Chapter VII

WATER REGIME

WATER REGIME

INTRODUCTION

Water is one of the earth's most widely distributed resources and has its own importance because of physiological need of biological regime. It is being the vital requirement for the successful raising of the crops; its availability in optimum quantity in the root zone, particularly at the critical stages of the crop growth is essential. Such moisture requirement of crops can either be met from precipitation through flow or from groundwater (Anonymous, 1991).

As it has already been eluded that the Chalthan area falls within the 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 conditions. Accordingly the groundwater regime is also adversely affected due to paucity of an adequate recharge.

Other side irrigation through canal water and its uncontrolled utilization adversely affects the soil and water regimes. The present study is one such example of excessive irrigation, which has caused an irreparable damage to these regimes. The author in this chapter has made an attempt to evaluate the overall water regime using seasonal secular data on water levels and the various chemical parameters.

SURFACE WATER RESOURCES

Surface water has always received priority in the field of irrigation in addition to the groundwater. It is 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. The waters of rivers and reservoirs are utilised for irrigation of large land areas while for small areas the local water bodies are used.

In the study area precipitation being the only source of surface waters, which form a surface runoff and generally stored in a pond, lake, reservoir etc. as there is no major ponds or lake lying within the area. The area is irrigated through the Kakrapar Left Bank Canal Command network.

RAINFALL

Rainfall (precipitation) is the prime source of all naturally available water in any area. Analysis of rainfall data of an area is not only important for crop planning but also for making meaningful predictions about the irrigation requirement in different seasons, runoff and storage in reservoirs, recharge to groundwater, incidence of floods etc. (Garg, 1998). It is also a well known that the duration, intensity and distribution of rainfall varies appreciably within a small area, at times even from village to village. Such variations are considered important for hydrological and hydrogeological studies of the area.

In the study area rainfall is being measured at Mota and Chalthan while in periphery of the study area it is measured at Palsana, Bardoli, Kadod and Orna. A long instrumental record of last 30 years of data collected from Indian Meteorological Department indicates very high variability of rainfall in the area. The study area receives its rainfall from the southwestern monsoon, which breaks during June end and reaches to its maximum intensity in July. About 95% of rainfall occurs during July - September. The mean annual rainfall in the study area is 1200 mm. The rainfall-time-series curve (Fig. 7.1) plotted for last 30 years i.e. 1971-1999 indicates that for about 14 years the area has received rainfall above average and remaining below average. The lowest rainfall experienced in this area was in year 1987 (444 mm) and highest rainfall experienced is in year 1976 (2236 mm).

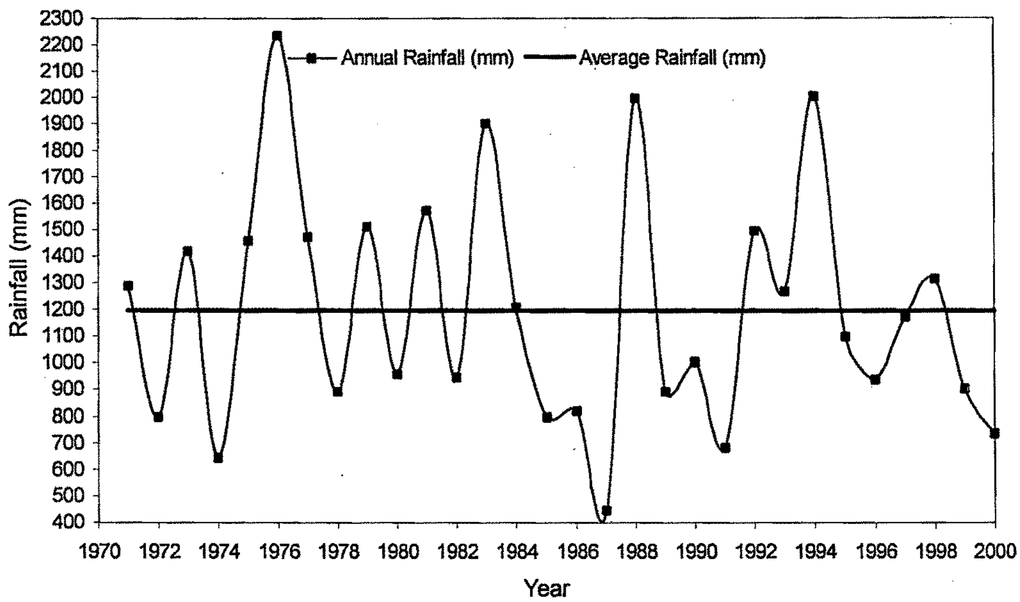

Fig. 7.1 Rainfall-Time-Series Curve for Chalthan Branch Canal Command Area.

CANAL WATER

In the Chalthan Command area irrigation is predominantly carried out through canal water. The canal network, which is 25 km long, off taking from Bardoli branch near Kantali village. The branch canal in the command area is unlined, where as the other lower order network is lined/unlined. The average annual canal flow of last 10 years based on observed discharge data, at 0 R.D. (Kantali) stands at 112368 cumsecs/year where as at 66 R.D. (Bagumara) it is 57572 cumsecs/year therefore almost 54796 cumsecs/year water is released in command area.

Quantitative data on Monthly canal discharge as recorded by the Command Area Authority for the period of 1991-1999 is given in Table 7.1. With a view to study the rainfall pattern vis-à-vis canal water discharge in the study area, the author has attempted a time-series analysis. Obtained time-series curve for precipitation and canal discharge parameters shows reciprocal relationship i.e. as the rainfall decreases, the canal water input accordingly increases; thereby indicative of constant crop-water requirement.

Table 7.1 Canal Discharge Records of Chalthan Branch.

Month	Canal Discharge in cumsecs/year								
	1991	1992	1993	1994	1995	1996	1997	1998	1999
January	6788	6438	8922	7739	6231	8849	7584	4643	11997
February	7983	6745	7421	7969	6297	6045	5406	10278	10536
March	8511	6036	9163	9226	9024	8932	10447	12063	11597
April	9300	1906	10534	9931	12438	6239	11861	14821	15331
May	8098	0	8682	9885	14316	13053	9191	11650	12842
June	12868	0	11881	4890	12292	7796	9311	12942	11812
July	8327	0	6821	0	7249	4256	12855	8446	8547
August	7713	0	14917	11393	11168	12145	4778	9214	13682
September	14095	7677	10393	6687	11791	6626	9650	5367	12046
October	15283	11245	7656	12742	9163	10899	11402	7294	5708
November	8963	14612	12542	12571	13105	10780	13956	13398	14363
December	6810	10896	10231	8078	8317	10914	7942	6628	5275
Total	**116730**	**67547**	**121156**	**103105**	**123386**	**108530**	**116380**	**118742**	**135735**
Average	8979	5196	9320	7931	9491	8348	8952	9134	10441

(Source: SIC, Surat)

