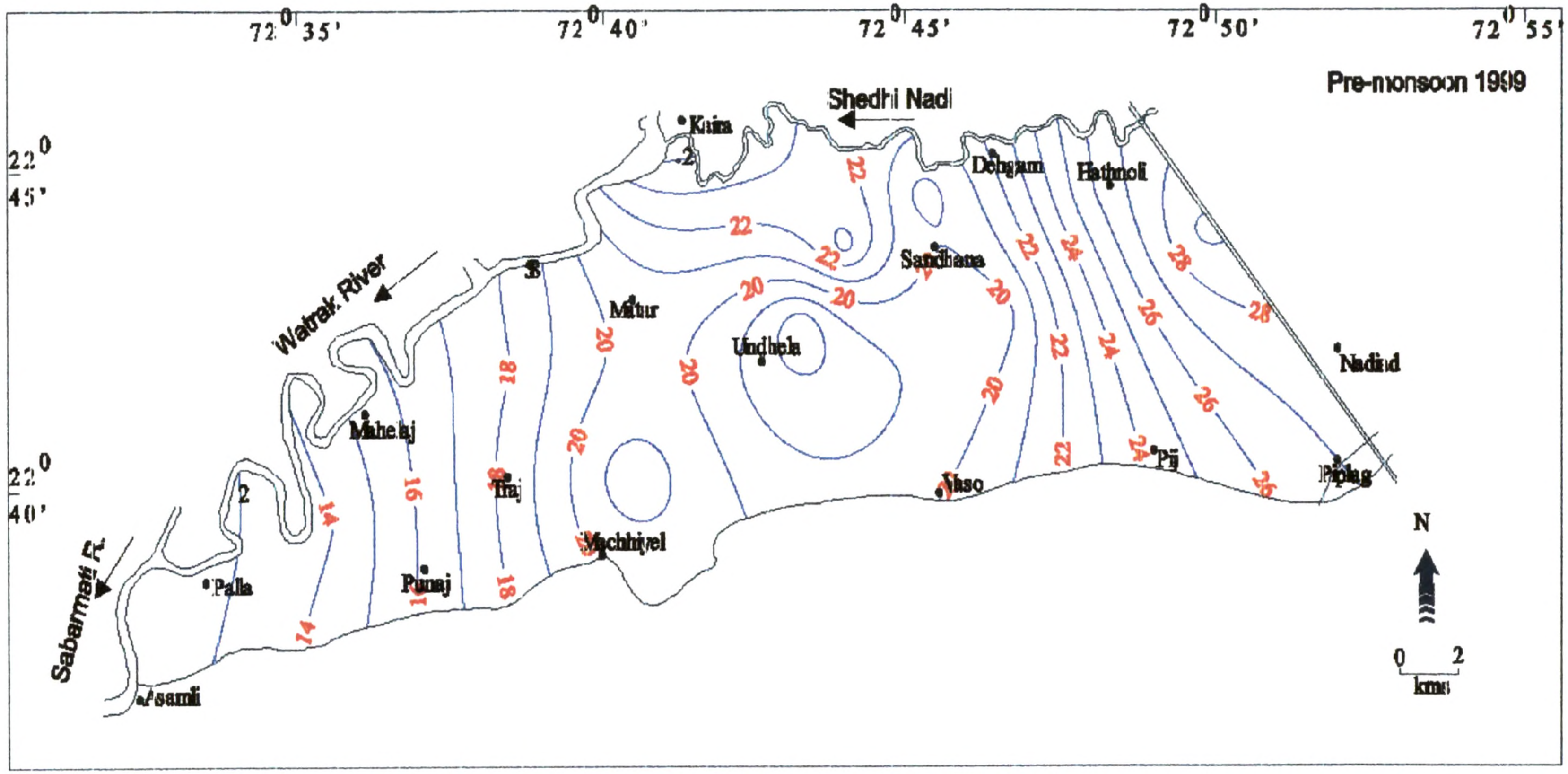

Fig. 8.12 Reduced Water Level Contour Plan of Matar Command Area. (Year: 1999)

The RWL contours for the subsequent years do not show much change in the direction of the flow. However, a significant rise in the water level has been witnessed during the period between 1976 and 1999. The developed ground water depression showing internal flow at the Sandhana show subsequent shift to west near Undhela and shows the maximum rise in water level from 12.5 to 20.5 m (8 m). The area west of Matar-Machhiyel Transact has reported the minimum rise of 2 m i.e. from 18 to 20 m.

SPATIAL HYDROGRAPHIC PROFILES

In order to assess the long-term change in the groundwater storage and its spatial quantitative trends, the author has drawn spatial hydrographic profiles (Fig. 8.13), along the longest axis of the study area i. e. Asamli-Dabhan (A-A'). The plotted hydrographic profiles, based on pre-monsoon water levels from pre-canal irrigation phase to the recent one; has brought out following conclusion:

1. There is considerable rise in the groundwater level after the inception of canal irrigation. The pace of groundwater level rise is rather more between 1976 and 1999 than the 1958-76 period.
2. The hydrographic profiles for the year 1958 and 1976 (Fig. 8.13 A) show almost 2.00 m decline in water level between Machhiyel and Asamli localities. This may be attributed to prolonged deficiency in rainfall recharge (between 1967-1975) and excessive groundwater utilization.
3. There is significant rise in water level i. e. 17 m between the period 1976 and 80 in upper reach and it tend to become zero around Undhela village.
4. Hydrographic profiles for the years 1980, 90 and 99 (Fig. 8.13 B) exhibits the rising trends in the water level particularly in upper reaches of the study area.
5. Spatial hydrographic profiles depicting pre-canal irrigation and recent level (Fig. 8.13 C) show overall rise in water storage ranging between 0.50 - 13.5 m. It is maximum in the upper command area and minimum in the lower command. This rise in the water levels clearly indicates recharge to the aquifers through the returned irrigation seepage and canal seepage. Minimum rise in water level in the lower reaches of the command is attributed to the surface drain, developed by the command authority for the purpose of controlling the rise in water level.

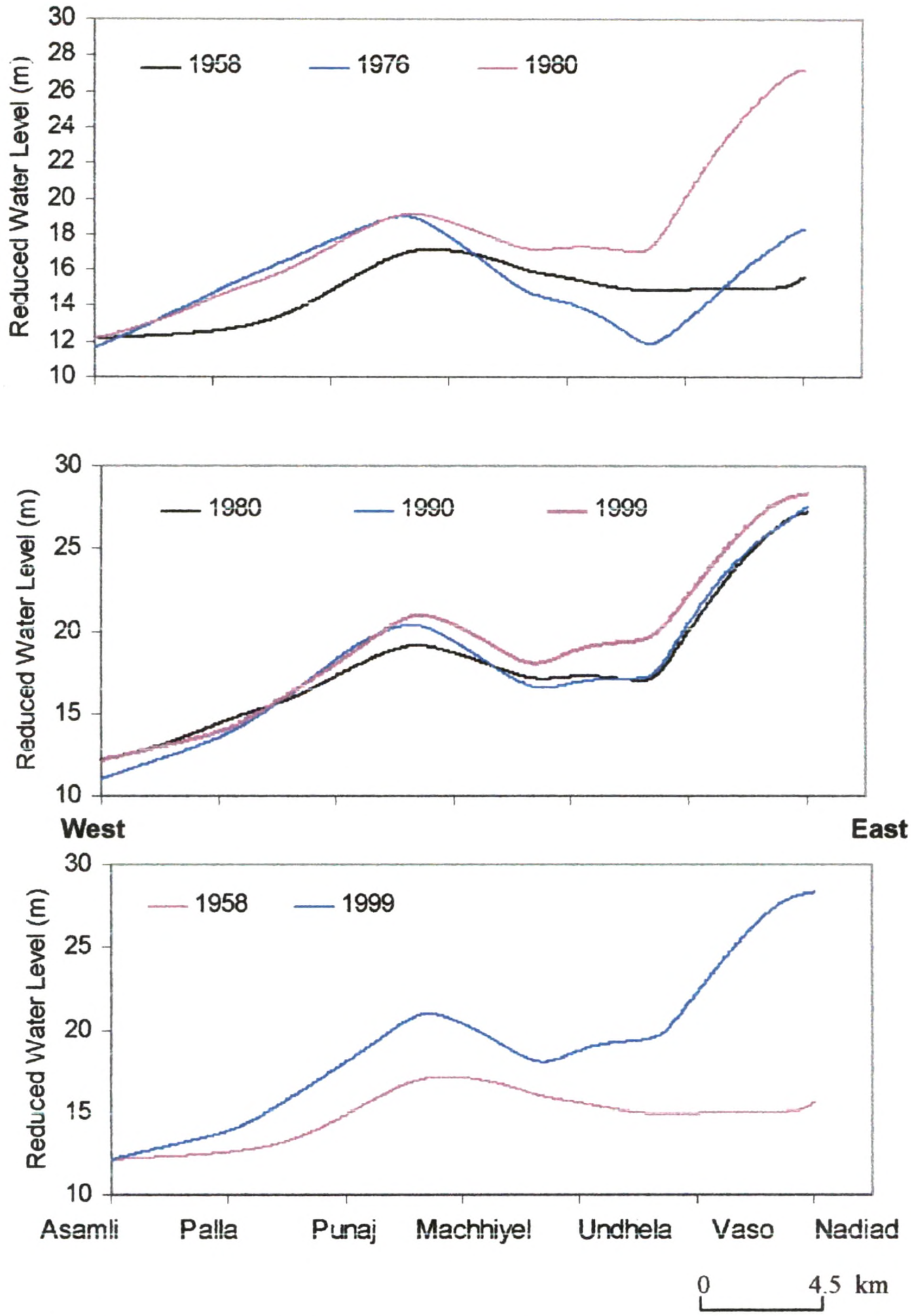

Fig. 8.13 Spatial Hydrographic Profile Along Asamli-Nadiad (A-A') Transact Showing Secular Changes in Groundwater Regime in Matar Command Area.

NET-CHANGE IN GROUNDWATER REGIME:

In order to estimate the spatial secular change in the groundwater storage, right from pre-canal irrigation to present (1999) period; the author has prepared a supplementary contour map by superimposition of 1958 and 1999 RWL contour maps. Then the positive and negative values were depicting net change in groundwater storage has been prepared (Fig. 8.14). It is significant to note from this map that over the period of 40 years entire Matar command area exhibit rise in water level. in the upper command, the rise is between 5-13 m, middle command 3-5 m and the lower command 1-3 m rise in water level is seen.

HYDRO ISO-BATH ANALYSIS:

Study and evaluation of static water level behaviour in irrigation command is of utmost importance from the point of view of waterlogging problems and the mitigatory measures. Periodic monitoring of water levels provides area specific details on its critical rise and help in classifying the area in accordance with the potential hazards.

Based on historical data on water level behaviour and authors own observation for three seasons, the author has prepared the hydro iso-bath maps for different periods i. e. pre-canal irrigation, achieved the 100 % irrigation potential phase (from 1976) to 1999 (at interval of 05 years), for both pre- and post-monsoon seasons. A case example for the year 1999 is give as in Fig. 8.15 and 8.16.

The prepared hydro iso-bath maps thus provide range of water level and its spatial coverage. The quantitative estimates prepared for different period on range of water levels i. e. 0.00-1.50 m (waterlogged), 1.50 - 3.00 m (prone to waterlogged), 3.00- 6.00 m (rise in water level) and more than 6.00 m (deep water level) are give in Table 8.4.

Table 8.4 Hydro Iso-Bath Estimates of Matar Branch Command Area.

Depth (m)	Year of Observation											
	1976		1980		1985		1990		1995		1999	
	Aerial Extent (ha) & Percentage											
	Ha	%	ha	%	Ha	%	ha	%	ha	%	ha	%
	Pre-monsoon											
0-1.5	0	0	0	0	0	0	0	0	2821.58	12.46	550.81	2.43
1.5-3.0	2255.22	9.96	590.22	2.61	3987.37	17.61	3538.37	15.63	5687.24	25.12	7945.98	35.1
3.0-6.0	6954.55	30.72	18458.38	81.53	16716.54	73.84	14074.76	62.17	11741.85	51.86	13349.9	58.97
> 6.0	13430.24	59.32	3591.41	15.86	1935.92	8.55	5026.92	22.2	2389.31	10.55	793.36	3.5
	Post-monsoon											
0-1.5	5690.92	25.14	5044.59	22.28	3161.71	13.97	5619.34	24.82	4757.95	21.02	6123.26	27.05
1.5-3.0	5503.32	24.31	12220.3	53.98	6451.92	28.5	6629.32	29.28	9518.01	42.04	10708.87	47.3
3.0-6.0	4291.99	18.96	4807.62	21.24	11864.11	52.4	10391.34	45.9	7507.66	33.16	5806.12	25.65
> 6.0	7153.76	31.6	567.52	2.51	1162.25	5.13	0	0.00	856.4	3.78	1.76	0.01

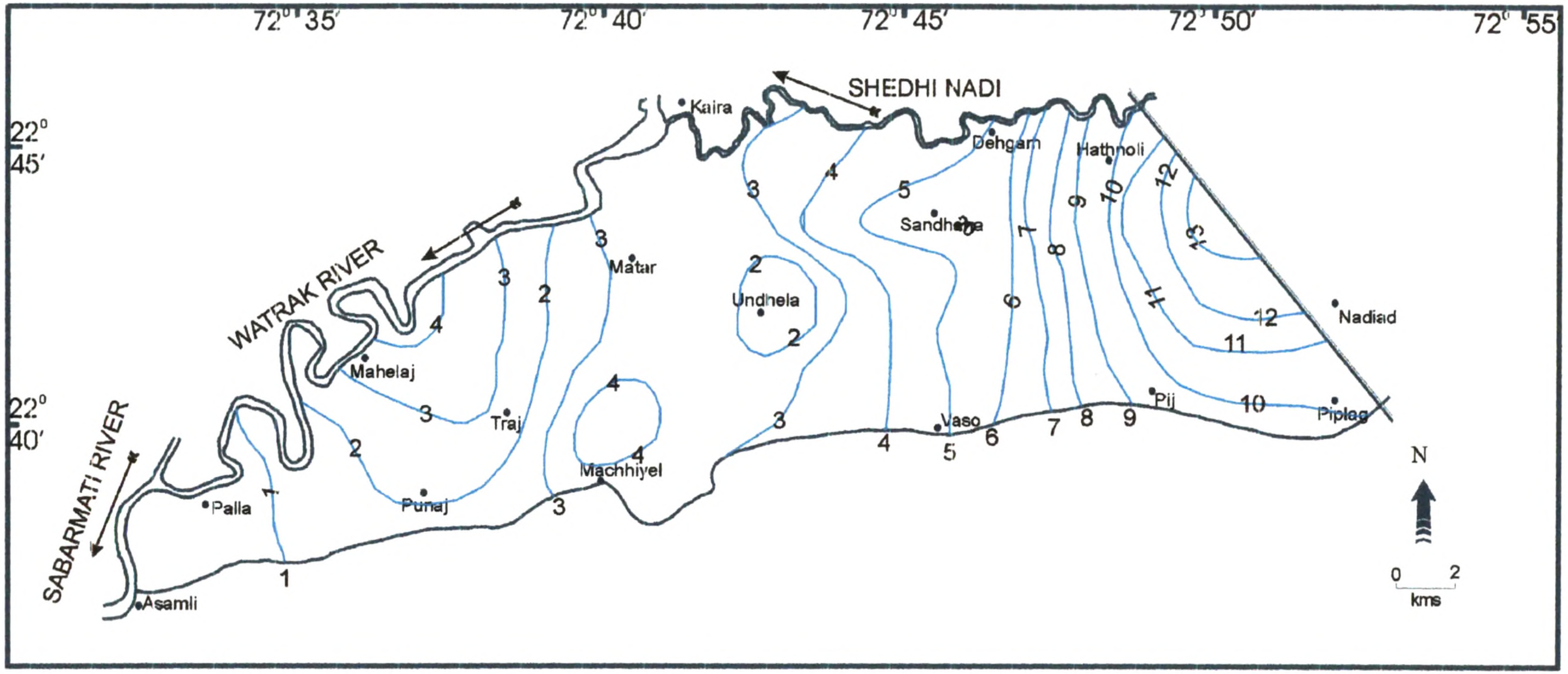

Fig. 8.14 Net Change in Groundwater Regime in Matar Command Area. (Year: 1958-1999)