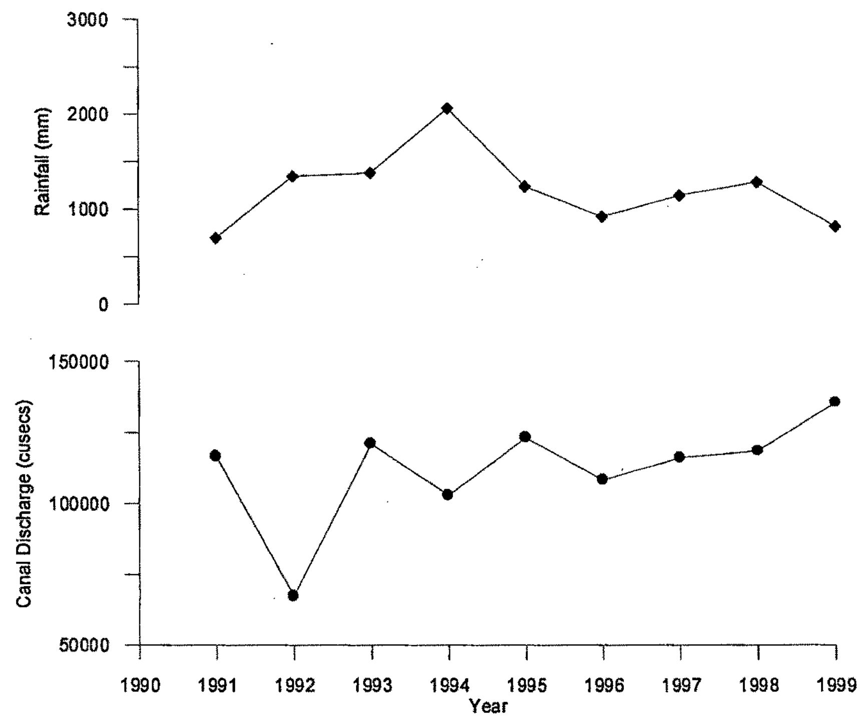

Fig. 7.2 Influence of Rainfall on Canal Discharge in Chalthan Branch Canal Command Area.

Canal Water Chemistry

Chemistry of canal water is important to understand the possible hydrochemical impact of irrigation on soil and groundwater regime. In order to obtain hydrochemical content of the canal water, the author has collected the canal water samples for post and pre monsoon seasons from the canal intake point. The obtained quantitative estimates on the various ionic content and physico-chemical parameters (Table 7.2) indicates that canal water fall within the desirable limits of irrigation as well as drinking water quality norms, as suggested by ICMR (1975), WHO (1984) and ISI (1983).

Table 7.2 Hydrochemical Characteristics of Canal Water in Chalthan Branch Canal Command Area.

Parameter	Post monsoon 1998	Pre monsoon 1999
PH	7.86	7.32
EC (mmhos/cm)	0.32	0.38
CO3 (mg/l)	0.0	0.0
HCO3 (mg/l)	70.76	82.96
Cl (mg/l)	64.97	84.85
SO4 (mg/l)	7.68	8.64
Ca (mg/l)	24.00	33.00
Mg (mg/l)	24.89	29.77
Na (mg/l)	4.37	4.83
K (mg/l)	1.17	0.0
TH (mg/l)	162	204
TDS (mg/l)	205	243
SAR (%)	0.15	0.15

GROUNDWATER RESOURCES

Study of groundwater regime covers not only the observation of the free groundwater level changes but also the water chemical composition changes. Study of the groundwater level changes helps in understanding the groundwater hydrodynamic regime, i.e. description of the laws governing groundwater level changes affected by natural and artificial factors. These observations make it possible to define the rates of groundwater level rise as a function of the irrigation factors, and these changes are attributed to the hydrogeological environ of the command area. Observations of the changes in chemical composition of groundwater permit us to describe the hydrochemical conditions of the groundwater, the formation and spreading pattern of the fresh water lenses adjacent to major canals, and the rate of groundwater salinisation.

As it has already been described that the Chalthan Branch Canal Command Area constitutes a part of Tapi and Mindhola interstream area of the South Gujarat alluvial plains. Therefore the occurrence of groundwater show strong influence of the distribution pattern and lateral continuity of alluvial sediments of appreciable porosity and permeability. Based on available sub-surface informations the author has attempted to make a broad assessment of the total hydrogeological regime of the Chalthan Command Area.

AQUIFER NATURE AND EXTENT

As the study area constitutes a part of flood plain system of Tapi and Mindhola rivers, these riverine deposits display intercalations of sands-silts and clays. Study through the bore hole logs of deeper tube wells and shallow bore wells adequately exhibits this pattern.

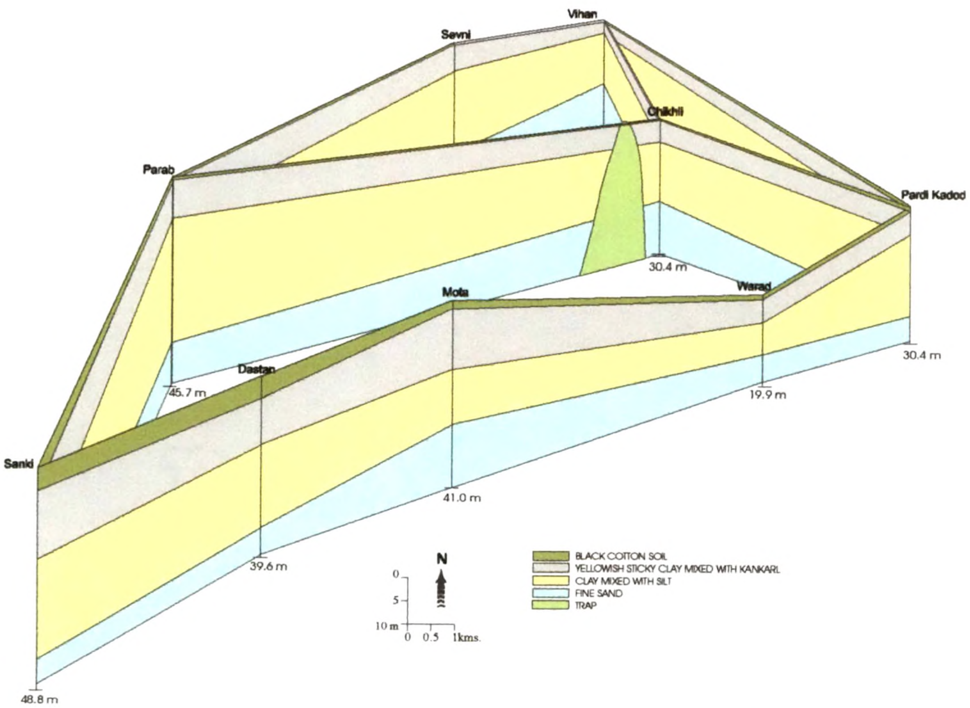

Fig. 7.3 Fence Diagram Showing Hydrogeological Characterization of Chalthan Branch Canal Command Area.

The prepared fence diagram (Fig. 7.3) based on shallow bore hole log records display the top semi-confined to confined aquifer is overlained by an almost 10-20 m thick silty clay aquitard layer. As the thickness of alluvium tends to increase westerly, the aquifer also enlarged accordingly and gets branched into multi layered aquifer system. The data has further revealed the presence of 3-4 aquifers within the depth range of 32 to 177 m. The hydraulic characteristic based on pumping results (Table 7.3) shows a wide range of the parameters viz. transmissibility (79 - 2965 m^2/day), specific capacity (0.088 - 18.15 m3/min/m), and discharge (200 - 3156 lpm) thereby indicating moderate to high potential of aquifer.

Table 7.3 Geohydrological Information of the Aquifers in Chalthan Branch Canal Command Area.

Sr. no.	Village	Taluka	Aquifer Zones Tapped (m)	D.D. m.	Disch. lpm	T m^2/day	Sp.Cap. m^3/min/m
Tube Wells							
1.	Alura	Kamrej	37.48 – 55.63 65.61 – 74.66 77.38 – 88.70 91.03 – 102.45	9.83	3156.20	958.82	13.22
2.	Vihan		20.00 – 40.00	3.29	2808	2965	15.00
3.	Dastan	Palsana	32.42 – 42.90 55.00 – 75.37 83.00 – 117.69	2.48	2702	1219.5	18.15
Shallow Wells							
Sr. no.	Village	Taluka	Total Depth m.	D.D. m.	Disch. m^3/min	T m^2/day	Sp.Cap. m^3/min/m
1.	Kadodra	Palsana	12.0	2.39	0.9626	191.10	0.40279
2.	Karan		7.45	4.63	1.0523	163.43	0.2272
3.	Sanki		9.15	3.96	1.3190	124.38	0.3331
4.	Jolwa		7.30	2.32	0.4902	184.90	0.2113
5.	Dastan		13.40	2.30	0.2035	79.01	0.0885
6.	Bagumara		10.50	2.17	0.5214	102.73	0.2403
7.	Haldharu	Kamrej	9.20	1.39	0.986		0.7093

GROUNDWATER CHARACTERISTICS

Groundwater level contour map not only presents a spatial distribution pattern of the water levels but also indicates groundwater movement direction and gradient. Also, the secular change in groundwater levels can very well point out the areas of excess withdrawal and recharge due to rainfall and returned irrigation seepage. The data on groundwater level and its fluctuation can be used to derive following inferences:

i) Assessment of groundwater availability on the basis of fluctuation in water levels;

ii) Relationship between water level fluctuations, rainfall and canal irrigation;

iii) Demarcation of waterlogged areas and areas with continued upward or downward trends in water level as secular changes; and

iv) Identification of areas prone to salt movement.

In the study area, water table has been monitored by the project authority through a close network of observation wells, since the inception of canal irrigation. For the purpose of precise evaluation of groundwater table fluctuations and movement and to establish prolonged changes in groundwater regime, the author has divided the entire study area into equal area grids of 10 sq.km each and selected a representative observation wells at each node (Fig. 7.4); by carefully scrutinizing already available well hydrograph records for further monitoring. The author has monitored each observation well along with some other ancillary wells at adequate locations for three different seasons from the point of view to collect information on seasonal water table fluctuation (APPENDIX I). Accordingly the groundwater samples have also been collected to study the behavioral changes in groundwater chemistry; seasonally as well as for the long term evaluation.

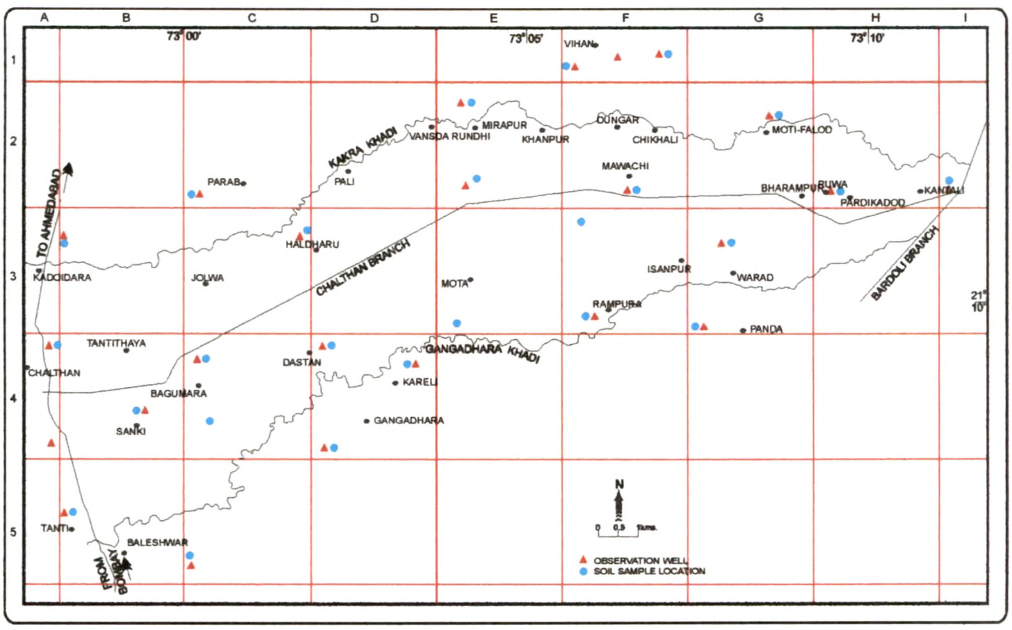

Fig. 7.4 Observation Wells and Soil Sampling Locations in the Study Area.

WATER LEVEL FLUCTUATION

The seasonal and secular changes in the groundwater levels have been studied through the reduced water level contours, spatial and temporal hydrographs, and hydrographic profiles. For this author has taken in to account the last 50 years of available water table records. The evaluation has been made at the interval of 20, 10 and 5 years changes in the groundwater regime i.e. 1950 - 70 - 80 - 90 - 95 and 1999.

Seasonal Behaviour of Water Level

Apart from minor diurnal and vector changes that affects the groundwater levels, it is important to study the seasonal behaviour of groundwater level, which in turn is influenced by the amount of precipitation and/or irrigation practices; ultimately reflects the change in water table thereby modification in groundwater storage. For this the author has prepared the reduced water level maps for both pre and post monsoon seasons, for the pre canal irrigation (1950) period and the present irrigation (1999) phase.

Pre Canal Irrigation Scenario (1950)

Prior to the inception of canal irrigation groundwater was the main source of irrigation. The constructed RWL maps for the pre and post monsoon seasons (Fig. 7.5) depict marginal change in groundwater storage. In the study area RWL contours are showing range from 7 to 27 m (pre monsoon) and 10 to 29 m (post monsoon). Therefore indicating an overall variation in groundwater altitude is to the order of 20 m in both the seasons. As there was no canal irrigation in the area, the fluctuations in groundwater storage corroborate the sole contribution made through rainfall recharge. The minimum change in groundwater storage (Fig 7.6) has been observed at Rayam (1.4 m) where as at Kadodara the maximum change (4.8 m) has been observed. However, the average annual change in the groundwater storage is in command area stands at 3 m or so.

The behavioral pattern of the RWL contours points to a strong influence of topography as well as the lateral distribution pattern of aquifers. The overall groundwater movement is in conformation with the surface drainage i.e. westerly. The observation on groundwater gradient is gentle - moderate - gentle in upper, middle and lower reaches respectively of the command area. This pattern depicts lensoidal nature of aquifers occurring at different depths. Overall dynamics characteristics of water levels are given in Table 7.4.

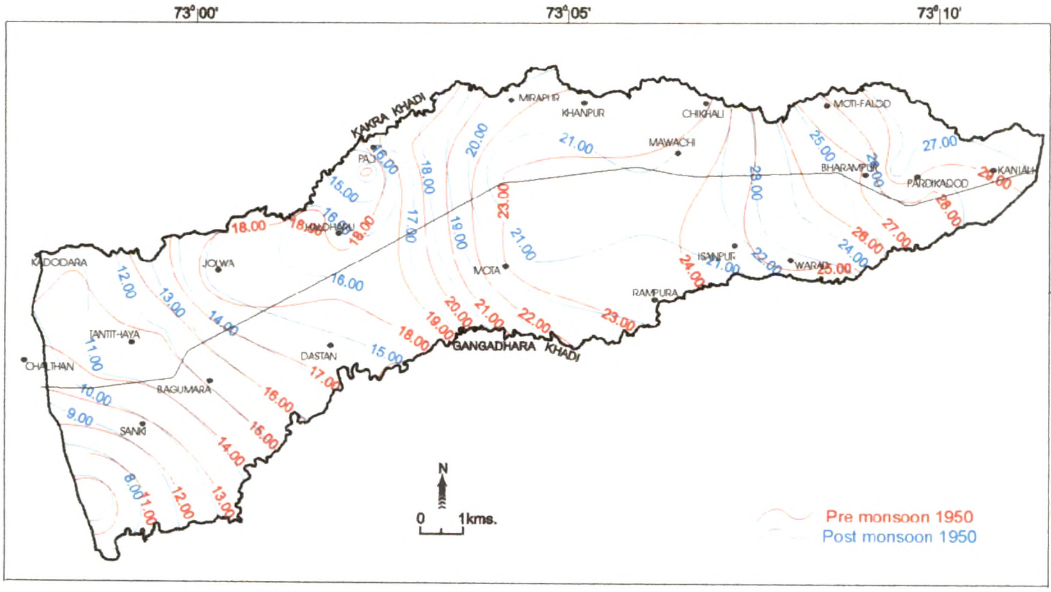

Fig. 7.5 Reduced Water Level Contour Plan of Chalthan Command Area (Pre & Post monsoon 1950).