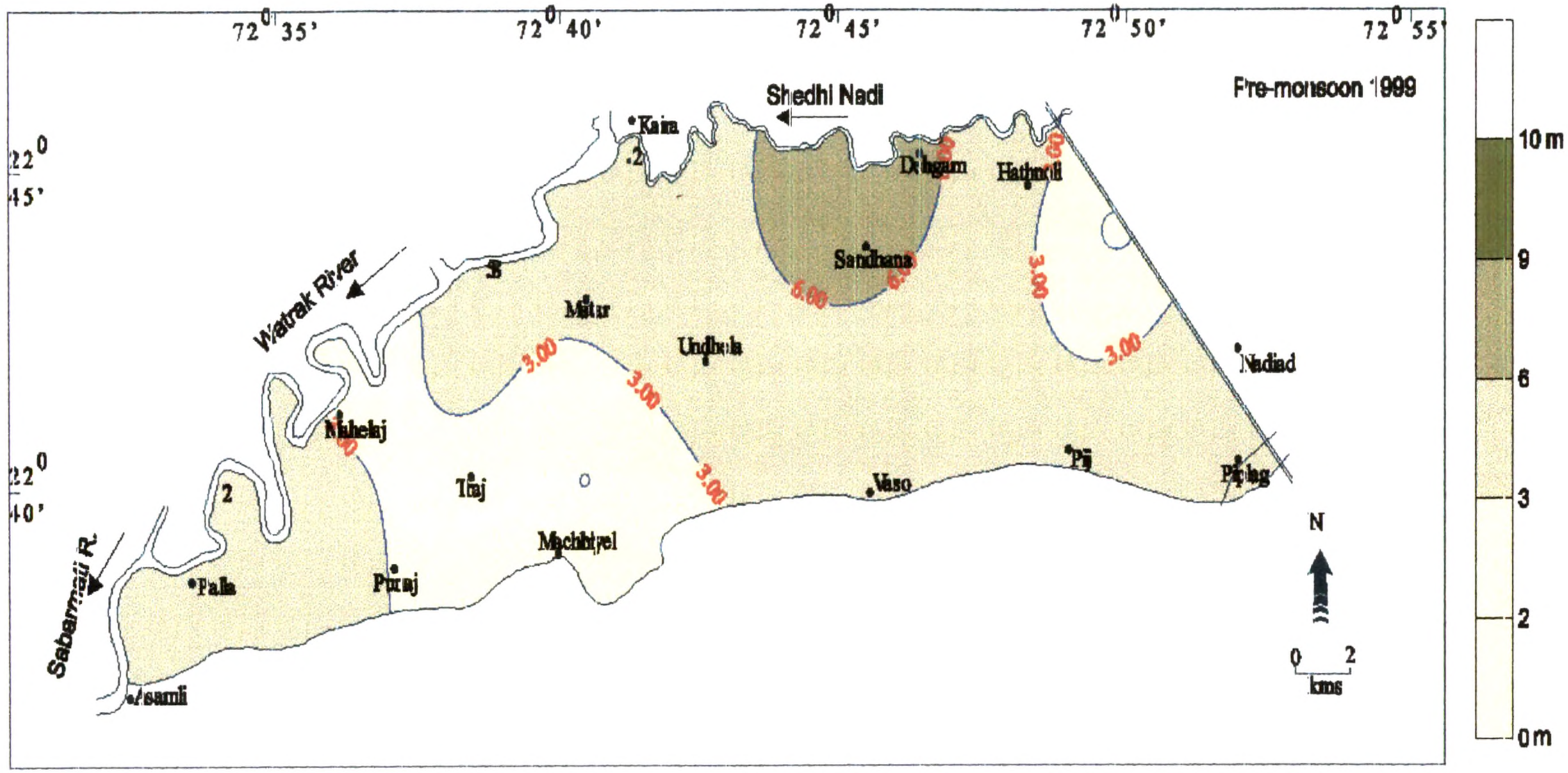

Fig. 8.15 Hydro Iso-bath Map of Matar Command Area. (Year: Pre-monsoon 1999)

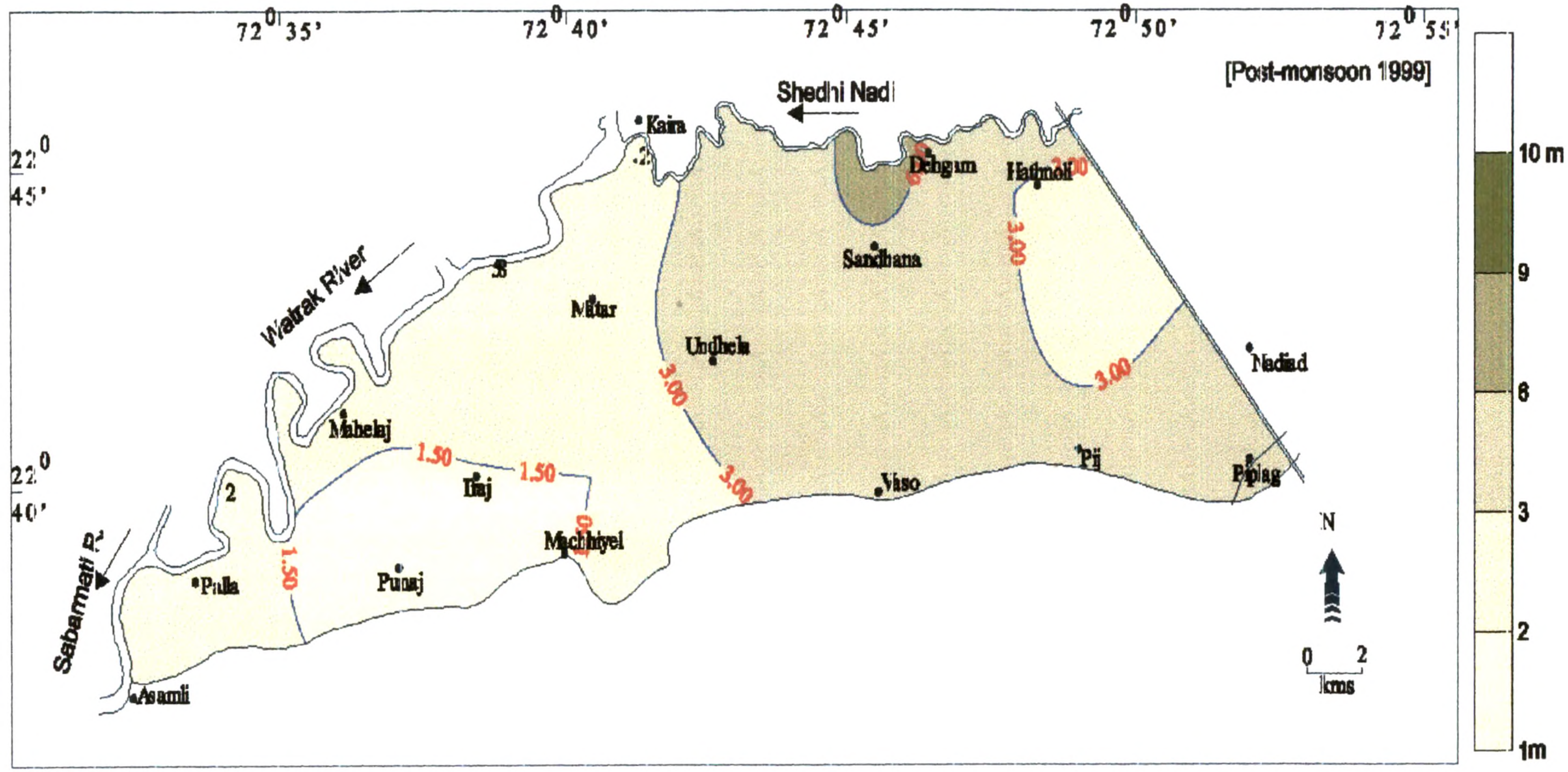

Fig. 8.16 Hydro Iso-bath Map of Matar Command Area. (Year: Post-monsoon 1999)

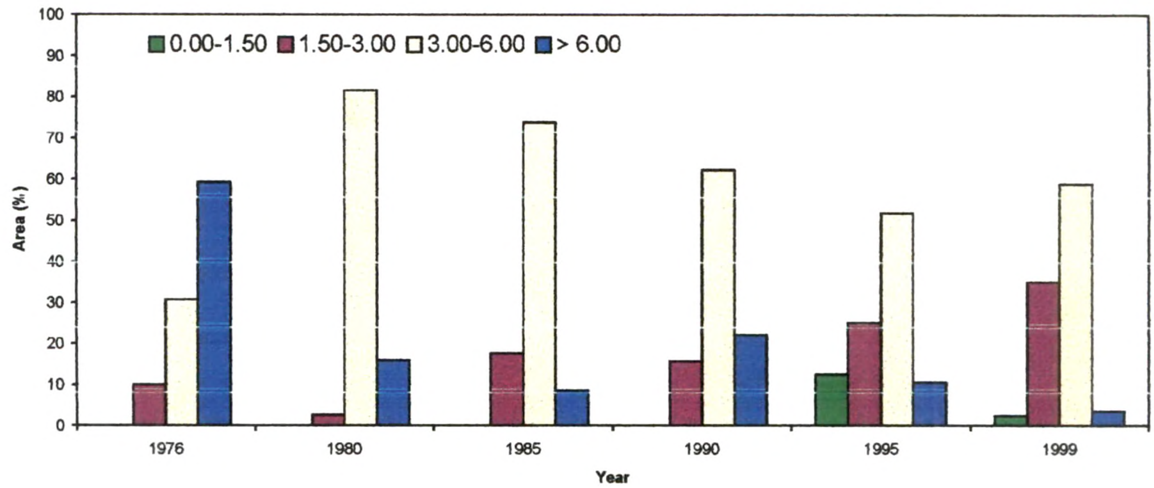

Fig. 8.17 Hydro Iso-Bath Trends in Matar Command Area

The obtained estimates for the pre-monsoon season show almost 60 % of the area was having water table > 6.00 m in 1976; this has been reduced to mere 3.50 % in 1999. In a time span of 25 years almost 37.00 % of the command area has been fallen in the categories prone to waterlogged (35.00 %) and waterlogged (3.00 %). The situation during post-monsoon season is still worsened, where in almost 25.00 % change is witnessed up to 3.00 m water table depth categories. Almost 75 % command area has now falling under the categories of prone to waterlogged (47.31 %) and waterlogged (27.50 %). The water table more than 6.00 m not even covers 1.00 % of the total command area. The prepared histogram (Fig. 8.17) with the help of hydro iso-bath data clearly establish the discussed facts.

Based on the above inferences if the adequate measures are not adopted, the large part of the command shall be inviting and ecological disaster.

GROUNDWATER CHEMISTRY

The quality of groundwater is an important as the quantity. The suitability of natural water for any particular purpose depends upon the standards of acceptable quality for the respective use. Study of groundwater chemistry form a part of chemical hydrogeology. Chemical hydrogeology is the study of chemical energy of the hydrogeologic system and can be defined as simply as a study of geologic and hydrologic controls on the chemical character of groundwater (Beck, 1993). Hydrochemical investigations are basically carried out to determine groundwater circulation and its velocity and its sources, concentration, behaviour, and fate of chemical constituents. Chemistry of groundwater is governed by the factors related to chemistry of infiltrating water, which is largely controlled by air temperature, frequency, vegetation and soil cover, mineralogy and thickness of the material, potentiometric head distribution regulating flow path and residence time; are additional factors that effects the chemistry of groundwater.

Dissolved salts are mainly contributed to the groundwater by the process decomposition involving hydrolysis, hydration, solution, oxidation and carbonation under various geochemical environments (Cadek et. al. 1968). The significance of dissolved elements in groundwater could be characterised according to its source fate, mobility, toxicity, abundance and economic value. In the present study the author has attempted to evaluate the groundwater chemistry from the point of view of long term irrigation practices vis-a-vis consequences of possible enrichment in dissolved constituents causing adverse environmental impacts.

CHEMICAL EVALUATION OF GROUNDWATER

Electrical Conductance (EC):

Electrical conductance of water helps to determine the salinity level of the water by measuring the ionic concentration. Detail analytical data for the three seasons measured by the author are given in the Annexure III. The electrical conductance in the area found to be greater than 1000 mmhos/cm through all the three seasons. The electrical conductance of the area falls in the range of 1000-3200 mmhos/cm. the data indicates that there is considerable increase in the electrical conductance with time. The exceptionally higher values have been found in wells located at Bamroli (4140 mmhos/cm), Sokhada (4784 mmhos/cm), Nadiad (6425 mmhos/cm), Pij (3956 mmhos/cm), Matar (6716 mmhos/cm), Pipriya (4600 mmhos/cm), Punaj (5612 mmhos/cm), Kharenti (4600 mmhos/cm), and Asamli (8648 mmhos/cm). These all wells are scattered over the entire command area. Study on seasonal fluctuation in electrical conductance with respect to each soil type, has revealed that the moderate textured sandy loam soil shows higher order of fluctuation as compared to the sandy clay loam, clay loam and clayey soils. This higher order of fluctuation may be ascribed to monsoon recharge that result in to dilution of groundwater (Pariente, 2001). Whereas in case of sandy clay loam, clay loam and clayey soils the fluctuation in electrical conductance has been observed very low to negligible. However, with time electrical conductance shows an increasing trend. This gain in electrical conductance may be attributed to low permeability of the soils, which impedes the movement of water and hence the higher residing time and more interactions with the sediments.