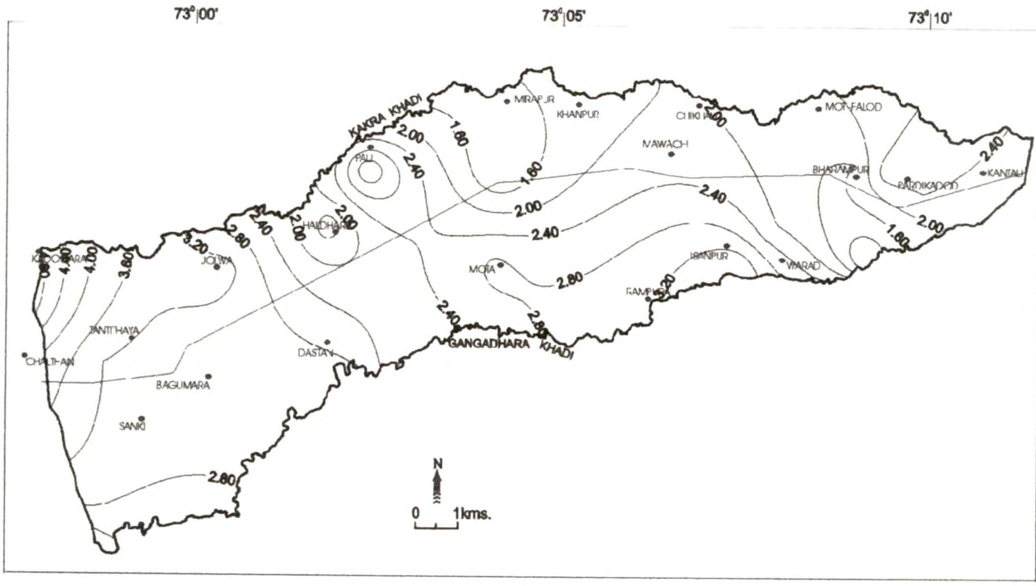

Fig. 7.6 Net Seasonal Change in Groundwater Storage in Chalthan Command Area (1950).

The seasonal behavior of groundwater level and storage has been studied by overlapping pre and post monsoon reduced water level contours (Fig. 7.8). Through the study of these maps following inferences may be drawn.

1. The RWL exhibits an overall rise from pre canal irrigation phase to the present day.
2. The RWL values are ranging between 2 and 32 m during pre monsoon season and between 4 and 34 m during post monsoon season.
3. The groundwater movement directions for both seasons remain westerly. However the gradient (Table 7.4) tends to increase from upper command to lower command area. This increasing trend in groundwater gradient in upper, middle and lower parts i.e. 1:1365 - 1:437 - 1:233 (pre) and 1:910 - 1:525 - 1:202 (post) may be attributed to the distribution pattern of the aquifers with in the structurally controlled basin. The earlier discussed sub-surface hydrogeological profiles adequately support this causative factor.

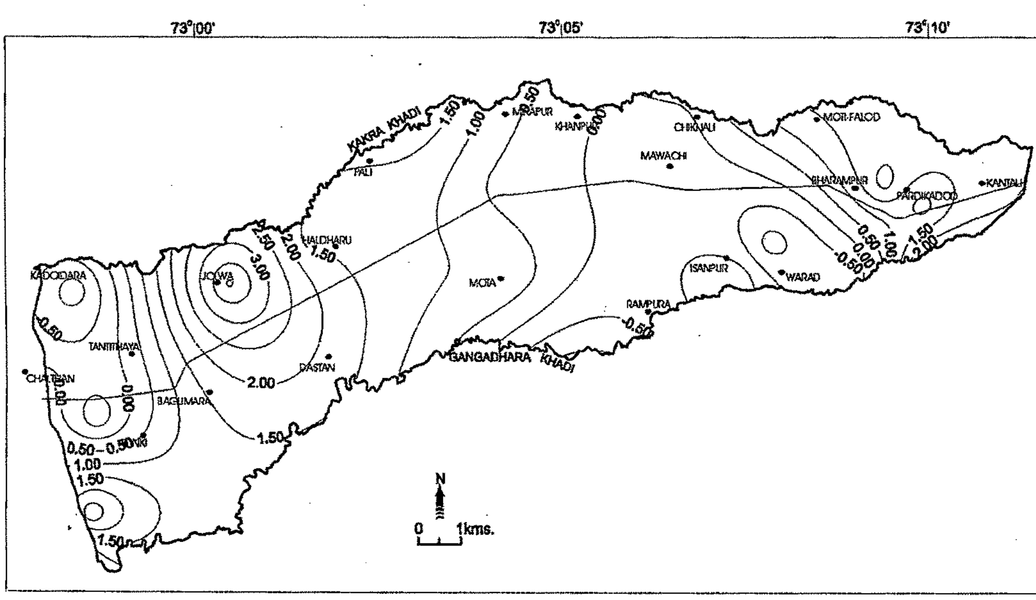

Fig. 7.8 Net Seasonal Change in Groundwater Storage in Chalthan Command Area (1999).

4. The seasonal rise and fall in RWL as depicted in Fig. 7.8 indicates, 0.5 - 4.15 m rise. This seasonal rise in water levels is maximum in the lower reaches around Jolwa. Significantly the area around Kadodara (lower reaches) exhibits 1.3 m fall in water levels. The net rise in RWL may be attributed to the returned irrigation seepage and the monsoonal recharge. However, fall in

water level around Kadodara could be on account of sub-surface outflow to Kankra Khadi.

Although there is no significant change in the contour patterns as well as groundwater movement direction from pre canal irrigation scenario (1950) to the present post canal irrigation period (1999). The RWL of 1950 and 1999 show marked change in groundwater gradient particularly in the upper and lower parts of the command (Table 7.4). This marked decrease in groundwater gradient in upper reaches may be attributed to continual rise in water level due to returned irrigation seepage and less groundwater abstraction. However increase in groundwater gradient in lower parts can be ascribed to observed conjunctive use of canal and well irrigation.

In order to demarcate the net seasonal change in groundwater level fluctuation during 50 years time i.e. 1950 to 1999, author has prepared spatial hydrographic profiles (Fig. 7.9 & 7.10) along Karan - Kantali (A-A') transact.