The prepared bar diagram on electrical conductance tends for different soil types (Fig. 8.18 a & b) are in conformation to above cited explanations.

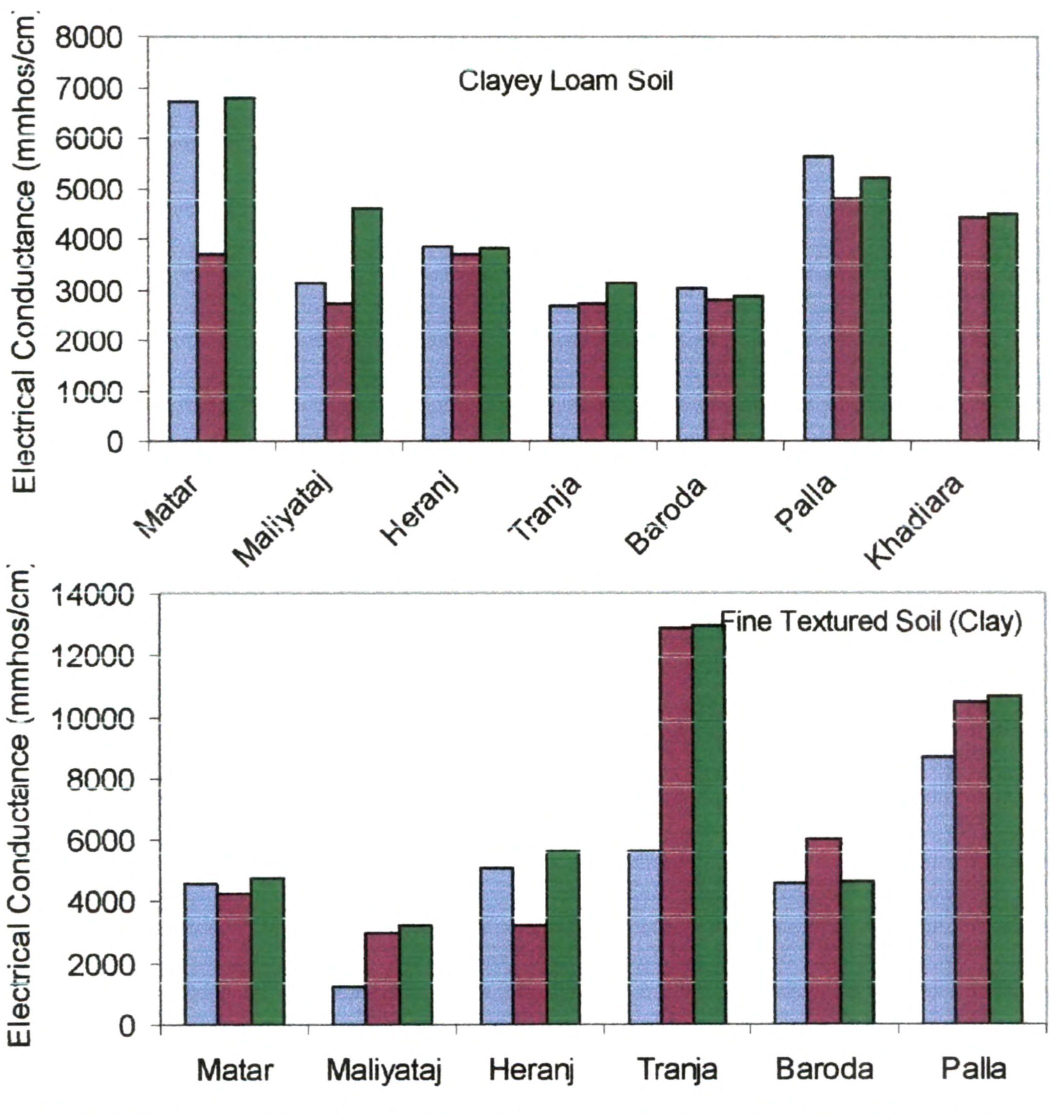

Fig. 8.18 a Seasonal Variation in Electrical Conductance of Groundwater in Matar Command Area.

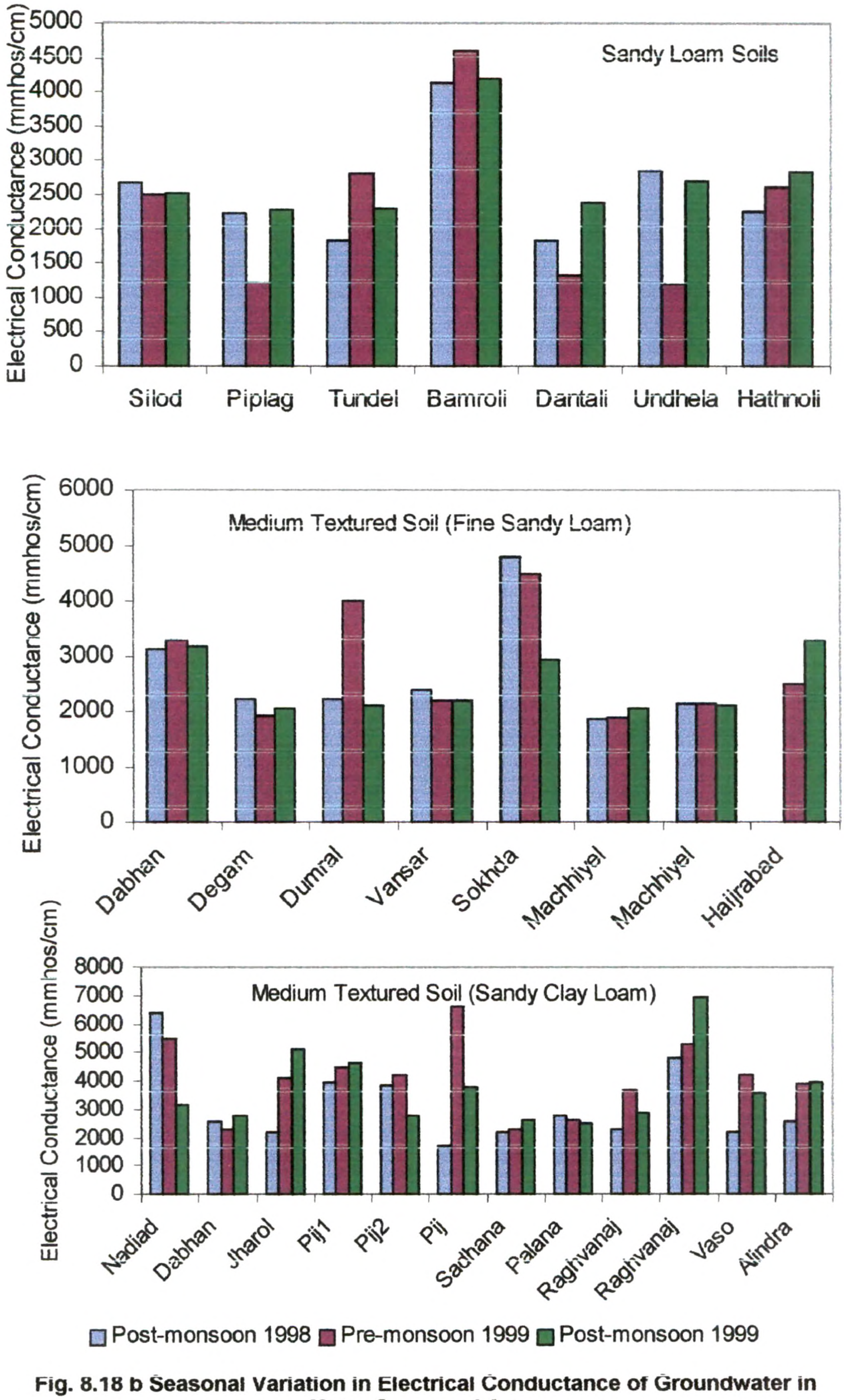

Fig. 8.18 b Seasonal Variation in Electrical Conductance of Groundwater in Matar Command Area.

In order to evaluate long term behaviour of EC, the author has collected the hydrochemical data including pre-canal irrigation phase. The data on annual changes in EC values, over the period of 40 years through pre-monsoon records are given in Table 8.5. It is evident from the table that during the pre-canal irrigation phase electrical conductance was considerably low (65 - 531 mmhos/cm). After 40 years sharp rise in EC values is observed (400 and 12900 □mhos/cm). The plotted bar diagram (Fig. 8.19) considering long term change in EC values shows considerable rise in EC values from 1976 onwards; majority of the location the EC values have crossed 3000 mmhos/cm i. e. saline water category. These increasing trends in EC values are suggestive of excessive recharge from returned irrigation seepage and rainfall and less groundwater abstraction. Due to this there is continual enrichment of the dissolved salts thereby rising trends in EC.

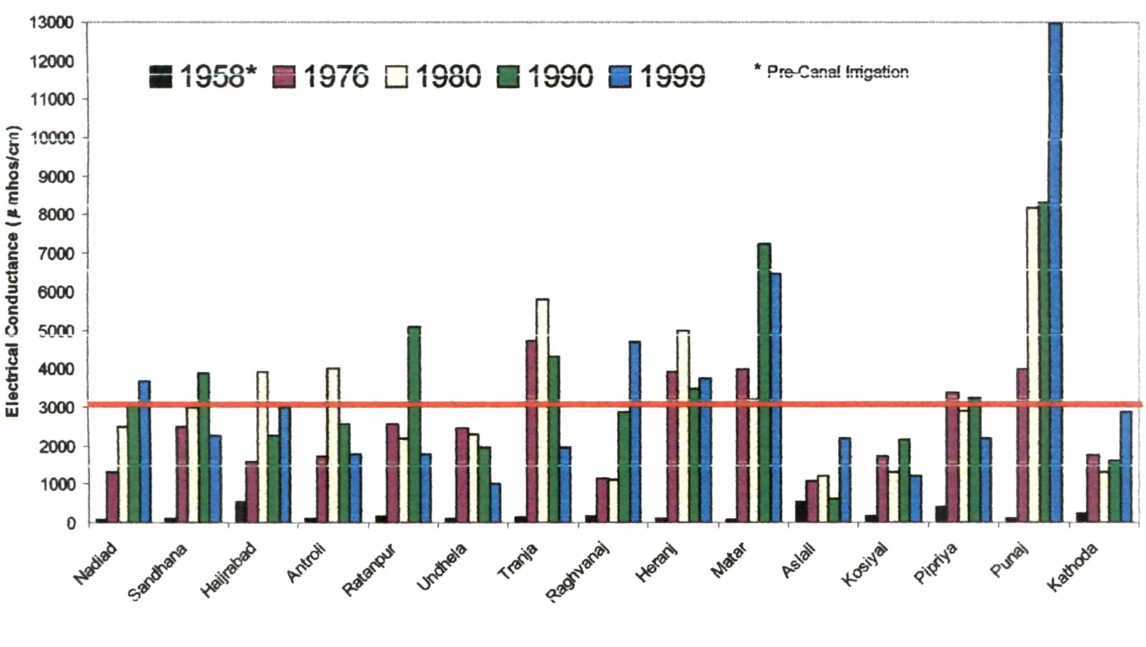

Fig. 8.19 Location Specific Secular Variation in Electrical Conductance of Groundwater in Matar Command Area.

Table 8.5 Secular Variation in Electrical Conductance in Matar Command Area

(* Pre-Canal Irrigation Scenario, Pre-monsoon)

Location	Year of Observation						
	1958*	1976	1980	1985	1990	1995	1999
	Electrical Conductance □mhos/cm						
Nadiad	81	1320	2500	2800	3060	7668	3680
Sandhana	85	2500	3000	856	3876	745	2268
Haijrabad	531	1570	3900	3813	2244	1944	2997
Antroli	98	1720	4000	2484	2550	2052	1782
Ratanpur	155	2550	2200	2116	5100	1944	1782
Undhela	96	2450	2300	1840	1938	1188	1008
Tranja	120	4700	5800	3404	4320	2300	1944
Raghvanaj	156	1130	1100	3680	2856	6048	4698
Heranj	115	3920	5000	4508	3478	4536	3726
Matar	65	3970	3200	5060	7236	8280	6480
Aslali	528	1080	1200	708	605	662	2187
Kosiyal	169	1720	1300	1840	2164	2484	1215
Pipriya	418	3380	2880	2300	3240	2760	2187
Punaj	110	3970	8200	7728	8320	9200	12960
Kathoda	240	1760	1300	1104	1620	1932	2855

Taking in to account the EC classification for irrigation water quality, the author has categorized these EC values in to 04 groups. Latter with the help of iso-bath contours computed the aerial coverage of an individual group for different years during pre- and post-monsoon season (Table 8.6). This long term conspicuous changes observed in percentile coverage of an individual EC categories during pre- and post-monsoon periods is under the varied factors viz., soil type, monsoon recharge, lateral extent and hydraulic behaviour of an individual aquifers, returned irrigation seepage and the groundwater utilization.

Table 8.6 Temporal Aerial Distribution Pattern of Electrical Conductance in Matar Command Area

E. C. mhos/cm	Year of Observation											
	1976		1980		1985		1990		1995		1999	
	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	ha
	Aerial Extent (ha) & Percentile Value											
	Pre-monsoon											
0-1000	0.00	0.00	0.00	0.00	0.13	30.51	0.64	145.08	1.76	397.84	0.00	0.00
1000-2000	6.10	1380.65	5.10	1155.66	4.44	1005.90	4.75	1075.31	29.66	6714.36	6.10	1380.65
2000-3000	46.66	10564.36	20.66	4677.14	27.01	6115.18	23.09	5228.42	34.43	7794.10	46.66	10564.36
> 3000	47.24	10694.99	74.24	16807.21	68.41	15477.47	71.52	16191.23	34.16	7733.71	47.24	10694.99
Post-monsoon												
0-1000	6.73	1522.60	0.01	1.92	0.00	0.00	8.83	1999.69	1.35	306.48	0.00	0.00
1000-2000	41.93	9492.14	19.24	4356.05	6.52	1475.39	24.30	5500.69	31.57	7146.59	10.15	2298.33
2000-3000	24.00	5434.31	36.67	8302.92	22.95	5196.91	23.88	5406.95	34.41	7791.09	45.79	10367.50
> 3000	27.35	6191.00	44.08	9979.15	70.53	15967.71	42.99	9732.67	32.67	7395.83	44.06	9974.18

Hydrogen Ion Concentration (pH):

This parametric is basically suggestive of acidic, neutral-alkaline-basic chemical environment. The study of pH data right from pre-canal irrigation period to the present does not show any significant change (Table 8.7). However, the obtained pH values and their trend are indicative of slight increase thereby developing tendency towards alkalinity. Further the quantitative evaluation of this parameter (Table 8.8) indicate that 33.00 % of the area (7414.31 ha.) which was under the pH of greater than 8.5 during 1976 now shows considerable change i. e. between 7.5-8.5. This improvement in pH may be attributed to the flushing of the alkaline groundwater with the good quality of the canal water (USGS, 1954).

Table 8.7 Secular Variation in pH of Groundwater in Matar Command Area

Location	Year of Observation						
	1958*	1976	1980	1985	1990	1995	1999
	pH						
Nadiad	8.00	8.80	9.00	8.10	8.80	8.70	8.10
Sandhana	7.50	8.10	8.30	7.60	8.30	7.80	8.20
Haijrabad	7.50	8.10	8.60	7.60	8.10	8.30	8.40
Antroli	8.00	7.40	8.80	7.70	7.90	8.00	8.20
Ratanpur	8.00	8.50	8.80	7.50	8.20	7.90	8.00
Undhela	8.00	8.50	8.50	7.70	8.30	8.80	8.20
Raghvanaj	7.00	8.30	7.50	7.30	8.10	7.30	7.70
Heranj	7.00	8.50	8.20	7.70	8.90	8.00	8.40
Matar	7.50	9.00	8.10	7.40	7.60	8.00	8.10
Tranja	7.50	8.60	8.20	7.40	7.80	7.60	8.10
Aslali	8.50	9.00	8.40	7.80	8.80	7.50	7.50
Kosiyal	8.50	9.00	8.50	7.50	8.50	7.50	7.00
Pipriya	8.00	8.60	8.50	7.30	8.40	7.80	8.30
Punaj	8.00	8.00	8.40	7.60	7.90	7.50	7.70
Kathoda	7.50	8.00	8.40	7.20	8.30	7.10	7.60

*** Pre-Canal Irrigation Scenario**

Table 8.8 Temporal Aerial Distribution Pattern of pH in Matar Command Area

pH	Year of Observation											
	1976		1980		1985		1990		1995		1999	
	Aerial Extent (ha) & Percentile Value											
	%	Ha	%	Ha	%	Ha	%	ha	%	Ha	%	Ha
	Pre-monsoon											
< 7.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5-8.5	67.25	15225.69	59.71	13517.29	65.93	14925.58	94.67	21432.88	98.82	22370.71	100	22640
> 8.5	32.75	7414.31	40.29	9122.71	17.04	3857.22	5.33	1207.15	1.19	269.27	0.00	0.00
	Post-monsoon											
< 7.5	0.00	0.00	0.00	0.00	1.03	233.83	8.85	2003.48	15.06	3409.72	21.75	4923.17
7.5-8.5	54.15	12258.46	100	22640	97.93	22172.36	82.30	18633.08	69.88	15820.55	78.25	17716.84
> 8.5	45.85	10381.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total Dissolved Solids:

This parameter comprises dissociated and associated substance, but not suspended material, colloids or dissolved gases. The amount and character of the dissolved substances depends upon the chemical composition and physical structure of rocks, temperature, duration of contact time, dissolved constituent already available in solution, pH and Eh conditions (Hem, 1959). The total dissolved solids content can amount to less than 10 mg/l in rain and snow, less than 25 mg/l in water in humid regions with relatively insoluble rocks, and more than 3,00,000 mg/l in brines (Davis and De Weist, 1967).

Matar command area shows considerable seasonal fluctuations in TDS values. As the groundwater is associated with the alluvium aquifer, perhaps availability of an ideal storage and monsoon recharge lead to an overall enrichment in salts during post-monsoon period. Exceptionally higher TDS values are shown by the wells at Punaj (8256 mg/l), Asamli (6720 mg/l), Nadiad (3520 mg/l), Raghvanaj (3392 mg/l), Pipriya (2752 mg/l), Kharenti (3840 mg/l) and Sokhada (2880 mg/l).

Long-term variation in TDS (Table 8.9) does not show any specific pattern. However, the groundwaters in the lower reaches of the command show marked increased in TDS. This increase may be attributed to an over groundwater movement to that area, dominance of clayey sediments and inherent sediment salinity. As TDS is to be considered as a vital quality parameter in soil and water quality classifications; the author has developed the contour plans for asserting the spatial change during 1976 and 1999 i. e. 25 years.

Table 8.9 Secular Changes in Total Dissolved Solids (mg/l) in Matar Command Area

(Pre-monsoon)

Location	Year of Observation						
	1958*	1976	1980	1985	1990	1995	1999
Nadiad	51.84	844.80	1600.00	1792.00	1958.40	4907.52	2355.20
Sandhana	54.40	1600.00	1920.00	547.84	2480.64	476.80	1451.52
Haijrabad	339.84	1004.80	2496.00	2440.32	1436.16	1244.16	1918.08
Antroli	62.72	1100.80	2560.00	1589.76	1632.00	1313.28	1140.48
Ratanpur	99.20	1632.00	1408.00	1354.24	3264.00	1244.16	1140.48
Undhela	61.44	1568.00	1472.00	1177.60	1240.32	760.32	645.12
Tranja	76.80	3008.00	3712.00	2178.56	2764.80	1472.00	1244.16
Raghvanaj	99.84	723.20	704.00	2355.20	1827.84	3870.72	3006.72
Heranj	73.60	2508.80	3200.00	2885.12	2225.92	2903.04	2384.64
Matar	41.60	2540.80	2048.00	3238.40	4631.04	5299.20	4147.20
Aslali	337.92	691.20	768.00	453.12	387.20	423.68	1399.68
Kosiyal	108.16	1100.80	832.00	1177.60	1384.96	1589.76	777.60
Pipriya	267.52	2163.20	1843.20	1472.00	2073.60	1766.40	1399.68
Punaj	70.40	2540.80	5248.00	4945.92	5324.80	5888.00	8294.40
Kathoda	153.60	1126.40	832.00	706.56	1036.80	1236.48	1827.20

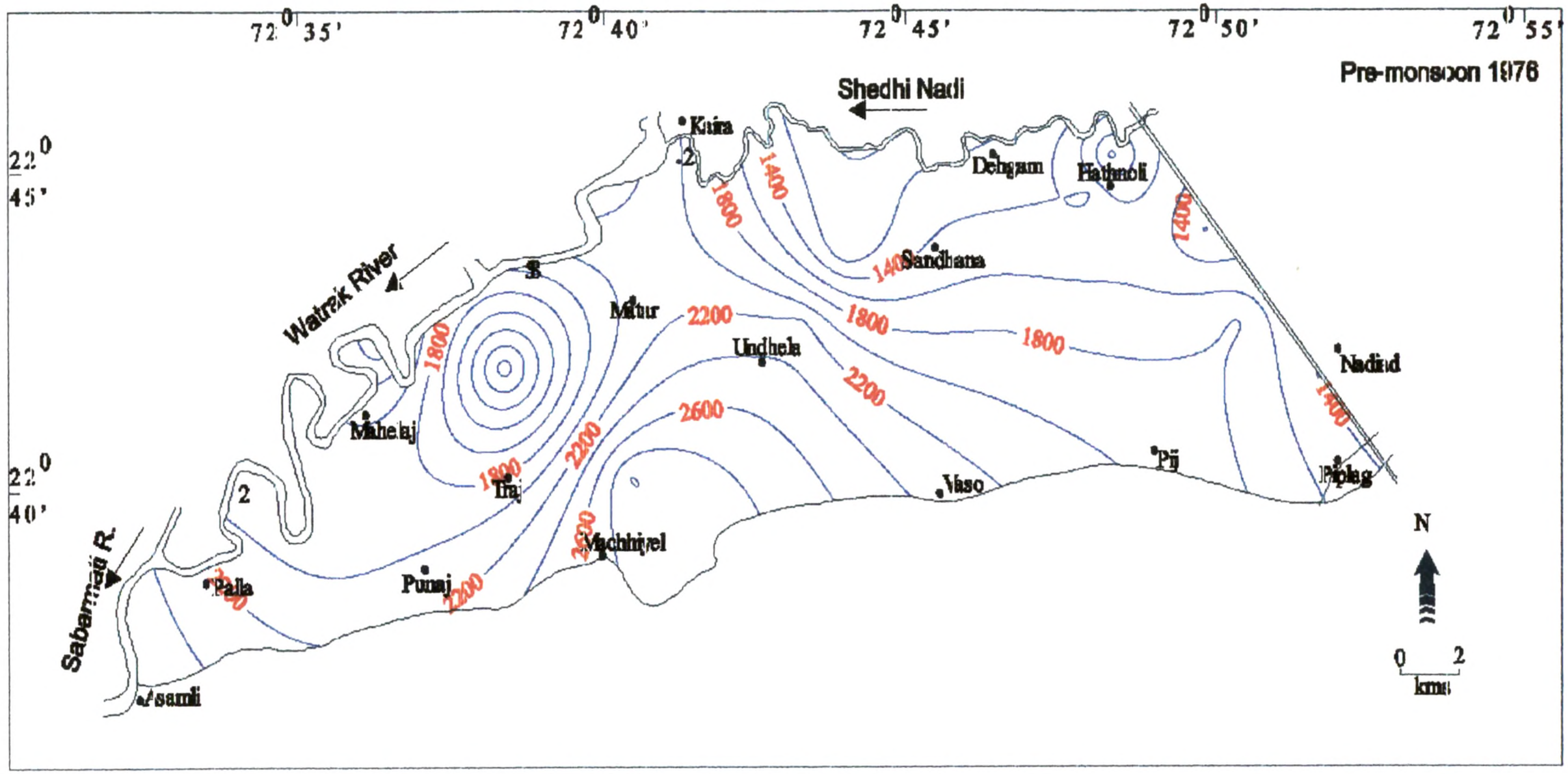

Fig. 8.20 Iso-TDS Contour Diagram of Groundwater in Matar Command Area. (Year: Pre-monsoon 1976)

The contour trend during the pre-monsoon 1976 scenario (Fig. 8.20) depicts that the TDS values are ranging between 800-2900 mg/l. The pattern indicates that the trend of increase in TDS is due southward and SE direction. The figures shows development of minima (800 mg/l) near Mahelaj and maxima of 2000 mg/l at Machhiyel, Hathnoli where as the entire command has TDS between 100 and 1500 mg/l.

Iso-TDS contour map (Fig. 8.21) for the year 1999 shows significant and overall rise in TDS content. This rise is noteworthy in the lower reaches of the command where in around Mahelaj TDS is attaining almost 9000 mg/l mark. Similarly there exists another maxima of 4000 mg/l near Nadiad in upper reaches of the command. It is significant to note that the middle reaches shows considerable improvement in TDS (i. e. 2800 to 2000 mg/l) might be on account of the existence of groundwater mound with radial outflow conditions.

This increasing scenario in TDS may be attributed to the groundwater flow under the available hydraulic gradient ultimately carrying the salts to the lower reaches, a zone serving the hydraulic (outflow) boundary.

Ionic Variation:

Sodium:

Plagioclase feldspars (Albite) which acts as a primary source, and the secondary less important sodium containing minerals such as Nepheline, Sodalite, Jadeite, Arfvedsonite, Glaucophane, Aegirine and members of Zeolite family forms major sodium constituent of igneous and metamorphic rocks on the earth. Sodium gets liberated during the decomposition of these silicates by the process of hydrolysis. The high solubility of sodium salts and limited degree of sorptive bonding of sodium on to clay mineral and other adsorbent lead to a considerable enrichment in sea and evaporite deposits (Matthess, 1982). In precipitates, the carbonate rocks sodium is only a minor constituent. Sodium also occurs as a cyclic salt or as a part of terrestrial dust in precipitation in small amount. However, its concentration is observed more in coastal areas (Riehm, 1961). Sodium is a bio-element and occurs in various chemicals used by man that ultimately enters in groundwater regime as pollutant (Feth, 1966). Solubility of sodium salts is very high, occasionally the solubility limits of sodium salt even exceeded, particularly inland drainage basin, where it leads to the precipitation of sodium salts such as $NaCO_3$, $NaHCO_3$, Na_2SO_4 and $NaNO_3$ (Langbein, 1961; Toth, 1966). The highest sodium concentration occurs in the association with Cl^-.