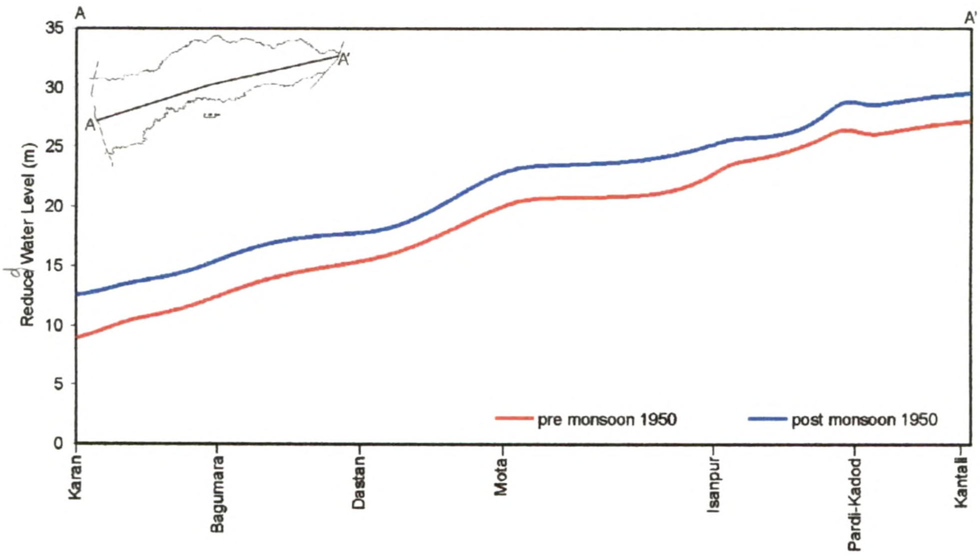

Fig. 7.9 Spatial Hydrographic Profile Along Karan - Kantali (A-A') Transact Showing Seasonal Changes in Groundwater Regime in Chalthan Command Area (1950).

The profile shows a marked fluctuation during pre canal irrigation scenario (Fig. 7.9) but present day canal irrigation scenario (Fig. 7.10) the seasonal water level fluctuation has considerably reduced as compared to 1950. Some of the area showing decline in groundwater levels during post monsoon season in 1999, specifically between Isanpur and Pardi Kadod may be attributed to the change in irrigation pattern from well irrigation to canal irrigation and increase in surface water use.

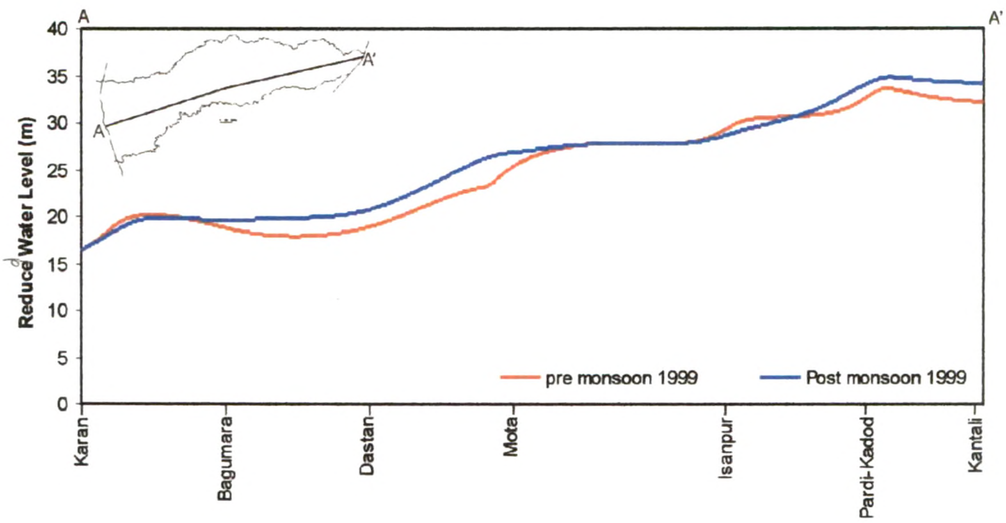

Fig. 7.10 Spatial Hydrographic Profile Along Karan - Kantali (A-A') Transact Showing Seasonal Changes in Groundwater Regime in Chalthan Command Area (1999).

Secular Behaviour of Water Levels

Groundwater levels are variant in space and time. A long term annual time series records of groundwater levels help in assessing the declining and rising trends of groundwater table thereby demarcating the areas of over exploitation and water logging (Healy, 2002). Evaluation of water level fluctuation in canal irrigation command from the point of view of its long-term behaviour is vital in understanding the impact on water regime and to define preventive measures to reduce the negative impacts of irrigation.

Since the inception of canal, the Chalthan branch canal command area has been consistently monitored by the Soil Survey Division, with a view to study the irrigation impact on groundwater regime. In order to study the secular changes in groundwater regime the author has collected the available data and also substantiated his own observations and prepared the RWL contour maps and various hydrographic profiles at the various time span. For this 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 & De Wiest, 1967). The data on static water levels observed at some of the stations in study area are given in Table 7.5.

The reduced water level contour maps prepared for the years 1950, 1970, 1980, 1990, 1995 and 1999 shows more or less similar pattern in groundwater table conditions and indicate normal westerly gradient i.e. due WSW, which ultimately bifurcates in the lower reaches of the command area, i.e. NW and SW. However, a significant rise in the water levels has been witnessed during the period between 1950 and 1999. The estimated groundwater level rise during this period is ranging between 8.6 and 0.9. A well located at Tantithaiya village shows marked rise of 8.6 m.

Table 7.5 Secular Water Table Scenarios in the Chalthan Branch Canal Command Area.

Village	Pre-monsoon Static Water Level (m)						
	1950	1970	1980	1985	1990	1995	1999
Vihan	11.50	10.90	1.75	2.40	3.05	2.50	2.80
Chikhli	10.00	5.80	4.20	2.10	2.10	2.40	2.10
Haldharu	8.50	13.70	3.60	4.60	4.35	6.10	2.67
Pali	11.90	13.60	1.50	1.60	3.40	4.50	5.00
Bharampur	10.00	4.75	5.80	5.90	6.20	4.65	4.75
Khoj pardi	10.00	5.20	5.50	4.40	6.80	4.00	5.90
Mota	7.50	4.70	2.10	2.75	1.75	2.00	2.10
Isanpur	10.00	9.60	4.20	4.30	4.45	3.50	3.90
Chalthan	10.00	1.10	2.60	3.50	3.35	4.40	4.10
Tantithaiya	9.50	9.30	3.20	1.00	1.65	1.10	0.90

For the assessment of secular changes in groundwater storage author has prepared the RWL maps at various time intervals viz. 1950-70, 1970-80, 1980-90, 1990-95 and 1995-99. Accordingly the spatial rise and fall in groundwater storage have been estimated.

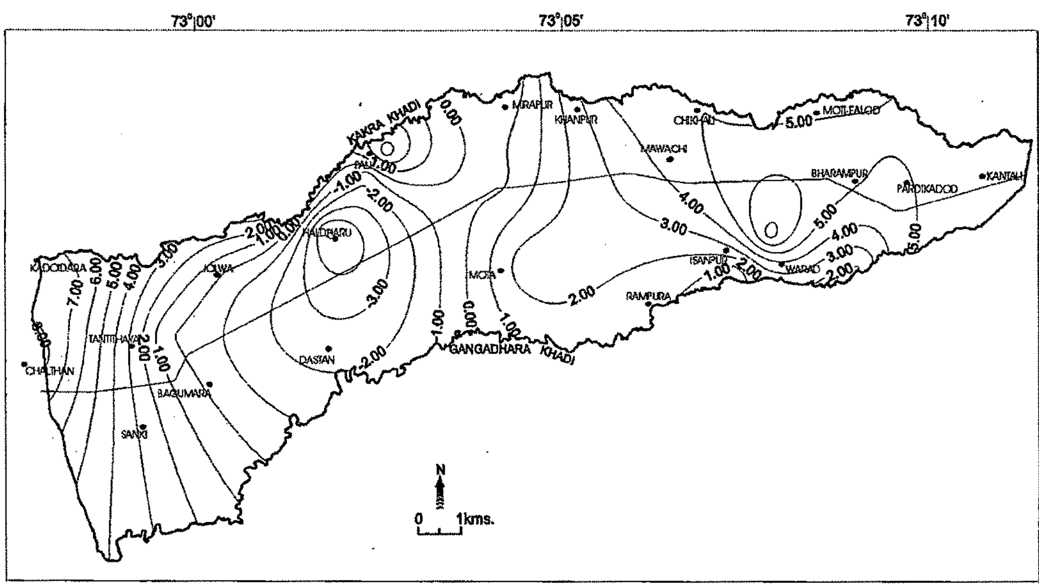

Fig. 7.11 Secular Change in Groundwater Storage in Chalthan Command Area (1950-70).