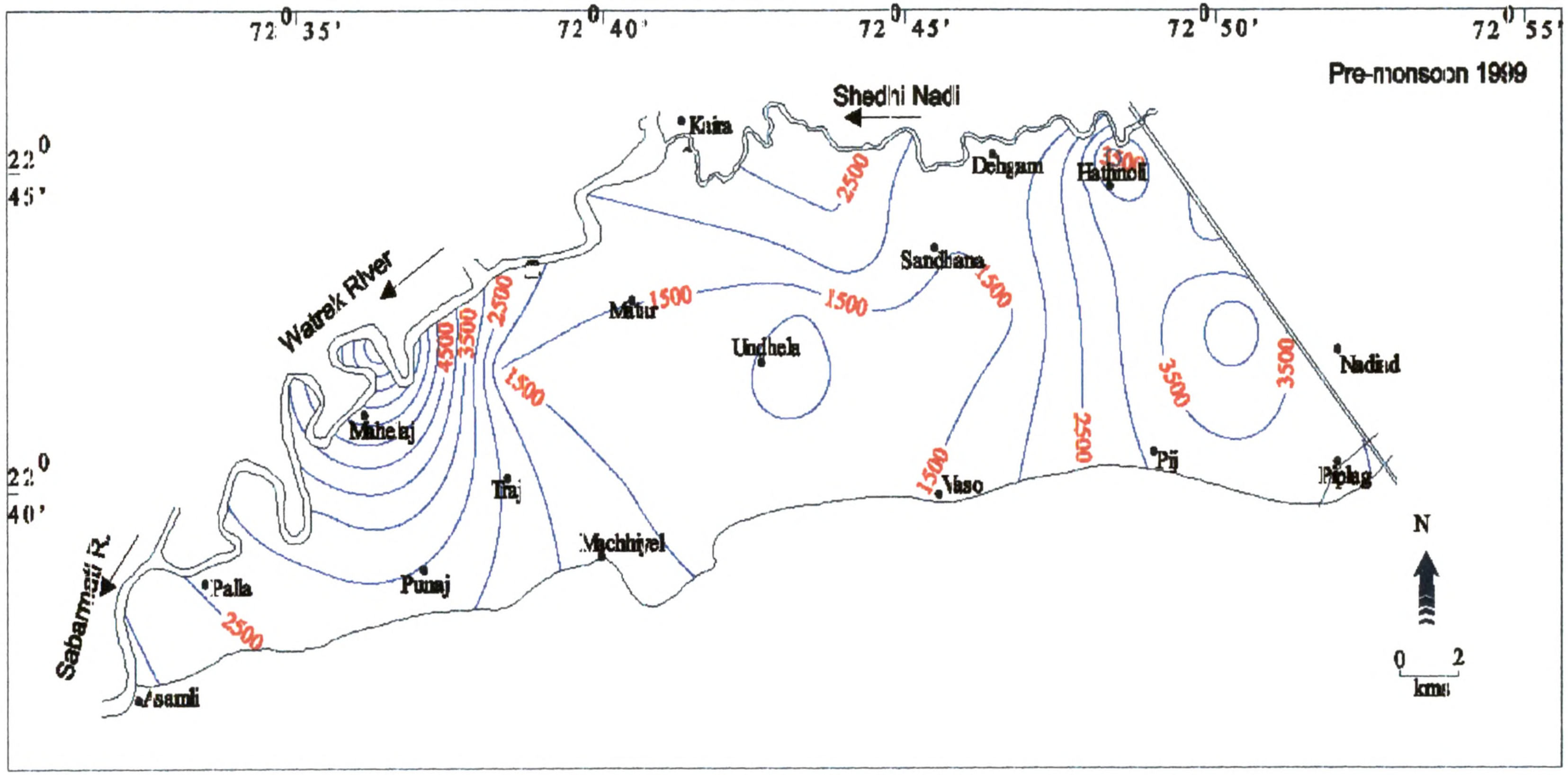

Fig. 8.21 Iso-TDS Contour Diagram of Groundwater in Matar Command Area. (Year: Pre-monsoon 1999)

Groundwater in well-drained area with good drainage and good amount of rainfall has less than 10 to 25 mg/l sodium. Sodium content of groundwater ranges from 1mg/l in humid region to over 100000 mg/l in brines (Hem, 1991). The re-use or non-utilization of water, which has high sodium content than natural water, for irrigation leaves the residue of sodium behind and causes the sodium hazards in soils.

The quantitative data on Na indicates that irrespective to the area and season, these two ions dominate the other cations. It is observed that Na content during the pre-monsoon 1999 ranging between 160.92 and 712.68 mg/l. The exceptionally higher values area shown by the water samples from localities viz., Dabhan (852 mg/l), Pij, Bamroli (1160.98 mg/l), Khadiarapura (1531.12 mg/l), Raghvanaj (1990.23 mg/l), Punaj (4726.93 mg/l), Traj (1701.24 mg/l). Monsoonal recharge in the area has causes the dilution of water, in term of sodium content, at places viz., Pij (896.60 mg/l), Heranj (162.078 mg/l), Machhiyel (67.82 mg/l).

Post-monsoon 1999 data indicates that sodium content during the season ranging between 80.69 mg/l and 1202.81 mg/l with the exceptionally higher values at Punaj, Sokhada, Pipriya, Heranj and Bamroli.

This overall seasonal rise in sodium content in the groundwater may be ascribed to numerous reasons i. e. (I) Groundwater recharge from rainfall and returned irrigation seepage thereby rise in water table; (II) Sodium on leaching from rocks tend to remain in solution, it takes in no important precipitation reactions like Ca and Mg and (III) Sodium bearing water may under conditions participate in base exchange reactions whereby sodium replaces other cations in clay minerals (Hem, 1970; Matthess, 1982).

Potassium:

The average potassium content of igneous rocks is 25,700 mg/kg, which is slightly, less than the sodium content (Horn and Adams, 1966; Hem, 1970; Turekian, 1969). Common sources of potassium are the decomposition product of Orthoclase, Microcline, Biotite, Leucite and Nepheline in igneous and metamorphic rocks (Sravanth and Sudarshan, 1998). Upon migration the potassium content tend to be fixed partly by sorptive adsorption on clay and partly by taking part in formation of secondary mineral (Rankama and Sahama, 1960). In sandstone the potassium content is high because of adsorbed potassium in cementing material and by weathered potassium feldspar and micas (Hem, 1970). Potassium is also used as an agricultural fertilizer which lead to significantly higher concentration in groundwater (Harth, 1965). The lower geochemical mobility of potassium is the main factor for an overall low concentration than sodium. The concentration of potassium ranges from 1mg/l to about 10-15 mg/l in potable water (Hem, 1991).

Potassium content in the groundwater hardly exceeds the 40.00 mg/l, and does not show any significant change during the post-monsoon period. This element is an important plant nutrient and thus takes part in the biological cycle and returns back to the soil by plant decay. Also, its lower geochemical mobility in fresh water could be the possible reason for its lower and balanced concentration.

Calcium:

Groundwater in contact with sedimentary rocks of marine origin derives most of their calcium content from solution of Calcite, Aragonite, Dolomite, Anhydrate, and Gypsum (Davis and De Weist, 1967). In Igneous and Metamorphic rocks, decomposition and disintegration also releases calcium from calcium bearing minerals such as Apatite, Wollastonite, Fluorite, Feldspars, Amphibole and Pyroxene group minerals. Calcium also originates as a cyclic salts from seawater or from the dust of calcareous rocks and industrial emissions (Matthess, 1982). The range of calcium concentration in groundwater also depends on the solubility of $CaCO_3$, sulphate ($CaSO_4$) and to lesser extent chloride ($CaCl_2$). The solubility of $CaCO_3$ depends upon the partial pressure of CO_2 in atmosphere (Pawar, 1996). The groundwater has Ca concentration ranging between 70-100 mg/l (Hem, 1991). Calcium ions are removed from the groundwater by ion exchange with sodium and other ions on clay. This process usually takes place at the interface of Na-Cl rich water and fresh water. The same process also comes about in soils for irrigated by salt bearing surface water (Hem, 1970).

The observed calcium content during the post-monsoon 1998 is ranging between 6.01 and 30.06 mg/l. Exceptionally higher values of Ca has been observed around the localities Sokhada (41.68 mg/l), Baroda (46.49 mg/l), Kharenti (46.49 mg/l), Raghvanaj (112.22 mg/l) and Aslali (128.26 mg/l). On seasonal changes in Ca concentration, the pre-monsoon 1999 data shows somewhat increase in the calcium content i. e. 4.00 to 46.09 mg/l with the higher values reported at the Bamroli (117.03 mg/l), Pij (109.01 mg/l), Heranj (112.22 mg/l). Further monsoon recharge i.e. post-monsoon 1999 the calcium content shows increase in concentration and ranges between 20.04 and 60.12 mg/l. The relative increase in the calcium content with time may be attributed to the rising trend of the groundwater levels and continuous building up of the salt.

Magnesium:

The common sources of magnesium in groundwater are dissolution of Dolomite and magnesium calcite in sedimentary rocks; weathering of Olivine, Biotite, Hornblende and Augite in igneous rock; Serpentine, Talc, Diopside and Tremolite in metamorphic rocks alteration of clays and freshwater-seawater mixing. In the presence of carbonic acid in water, magnesium carbonates is converted in to more soluble magnesium bicarbonate (Karanth, 1987).

$$MgCO_3 + CO_2 + H_2O = Mg(HCO_3)_2$$

The solubility of magnesium carbonate is much greater than that of the $CaCO_3$ and hence it does not precipitate under the normal condition (Hem, 1970, 1991).

Overall magnesium content in the groundwater ranges between 0-36.47 mg/l. Exceptionally higher concentration of the magnesium has been observed from Jharol (345.10 mg/l), Raghvanaj (400.90 mg/l), Punaj (517.60 mg/l), Kharenti (133.59 mg/l). As such lower concentration of magnesium may be attributed to its lower geochemical abundance and occasionally be attributed to cation exchange (Davis and De Weist, 1967; Matthess, 1982). Higher values observed locally may be attributed to the continual accumulation of magnesium rich salts derived in solution from the catchment areas having magnesium rich rocks like Serpentinite, Olivine basalt etc. Also, the clayey soils in the command area are dominated by the mica with higher magnesium content as magnesium carbonate, which has higher solubility in water in the presence of the CO_2 (Matthess, 1982).

Chloride:

Majority of chloride in groundwater comes form ancient seawater entrapped in sediments, solution of halite, and related minerals of evaporate deposits (Walton, 1970). In Igneous rocks chloride found in Scapolites, Sodalites, and Apatite and also as liquid inclusion in minerals (Correns, 1956, Goguel, 1965). Chloride ions are not retained in permeable rocks and in impermeable rocks it deposits as NaCl (Hem, 1970). The Cl^- ion is cyclic which may occurs in terrestrial evaporates deposits, volcanic emanation, and man-made air-borne pollutant in atmosphere (Matthess, 1982).

The geochemical data for post-monsoon 1998 shows the chloride concentration varies between 124.08 mg/l and 1240.85 mg/l. The seasonal changes i. e. post-monsoon 1999 shows slight variations in chloride concentration ranging between 106.36 mg/l and 1572.05 mg/l in the period of post-monsoon 1999. Exceptionally higher concentration of the chloride has been observed at the Hathnoli (2398.75 mg/l), Degam (2029.33 mg/l), Jharol (2066.20 mg/l), Dumral (2006.99 mg/l), Dantali (2849.71 mg/l), Vansar (2588.07 mg/l), Pipriya (3478.29 mg/l) Punaj (9111.42 mg/l), Asamli (7338.77 mg/l) and Hathnoli (9984.27 mg/l).

This exceptional and overall rise in the chloride content of the water may be ascribed to the rise in ground water levels due to over irrigation and return irrigation seepage. Also, the exceptionally higher values observed in the lower command areas might be account of clayey nature of soils. The small dimensions of the interstices in the clayey soils prevents the chloride ions to pass through and hence resulted in to higher concentration results (Hem, 1970).

Carbonates and Bicarbonates:

The system

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3- + H^+ \Leftrightarrow CO_3 + H^+$$

is very important in water, contributing the formation of various carbonate species that originate from carbonates in rocks and free carbon dioxide. In the lithosphere the carbonate concentrations found in Caustobiolites (of organic origin) and carbonate rocks. The total CO_2 content in groundwater divided in to free CO_2 (dissolved CO_2 and associated H_2CO_3) and bounded CO_2 (CO_3 and HCO_3) (Matthess, 1982). Water when charged with CO_2 from the atmosphere and as it passes through soil and rocks, reacts and forms carbonates and/or bicarbonates. Hem, 1970 and Derver, 1982 have defined that when pH of groundwater is below 4.3, the carbonates species exists in form of H_2CO_3, as it lies between 4.3 and 8.5 i.e. $8.5 > pH > 4.3$, the carbonate content changes to form of Carbonates (CO_3) and when the groundwater crosses the limits of the pH above 8.5 (i. e. $pH > 8.5$) the carbonate from changes to the Bicarbonate (HCO_3) (Hem 1970). Under the natural condition bicarbonate concentration in groundwater ranges from 100- 200 mg/l (Davis and De Weist, 1967).

Bicarbonate

The bicarbonate is the second dominating anion in the groundwater of the study area. Bicarbonate concentration in the groundwater during the post monsoon 1998 is ranging between 61.017 mg/l and 305.085 mg/l. The seasonal as well as return irrigation seepage resulted in the slight decrease and present day it is ranging between 61.017 mg/l and 290.44 mg/l. Higher concentration of the bicarbonate is reported in the localities viz., Piplag, Pij, Traj, Kosiyal, Aslali, Palla, Asamli, Machhiyel.

Carbonate

The analytical data indicates that the carbonate content of the water remains within the limits of the 45 mg/l during the post-monsoon 1998 and the range is modified to the 54 mg/l during the pre-monsoon 1999. Further during the post-monsoon 1999 the carbonate content of water shows slight decrease in its concentration and limited to the 53.11 mg/l. This slow rise in the carbonate content is attributed to the release of the carbon dioxide under the higher water table condition.

Sulfate:

Sulfur with an average concentration of 410 mg/kg is relatively minor constituents of igneous rocks, 945 mg/kg in resistates, in hydrolysates 1850 mg/kg and in seawater 904 mg/kg, in precipitates at 4550 mg/kg reflects the geochemical mobility. Geochemical consideration has lead that sulfur is uniformly present in sea, in evaporites, in sedimentary rocks originally came from magmatic gases (Ricke, 1961). The sulfate is contained in Feldspathoid minerals (Nosean, Hauyne). It also occurs in gypsum, anhydrates and in potash salt deposits, or as cementing material and/or enclosed within the layer or cracks in sedimentary rocks. Calcium sulfate ($CaSO_4$) and sulfate of sodium (Na_2SO_4), occurs in marine and terrestrial evaporate deposits (Matthess, 1961, 1982). Considerable sulfate also added to hydrological cycle by precipitation, dust of continent, biochemical degradation of organic substance in soil, leachable sulfate from fertilizer applied (Rifferburg, 1925; Collins and Williams, 1933, Junge, 1954). Sulfate in groundwater circulating through sedimentary rocks may be naturally derived from dissolution of soluble sulfate minerals, the oxidation and solution of reduced sulphur minerals (Moncaster et. al. 2000).

From the analysis it has been found that the sulfate content during the post-monsoon 1998 ranging between 48.00 and 240.16 mg/l which has reduced to 48.00 to 144.09 mg/l during the post-monsoon 1999. This annual decline in sulfate content may be attributed to the increase in irrigation supply and gradual leaching of the soluble sulfate salts, through surface drainage as well as the subsequent flow, appearing in the streams (Hem, 1970).

WATER QUALITY EVALUATION

Climate, Environmental and Anthropogenic activity may deteriorate the surface water quality, where as the groundwater, which remains under the constant climatic conditions (i.e. temperature), clear and colorless makes it superiority to the surface water depending upon its function and purpose to be used. Sometimes, higher residual time or slow movement of the groundwater increases the interaction time with the substratum and thereby deteriorate the groundwater quality by increasing the dissolved constituents. Excessive irrigation practices will add the water with dissolved salt carried from the root zone and contribute to the groundwater also the water percolating rainwater with excess CO_2 and excess groundwater development sometimes contributes to the pollution of the groundwater. Therefore, it becomes necessary to evaluate the groundwater quality for the purpose specific utilization.

DRINKING WATER QUALITY ASSESSMENT

Over utilization and/or non-utilization of the groundwater and anthropogenic activities deteriorate the groundwater quality. The quality of groundwater also differs from place to place depending upon the nature and composition of aquifers and recharge area. The consumption of water for drinking and other purposes greatly depend on the chemical contents in the groundwater. For drinking water human being need balanced level of dissolved ionic concentration. Any deviation from desired level adversely affects the metabolism in human body and causes a variety of health hazards.

In order to eliminate the effect as a result of consumption of such a chemically imbalance groundwater, various standards and norms have been recommended by the World Health Organization (WHO), Indian Council of Medical Research (ICMR) and Indian Standard Institution (ISI). These standards (Table 8.10) define permissible limits of the different ions, the consumption of the groundwater with the below and above limits may cause the health hazards.

Table 8.10 Drinking Water Quality Standards vis-a-vis Groundwater Quality in Matar Command Area

(Chemical Parameters are in mg/l except pH)

Substance	W.H.O.	I.C.M.R.	I.S.I. (IS:10500)	MATAR COMMAND			
				Non-saline		Saline	River
				Pre-monsoon	Post-monsoon		
PHYSICAL PARAMETERS							
Color (hazen)	5 (50)*	5 (25)*	10	Color less⁺	Color less⁺	Color less⁺	Black⁺
Odor	Not desirable	Not desirable	Unobjectionable	Odorless	Odorless	Odorless	Strong ammonitic
Taste, JTU	Not desirable	5 (25)*	Agreeable	Normal	Normal	Saline	Not attempted
CHEMICAL PARAMETERS							
TDS	500 (1500)*	500 (1500)*	2000	700-2500	900-2800	2200 - 8500	3800
PH	7-8 (6.5-9.2)*	7-8.5 (6.5-9.2)*	6.5-8.5	7.3-8.6	7.4-8.3	7.8-8.3	7.8
TH	300 (600)*	300 (600)*	300	100-950	50-900	1000-2200	3900
Calcium	75 (200)*	75 (200)*	75	6 - 30	20 - 60	50-130	96.142
Magnesium	50 (150)*	50 (100)*	30	0-37	0-37	150 - 550	36.45
Chloride	200 (600)*	200 (1000)*	250	126- 1572	124 - 1240	2000 - 9000	750
Sulfates	200 (400)*	200 (400)*	150	48 - 240	40 - 230	240	515

(* Permissible limits of respective elements; + under normal eye vision)

As the study area constitute a part of irrigation command, response to recharge through rainfall and returned irrigation seepage has caused considerable variation in groundwaters' chemical content. Hence for the purpose of evaluation of groundwater quality, the author has divided the study areas' groundwater in to two categories viz., Saline and Non-saline. The river water chemistry, which is carrying considerable industrial pollutants, has also been analyzed to study the influence of its chemistry in the groundwater through recharge i. e. proximal peripheral areas of river channel. The physical observation during the fieldwork and chemical characteristics for the groundwater has been described in the Table 8.10.

The physical characteristics of the groundwater samples by and large indicate that the groundwater is colorless, odorless and is of the normal test. However, the groundwater from the lower command has brackish to saline taste, where as groundwater samples collected from the wells located near vicinity of the rivers Watrak and Sabarmati viz. Palla, Asamli, Baroda etc. has shown the color varying from Black to Cherry Red which is attributed to industrial effluents discharged in Watrak and Sabarmati Rivers. The groundwater samples from adjoining are giving strong ammonitic smell.

The chemical characteristics of the water samples from the command area depicts that the wells belongs to non-saline area are potable in nature i. e. all the elements are within the permissible limits. But the wells from the saline and near vicinity of the riverbank are showing the chemical content beyond their permissible limits, especially the hardness. The computation of groundwater quality for post- and pre-monsoon seasons has divulged no significant change in the groundwater quality. Therefore, overall groundwater quality deterioration in the quality study area may be attributed to continual recharge and non-utilization of the groundwater.

In order to estimate the level of pollution in groundwater especially in the river bank wells the author has calculated the sulfate to chloride and sodium to chloride ratios. The calculated data indicates that both the ratio values almost coincide with the ratio value of the river water indicating the recharge of the well with the river water. It has also been observed during the fieldwork that the people are practicing the irrigation by using polluted water directly from the river; the lower values obtained as the sodium to sulfate ratio in well water as compared to the river water points to proportional decrease in sodium over sulfate, mainly due to addition of sulfate from river water (Doshi and Paliwal, 1986).

Hardness:

The hardness of the water, which depends upon the total concentration of the dissolved solids, mainly expressed as measure of amount of calcium and magnesium dissolved in the water (Fetter, 1990). WHO and ICMR norms for evaluating the total hardness of the water, the dissolved solids up to 600 mg/l categorise as permissible for the drinking purpose.

The analytical data on groundwater hardness in Matar branch command area for the post-monsoon period suggests that the hardness do not exceeds the permissible limit. However, observations on subsequent seasons are indicative of continuous fall in its concentration. Exceptionally higher levels of the total hardness has been observed in the groundwater at Jharol (2095.14 mg/l), Pij (1414.33 mg/l), Bamroli (1139.47 mg/l), Raghvanaj (1679.46 mg/l), Undhela (919.50 mg/l), Mahelaj (2766.91 mg/l), Kharenti

(1399.34 mg/l), and Palla (1249.34 mg/l). The exceptionally higher values are shown by the area may be attributed to comparatively higher rise in water table rise leading to increase in the residence time as well as the dissolved constituents (Matthess, 1982).

Piper Tri-linear Diagram:

Piper Tri-linear plots (Piper 1953) gives an idea regarding the overall distribution and ionic characteristics of the groundwater. The diagram has been divided in to nine major fields and each field has been characterised by abundance of different ionic constituents. Author has plotted the analyzed chemical contents of the groundwater on the piper Tri-linear diagram for three different seasons i. e. Post-monsoon 1998, Pre- and Post-monsoon 1999, (Fig. 8.22, 8.23 and 8.24).

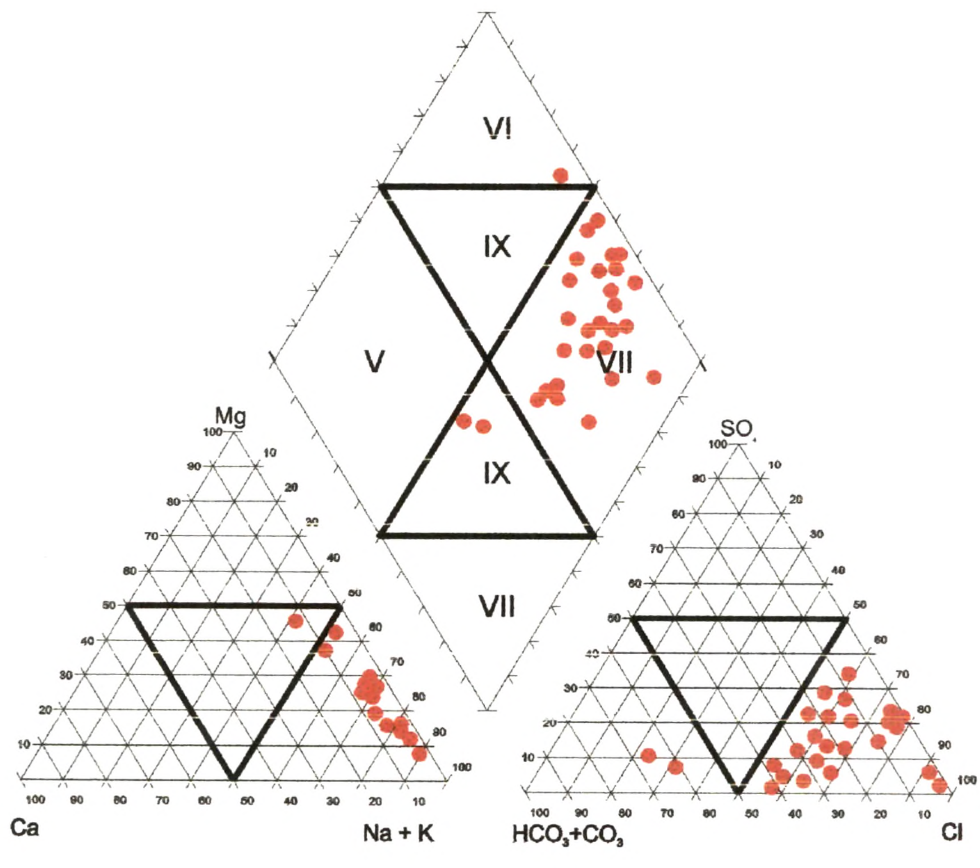

Fig. 8.22 Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose (Year: Post-Monsoon 1998)

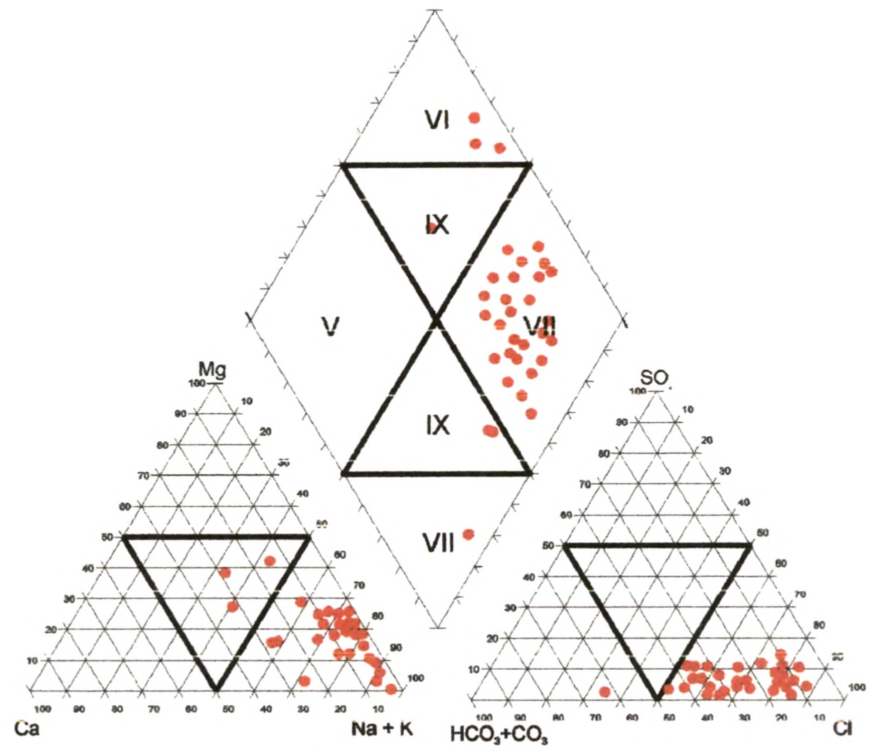

Fig. 8.23 Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose (Year: Pre-Monsoon 1999)

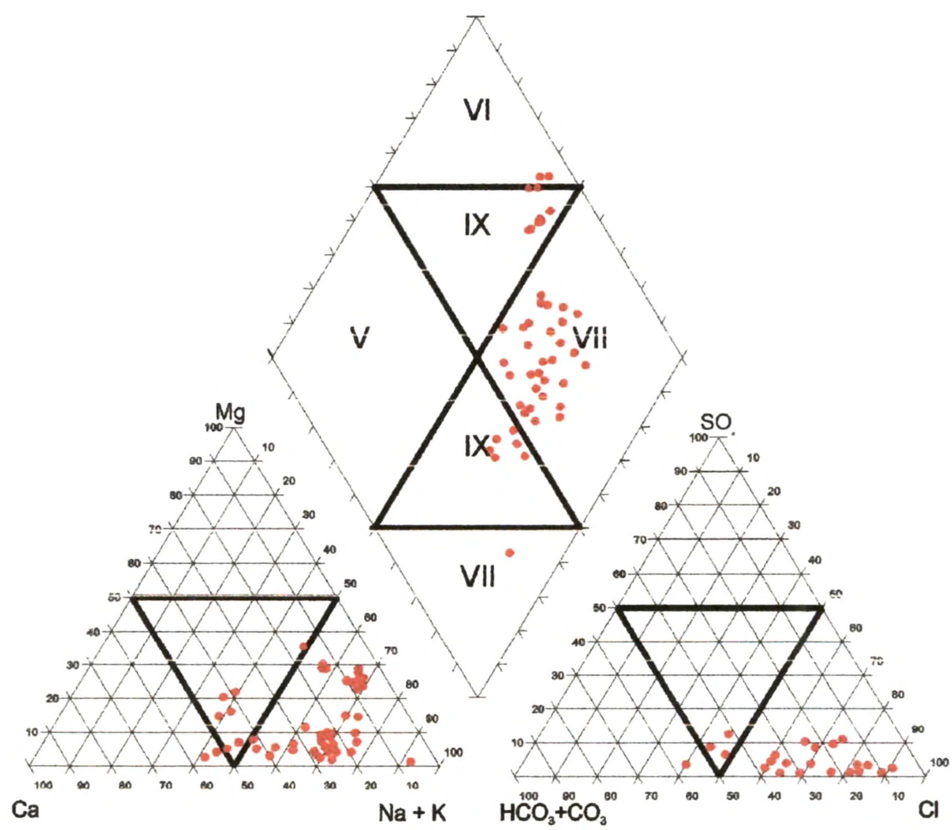

Fig. 8.24 Piper Tri-linear Diagram for Suitability of Groundwater Quality in MRBC Area for Drinking Purpose (Year: Post-Monsoon 1999)

The piper plots for all 03 seasons indicates that majority of the samples fall in the sodium-potassium dominance field among the cation (Left triangle) and chloride field among the anions (Right triangle). Therefore, the groundwaters are predominated by Na-K & Cl type. An overall chemistry of the groundwaters as seen on the central diamond indicates majority of the plots falling within field 7 thereby, suggesting non-carbonate alkali (primary salinity) exceeds 50% and chemical properties of groundwaters are dominated by alkalis and strong acids (Piper, 1953). Also, there is no significant change in chemical contents due to seasonal effects except a few samples viz., Mahelaj, Pipriya and Kosiyal, have been indicating non-carbonate hardness exceeds 50% i. e. secondary salinity (field 6) during post-monsoon 1998 (Fig. 8.22) now, exhibits shift to fields 7 and 9 in post-monsoon 1999 (Fig. 8.24).

IRRIGATION WATER QUALITY

When the water is applied for the irrigation, plant selectively uptake the nutrients and much has been left behind or may absorb the excessive nutrients which causes imbalance in the ionic distribution of the soil as well as the ionic enrichment or deficiency. Also, maintenance of the soil fertility depends on many factors beside the concentration of salts in irrigation water. Of the many factors that control productivity, composition of irrigation water is one playing important role by cumulative effect and therefore it is necessary to evaluate the water with regard to its usefulness in irrigation.