The temporal changes in groundwater storage as revealed from RWLs for the periods 1950-1970 shows positive and significant rise (+8 m) around Chalthan while it is negative (-4 m) around Haldharu village (Fig. 7.11).

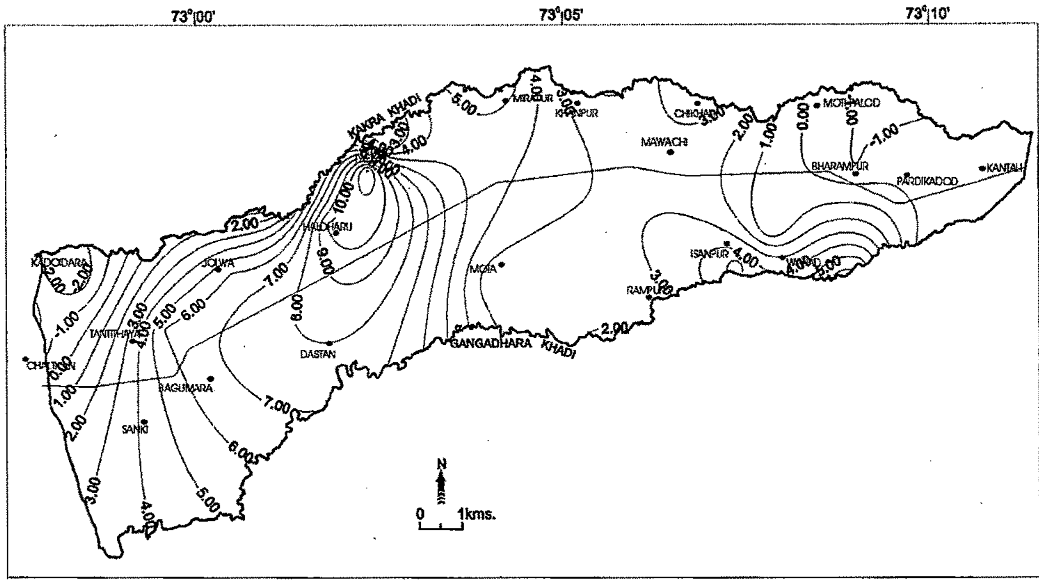

Fig. 7.12 Secular Change in Groundwater Storage in Chalthan Command Area (1970-80).

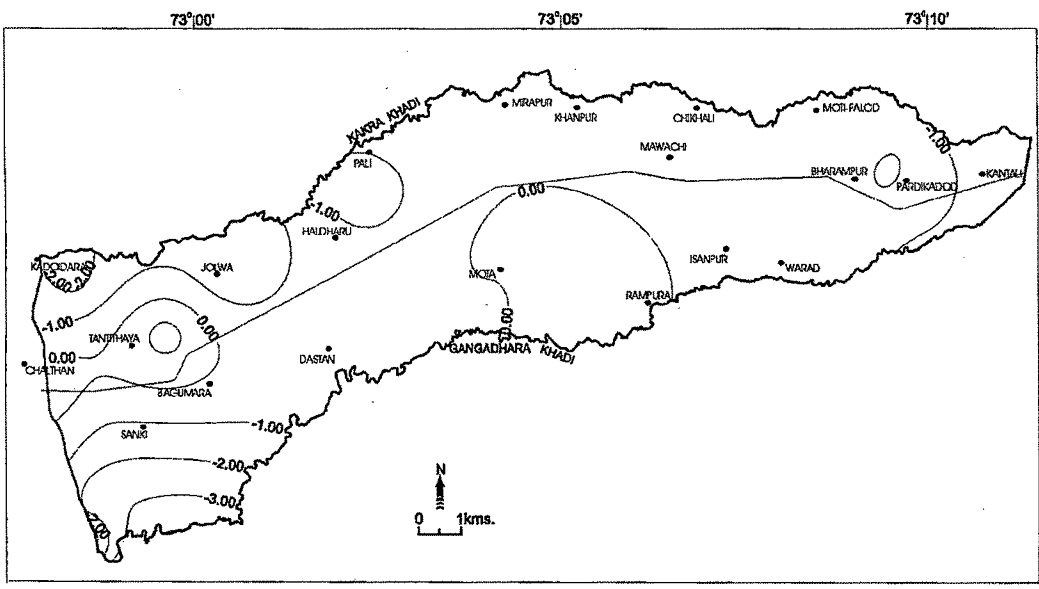

Fig. 7.13 Secular Change in Groundwater Storage in Chalthan Command Area (1980-90).

The subsequent scenario for the periods 1970-1980 also shows considerable rise in groundwater storage (Fig. 7.12). The maximum of 11.0 m rise has been observed in the area around Pali village. Contrary to this, the periods 1980 and 1990 does not show any significant change in groundwater regime, however certain wells show a marked decline (-3.0 m) in groundwater storage (Fig. 7.13) around Sanki village. The observation on change in groundwater storage during the periods 1990-1995 and 1995-1999 (Fig. 7.14 & 7.15) does not indicate any significant change.

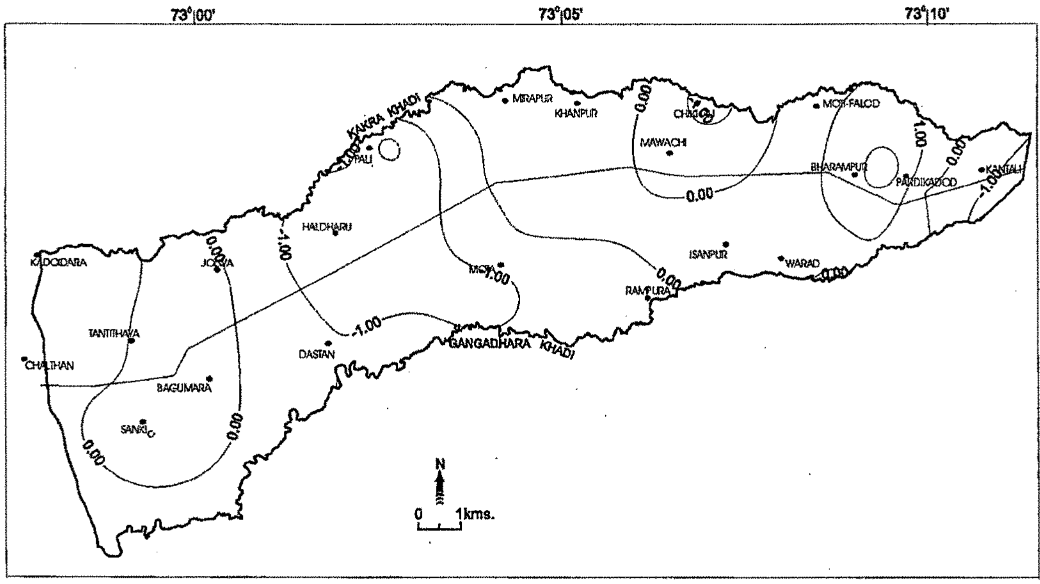

Fig. 7.14 Secular Change in Groundwater Storage in Chalthan Command Area (1990-95).

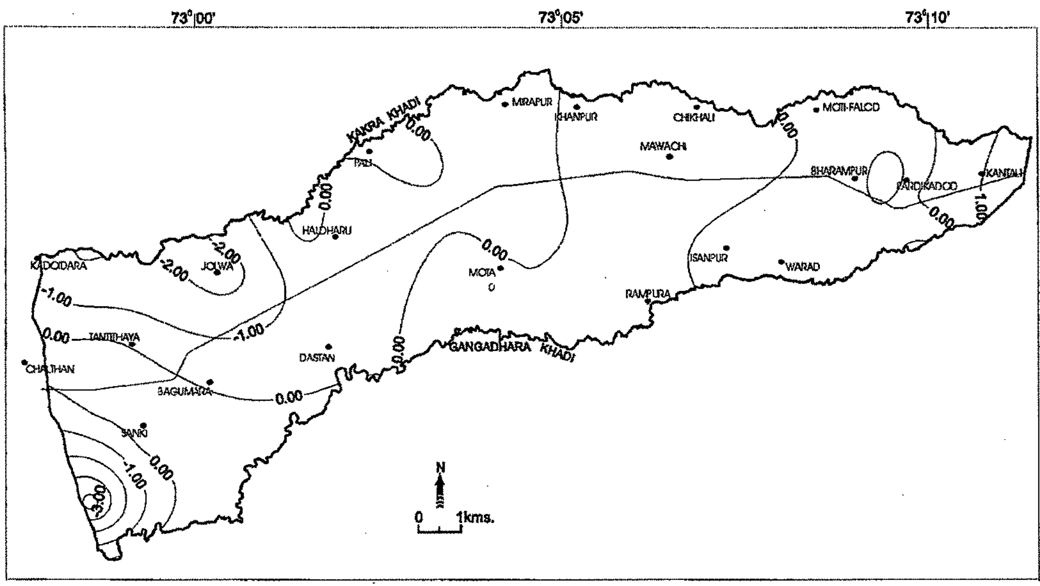

Fig. 7.15 Secular Change in Groundwater Storage in Chalthan Command Area (1995-99).

These above cited observations and spatial estimates on groundwater storage change at various time intervals point to very fact that the returned irrigation seepage has made a sizable contribution to the groundwater storage along with normal monsoonal recharge. Also, the latter stabilization in groundwater storage from 1980 onwards exhibits optimum level of aquifers and possibly the development of effluent conditions along minor streams and rivulets. However, the sporadic decline in groundwater storage particularly in lower reaches of the command may be attributed to change in irrigation practices, non-availability of canal water, therefore maximum groundwater utilization.

The well hydrographs (Fig. 7.16) of the selected observation wells in the command area are in conformation to the above-cited long term behavioral patterns in groundwater storage. Further there is a sharp rise in the groundwater levels after the inception of canal irrigation particularly during 1970-80. The period between 1980 and 1999 the fluctuation in groundwater levels remained steady.

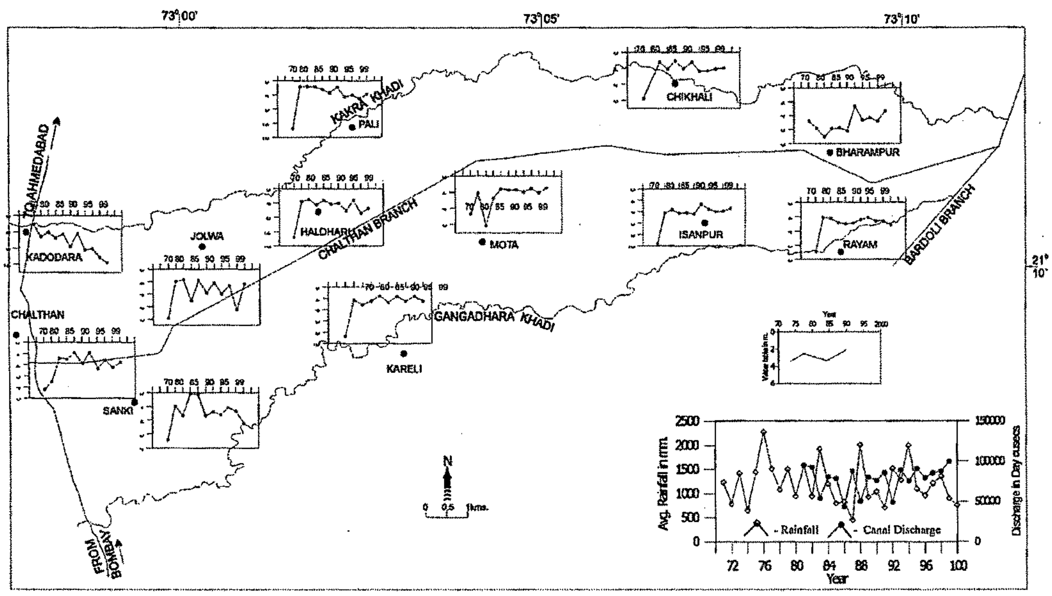

Fig. 7.16 Well Hydrographs of the Selected Observation Wells in Chalthan Command Area.

Spatial Hydrographic Profiles

The study of spatial hydrographic profiles holds its own importance to evaluate the lateral change in groundwater storage across the command area. For this the author has prepared the various hydrographic profiles along Karan - Kantali (A-A') transact by considering the pre monsoon water levels, for the years 1950-70-80-90-95 and 1999. The inferences made, based on these hydrographic profile are suggestive of

- There is considerable rise in the groundwater level after the inception of canal irrigation. The rise in groundwater is more pronounced in upper and middle and extreme lower parts of the transact during 1950 to 1970 while it continue to rise down Isanpur but it is bare minimum in upper reaches during 1970-80 (Fig. 7.17).

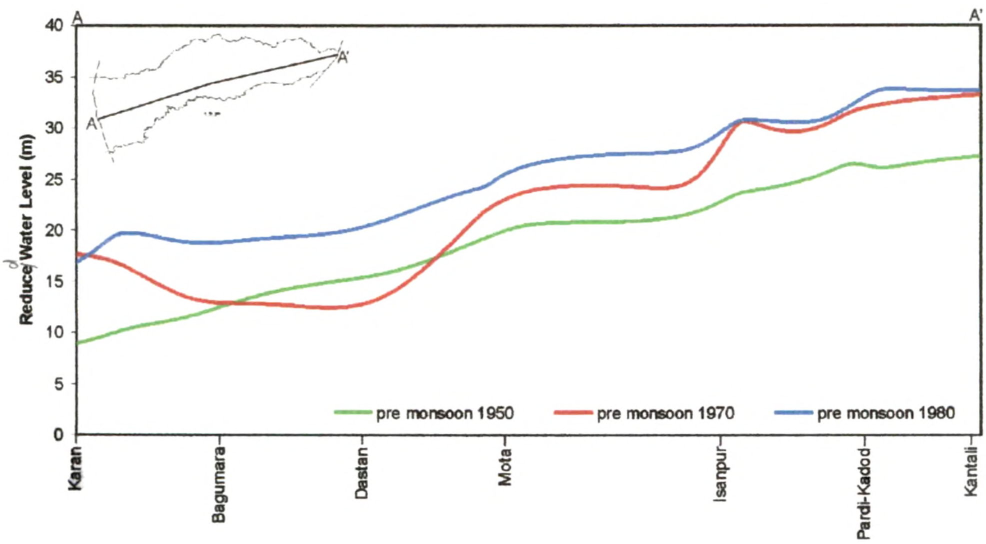

Fig. 7.17 Spatial Hydrographic Profiles Along Karan - Kantali (A-A') Transact in Chalthan Command Area (1950-70-80).