There exits several irrigation water quality guidelines and specifications to determine its suitability. The noteworthy approaches to evaluate the irrigation water quality have been suggested by the workers viz., Kelly, et. al. (1940), Dalip and Chawla (1946), Wilcox, (1948), Eaton, (1950), Mc Kee and Bacon (1953), U. S. Salinity Laboratory Staff (1954), Doneen (1964), Uppal (1964), Ramamoorthy, (1964), Bhumbla and Abrol (1972), Environmental Protection Agency (1973), Ayers and Westcot (1976), Gupta and Gupta (1997 a), Datta et. al. (1998).

The suitability of water for irrigation depends on the chemical parameter like TDS, relative composition of Na to Ca and Mg, HCO_3 to Ca and Mg, toxic effect of individual ions. Not only these, the soil nature and its composition., depth of water table, topography, and climate also limit or delimit the water use for irrigation. Besides this selective absorption of dissolved constituents in water by plants also brings change in water quality. To evaluate the suitability of water for irrigation purpose, the following paramcters have been considered.

a) Wilcox Irrigation Classification

b) Sodium Absorption Ratio

c) Residual Sodium Carbonate

d) Kelly's Ratio

e) Soluble Sodium Percentage

f) Schoellar Index

g) Specific Ion Effect

a. Sodium Percentage with Electrical Conductance (Wilcox Irri. Classification):

The ratio of sodium ions to the total cations content in conjunction with total dissolved solids or as electrical conductance can be used for the assessment of suitability of water for irrigation (Wilcox, 1948). The author utilised this method to evaluate the quality of groundwater and the seasonal behavioral pattern (Fig. 8.25).

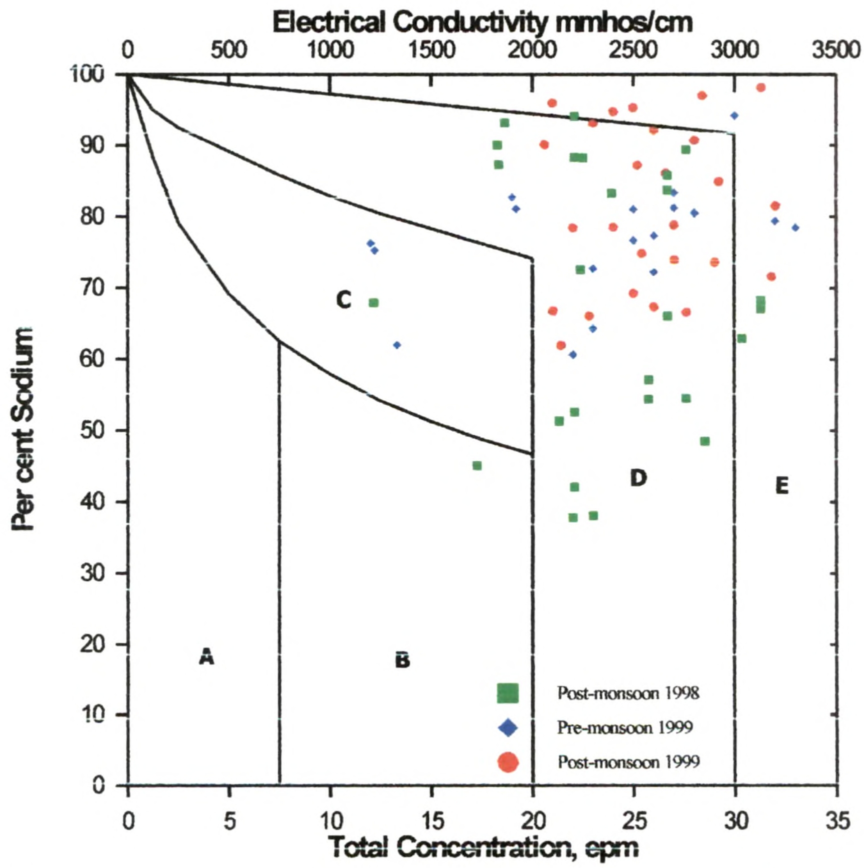

Fig. 8.25 Seasonal Changes in Groundwater Regime for Irrigation in MRBC area. (Year: Post-monsoon 1998, Pre- & Post-monsoon 1999)

The plotted values for the 03 seasons indicate gradual deterioration in groundwater quality. The post-monsoon period (1998) the data plots fall in B, C and D fields indicating suitable to unsuitable category. But the plots of the subsequent seasons indicate continuous vertical as well as lateral migration and all points are falling in the fields D and E categories indicating doubtful to unsuitable for irrigation.

b. Sodium Absorption Ratio (SAR):

Whenever the water high in sodium, applied to the soil some of the sodium is taken by the clay, which in exchange gives up the calcium and magnesium, what is known as base exchange. This base exchange also affects the basic soil properties like granularity and permeability, which facilitates easy tilling. But as the soil becomes rich in the exchange its physical properties get affected and it becomes difficult to till the surface layer (Sharma and Chawla, 1977). The ability of water to expel calcium and magnesium by sodium can be estimated with Sodium Absorption Ratio (Richards, 1954). Thus, the determination of SAR and plotting the electrical conductance with SAR in U. S. Salinity chart will, the groundwater can be evaluated for its suitability as irrigation water.

The plotted SAR and EC values on U. S. Salinity chart for different seasons (Fig. 8.26, 8.27 and 8.28) depicts that the groundwater belonging to C_3-S_2, C_3-S_2, C_3-S_3, C_4-S_2. C_4-S_3 and C_4-S_4 classes during the post-monsoon 1998. Subsequent seasons i.e. pre-monsoon 1999 and post-monsoon 1999, the plots show both lateral and vertical shift, indicating the salinity and alkali hazard of water over the area. Exceptionally higher values have been found at the localities viz., Nadiad (32.99), Dumral (42.68), Dantali (37.38), Pipriya (47.14), Sokhada (79.79), and Machhiyel (30.71).

This observed change in the quality indicate that there is more chance of the Base Exchange with time and hence develops the more salinity and alkalinity. The higher sodium content in the water may have came from the higher residual time in the canal water or slow movement of groundwater through the soil profile. The exceptionally higher values shown by the wells located in the lower command where the soil is mainly clayey impeding the movement of the groundwater, whereby the higher interaction and resulting in higher sodium content in water.

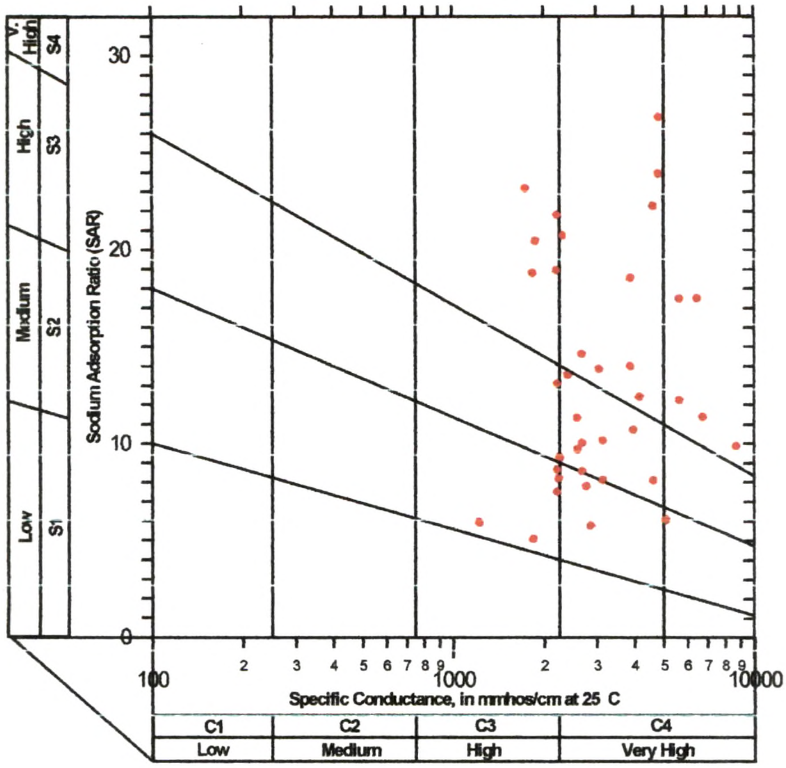

Fig. 8.26 U. S. Salinity Diagram Showing Secular Changes in Groundwater Regime of MRBC area. (Year: Post-monsoon 1998)

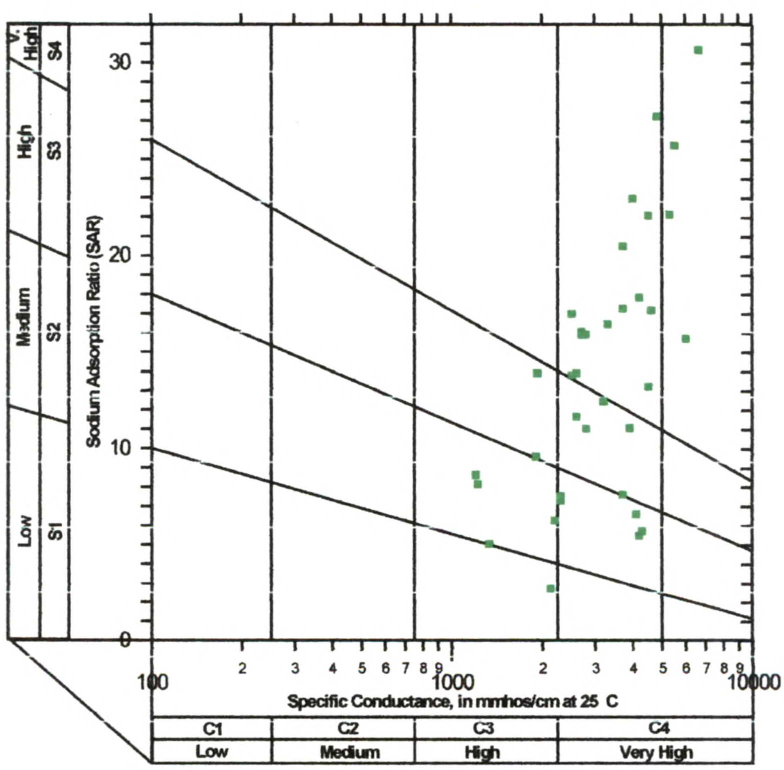

Fig. 8.27 U. S. Salinity Diagram Showing Secular Changes in Groundwater Regime of MRBC area. (Year: Pre-monsoon 1999)

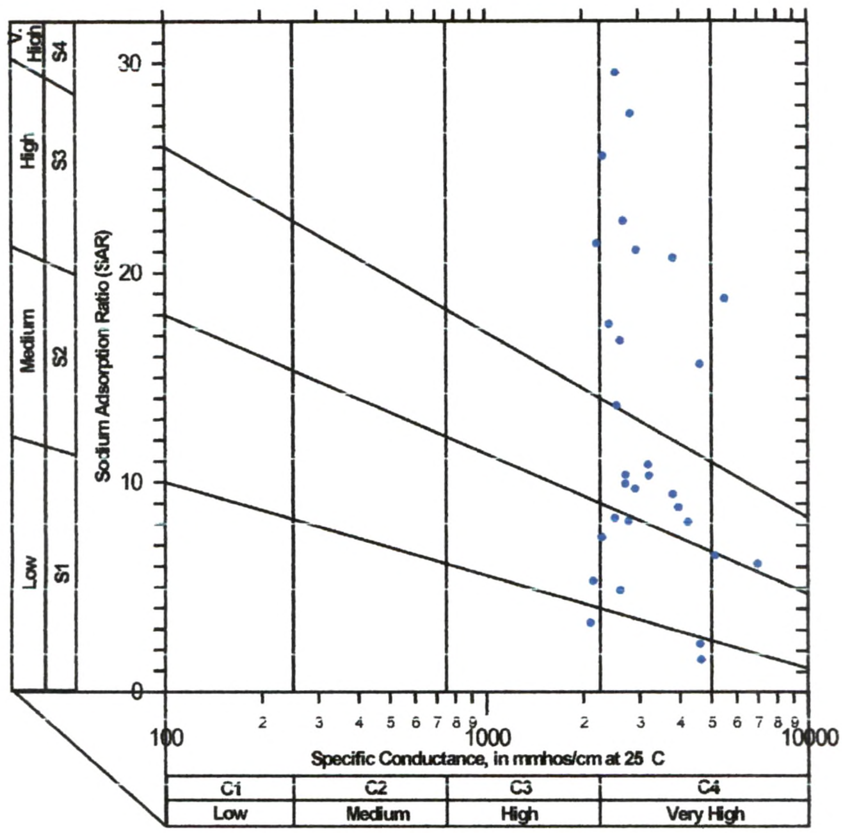

Fig. 8.28 U. S. Salinity Diagram Showing Secular Changes in Groundwater Regime of MRBC area. (Year: Post-monsoon 1999)

c. Residual Sodium Carbonate (RSC)

One of the characteristics of many ground and surface water is the presence of Bicarbonates. Water containing high concentration of bicarbonates, have normal tendency to precipitate of Ca and Mg as carbonate. It is also evident that the depletion of bivalent ions in the soil solution leads to the increases in-situ SAR and consequently to ESP. Eaton (1950) has proposed the concept of RSC on the basis that all Ca and Mg precipitate as the carbonates. The empirical formula given for the calculation of RSC is

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

All ionic concentration is in meq/l.

The various ranges in RSC are suggestive of i. e. RSC > 2.5 is definitely hazardous, 1.25-2.5 is marginal and < 1.25 meq/l is safe for the irrigation.

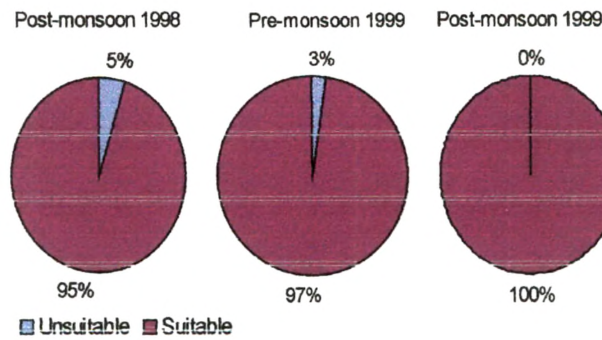

Fig. 8.29 Groundwater Quality Evaluation for Irrigation Purpose using Residual Sodium Carbonate.

By considering the above limits author has calculated the RSC values for three different seasons (Fig. 8.29). The RSC values of water for the season post-monsoon 1998 (Fig. 8.29a) indicates that almost all the wells (95 %) are showing the values less than 1.25 meq/l except Nadiad (12.20 meq/l), Silod (4.87 meq/l), and Dumral (3.10 meq/l). But during the pre-monsoon 1999 (Fig. 8.29b), the wells are found to improve in RSC values and all the wells (97%) are showing the values below 1.25 meq/l. Also the wells with the higher values are improved in their quality.

d. Kelly's Ratio (KR)

Kelly et. al. (1940) have proposed that the potential sodium problems in irrigation water could be reliably evaluated on the basis of following expressions:

$$KR = \frac{Na}{(Ca + Mg)}$$

Ionic concentration is in meq/l.

This ratio reflects alkali hazards of water. If Kelly's ratio is less than one or equal to one the water is good as it becomes greater than one the water becomes unsuitable and upon use of such water for irrigation soil has more chances to become alkaline in nature.

Author has evaluated the quality of groundwater in terms of the Kelly's ratio. Calculation of the KR for the season post-monsoon 1998 (Fig. 8.30a) indicates that most of the wells located in the area i.e. 82 % are showing the KR higher than 1 and about 18 % wells are having the values less than 1 which are mainly located in the upper command. KR values in the subsequent seasons indicates considerable increase where in about 95% of the wells are falling under KR greater than one and only 5 % wells fall under KR less than 1 category (Fig. 8.30b&c). Therefore based on Kelly's Ratio, it can be concluded that the groundwater in Matar command has been gradually attaining alkaline nature. This may be attributed to excessive irrigation, resulting in to concentration of salts in sub-soil horizon due to an overall rise in water table.

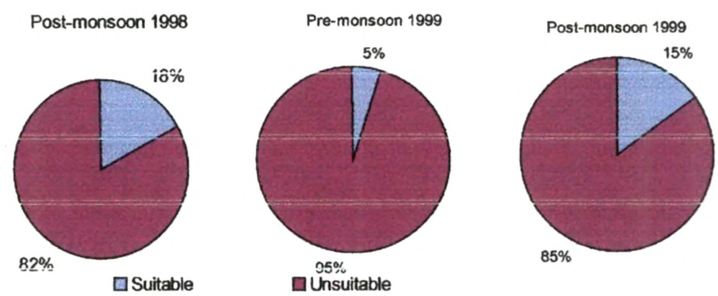

Fig. 8.30 Groundwater Quality Evaluation for Irrigation Purpose using Kelly's Ratio.

e. Soluble Sodium Percentage (SSP):

Wilcox (1955) has proposed classification scheme for rating irrigation water on the basis of soluble sodium percentage (SSP). The SSP can be calculated using following formula:

$$SSP = \frac{(Na)}{(Ca + Mg + Na)} \times 100$$

Ionic concentration is in meq/l

The water with SSP higher than 50 indicates its unsuitability in irrigation and vice-versa. Based on calculated SSP values the groundwater in almost 85% of the wells can be termed hazardous (Fig. 8.31) to soil upon application i. e. SSP > 50% and only 15%, which are mainly located in the upper command, showing the SSP value less than 50%. The SSP data for the subsequent years particularly during the post-monsoon season shows increase in SSP and almost all the wells shows the SSP greater than 50 %. The higher SSP in groundwater indicates that an application of such water, soil may impose the sodicity hazards.

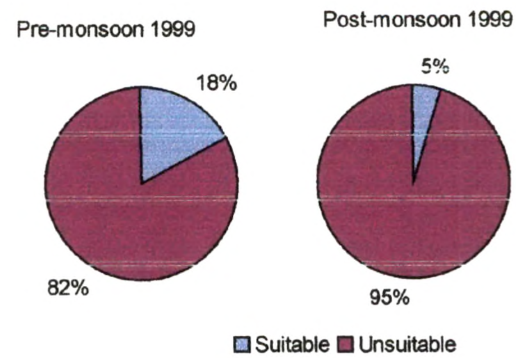

Fig. 8.31 Groundwater Quality Evaluation for Irrigation Purpose using Soluble Sodium Percentage.

f. Schoeller Index (SI):

Schoeller (1959) used an index known after him to determine the possibilities of ion exchange reaction taking place in groundwater. This index results due to changes in the chemical composition of groundwater. The Schoeller index can be determined as

$$SI = R \times \frac{\{Cl - (Na + K)\}}{Cl}$$

R = total ionic concentration in meq/l

where in the positive value of the ratio is indicative of base exchange reaction i.e. Na+K in water being exchanged with Mg and Ca. Similarly, negative value of the ratio is considered indicative of cation-anion exchange reaction i.e. chloro-alkaline dis-equilibrium (Schoeller, 1962). The calculated values of Schoeller index for the groundwater in Matar command area indicates that about 15% of well samples are showing the positive values indicating the base exchange during the post-monsoon periods, while about 33% of the wells during the pre-monsoon season showing the positive values (Fig. 8.32). The above data also indicates that the Base Exchange is more pronounced during the pre-monsoon or summer period.

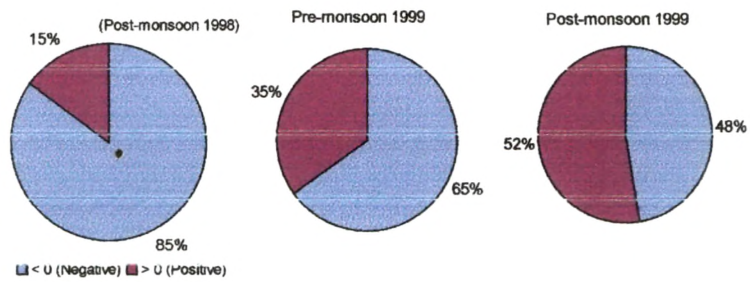

Fig. 8.32 Groundwater Quality Evaluation for Irrigation Purpose using Schoeller Index.

g. Specific Ion Effect:

In addition to salinity and sodicity hazards crops may get affected by low to moderate and high concentration of certain ions that may cause specific toxic symptoms and/or nutritional disorders. Some important ions whose concentration may become hazardous to plant growth are discussed here under:

- **Calcium:**

Generally a calcium soil is friable and easily worked, permits water to penetrate readily, and does not puddle when wet. Calcium is essential to normal plant growth and is abundantly supplied by most irrigation waters. When the calcium concentration exceeds the 35% is fit for irrigation purpose (Chhabra, 1995). Calcium deficiency is commonly found in the high rainfall and humid regions. In Matar command area the dissolved calcium content hardly exceeds by 35% therefore the groundwater is it is suitable for irrigation.

- **Sodium:**

Higher concentration of sodium in the groundwater generally causes the deficiency of K and scorching of leaf tips in addition to this deterioration in soil physical properties by dispersion of grains (Chhabra, 1995). Whenever sodium concentration exceeds by 60% of total cationic concentration, the groundwater considered unsuitable for irrigation. The adverse effect of sodium on the soil was more closely related to the ratio of sodium to the total cations in the irrigation water than to the absolute concentration of sodium. It has now been recognised that as percent of sodium increases in the soil solution larger quantities are absorbed during the exchange, replacing calcium and magnesium, thus resulting in alkali soil. The equilibrium of cation in solution and the generated exchange complex is of great significance when the ratio of sodium to complex and magnesium approaches 02, as the replacement power of the calcium is about twice that of sodium when expressed in equivalent weights.

In case of the Matar branch command the water samples from all the locations are showing the sodium percentage greater than the 60% reflecting possibilities of the development of hazards on application of water.

- **Magnesium:**

The saline groundwater occurring in arid and semi-arid terrain are commonly influenced by higher concentration of magnesium than calcium though sodium stand to be more predominant cation (Chhabra, 1995). Magnesium percentage can be calculated using the following formula

$$Mg\% = \frac{Mg}{(Ca + Mg)} \times 100$$

Ionic concentration is in term of meq/l.

and when it exceeds 50% it results in harmful effect on the soil (Szabolcs, 1989). Detailed studies has further substantiated that magnesium has more pronounced effect in heavy black clay soil than in the light textured soil and the ratio of Mg : Ca decreases with increasing SAR (Gupta, 1979). The reaction of magnesium is very much similar to that of calcium, i.e. it reacts with soap to give water its hardness; and has essentially the same effect on the physical and chemical properties of the soil. Magnesium is essential to plant nutrition and can replace calcium to a limited extent but not completely. It is an important constituent of the chlorophyll of green plants. Most crop plants develop normally with little or no sodium available to them, in case where sodium is essential for plant growth, the requirement is low (Rai, 1995).

The calculation of magnesium percentage and its interpretation indicates that majority of groundwater exceeds the limits and it further increase during the pre-monsoon season and the monsoon recharge results in the decrease in the magnesium percentage (Fig. 8.33).

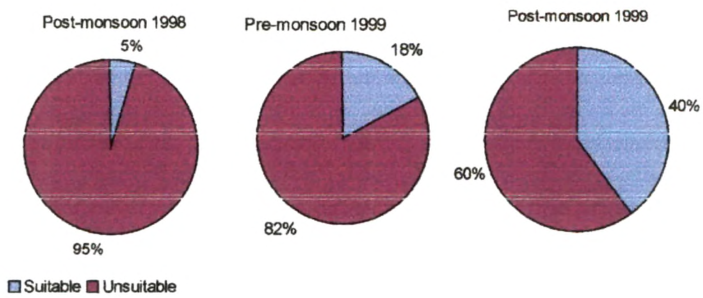

Fig. 8.33 Seasonal Fluctuation of Magnesium Concentration in Groundwater and Its Suitability for Irrigation Purpose.

HYDROGEOLOGICAL INFERENCES

From the above discussion, dealing with the various aspects of groundwater and surface water regime of the study area; the following inferences can be made:

(i) Water table monitoring in the command area before and after introduction of canal irrigation has revealed that there is a continuous rise in water table since last four decades and average rate of rise is to the order of 0.47 m / year.

(ii) In the study area aquifers are solely of 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 with lenses of the gravel and are of fluvio-marine in nature. The middle and upper parts, sand and clay exhibits 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 lacks surface drainage system. However, the existing palaeo-channels are as observed through satellite imagery represents the proto-courses of Shedhi and Watrak Rivers.

(vi) The rainfall, which constitutes an important input, as recharge to the groundwater ; tends to decrease northeasterly and restricted to the monsoon season only. The canal irrigation meant for kharif season irrigation water coupled with the rainfall has greatly neglected the groundwater abstraction.

(vii) Owing to incipient seepage directly from canal network, surface water ponds and the returned irrigation seepage; the water level are influenced by minimum seasonal fluctuations and maximum secular rise in upper command where as lower command area it is minimum.

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

(ix) The groundwater quality shows considerable variation. Owing to inherent sediment salinity and continual rise in water table has lead to upward migration of salts and an overall deterioration in the groundwater quality.

(x) The higher concentration of the TDS and Na &Cl has reached to the level that the water is unsuitable neither for the drinking nor for the irrigation purpose. The application of the water for irrigation purpose, in long term, may result in to the development of the sodicity.

Based on above salient characteristics the author had prepared the hydrogeological map of the Matar command area (Fig. 8.34). 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.

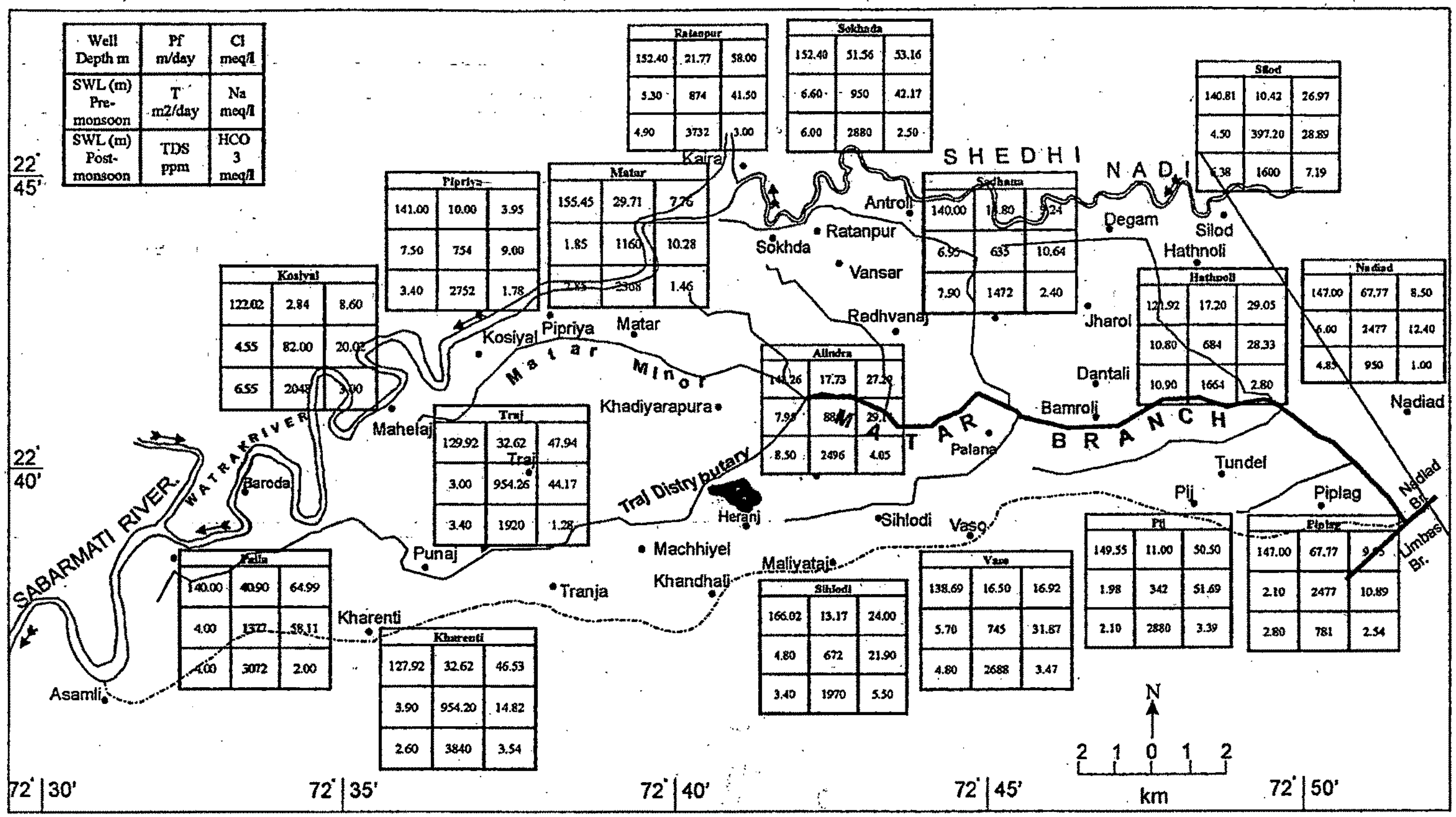

Fig. 8.34 Hydrogeological Map of Matar Command Area.