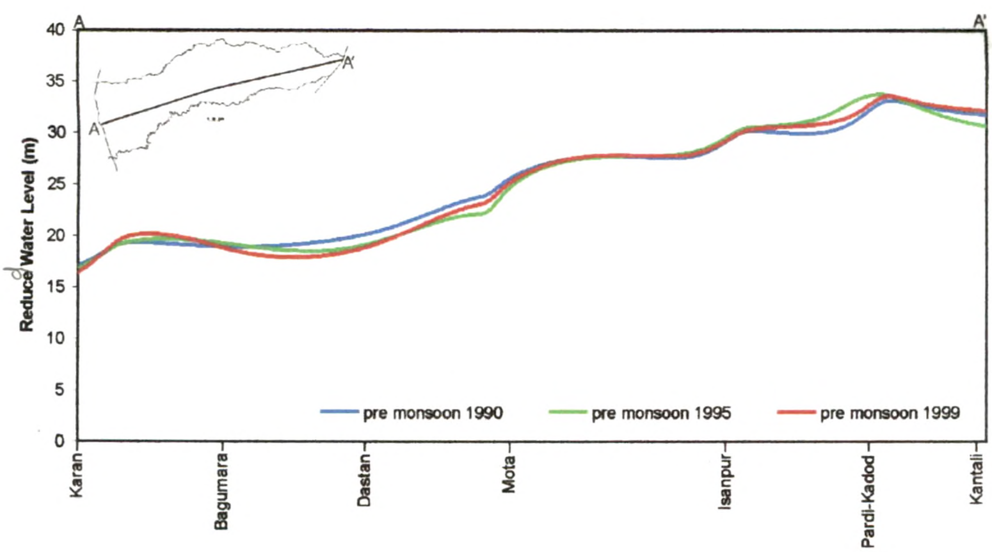

Fig. 7.18 Spatial Hydrographic Profiles Along Karan - Kantali (A-A') Transact in Chalthan Command Area (1990-95-99).

- Spatial hydrographic profiles for the years 1990-95-99 exhibits almost there is no stagnation in groundwater levels particularly between Mota and Isanpur villages (Fig. 7.18). It does show some marginal decline between Mota nd Bagumara villages.

Net Change in Groundwater Storage

In order to evaluate the net change in the groundwater storage, i.e. from pre-canal irrigation phase (1950) to present period (1999); the author has estimated rise and fall in groundwater storage after superimposition of 1950 and 1999 RWL contour maps.

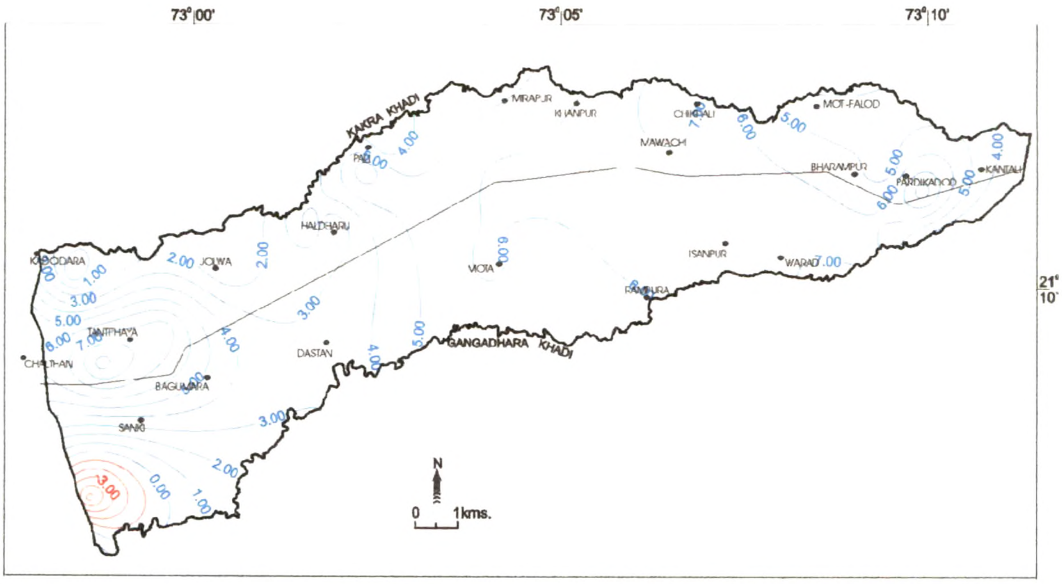

Fig. 7.19 Secular Change in Reduced Water Level Contours in Chalthan Command Area (1950-99).

The net change in groundwater storage as positive and negative value contour (Fig. 7.19) are suggestive of an average rise of 6.0 m in water levels in the command area during 40 years time span. Therefore the average rate of rise in water level stands at 15 cm/year. The maximum rate of rise i.e. 22.5 cm/year has been observed around Tantithaiya village while around Baleshwar (SW) and Kadodara (NW) shows fall in groundwater levels. The hydrographic profiles for 1950 and 1999 prepared along Karan - Kantali (A-A') transact (Fig. 7.20) also in conformation to above stated findings.

In the present study author has attempted to evaluate the groundwater chemistry from the point of view of long-term irrigation practices vis-à-vis consequence of possible enrichment in dissolved constituents causing adverse environmental impacts.

Chemical Evaluation of Groundwater

The groundwater quality varies in its concentration of dissolved substances depending on the hydro-geochemical conditions of the area and according to the season governing recharge and runoff. For the purpose of evaluation of groundwater chemistry and its seasonal and temporal changes, the concentrations of the dominant cations (*Ca, Mg, Na* and *K*) and anions (HCO_3, CO_3, SO_4 and *Cl*) and other physical characters have been employed. Detailed quantitative data on the groundwater chemical content analyzed by the author for post monsoon 1998, pre monsoon 1999 and post monsoon 1999 are given in APPENDIX II, III and IV, respectively. A critical appraisal on temporal changes in groundwater characteristics, by taking into account an individual parameter is given as under:

Electrical Conductance (EC)

The rate at which electricity is conducted is a measure of concentration of ions as well as ion activity in the solution (Sharma and Chawla, 1977; Hem, 1991). EC is also a measure of the degree of the mineralization of the water, which is dependent on rock water interaction, and thereby the residence time of the water in the rocks (Eaton, 1950).

In the study area EC varies from season to season and area to area. Although the EC value does not show much change during post and pre monsoon seasons, however there is slight enrichment during premonsoon season. The information on seasonal levels of EC is given in APPENDIX II, III and IV. The higher values (>3000 mmhos/cm) indicate saline nature of groundwater (Christiansen, 1973). Wells located at Mota and Tanti shows exceptionally higher values of EC.

In order to evaluate long-term behaviour of EC, the author has collected the past 30 years data from State Soil Survey Department. The decadal data on annual changes in EC values, over a period of 30 years are given in Table 7.6. From the data it is distinctly visible that there is continual and considerable increase in EC values from 1970 to 1990, specifically a well located at Mota and Isanpur shows marked rise in EC from 625 to 4600 mmhos/cm and 650 to 4210 mmhos/cm respectively. These observed trends in increased EC values till 1990 may be attributed to excessive irrigation and returned irrigation seepage although normal monsoonal recharge and non-utilization of groundwater for irrigation may also be responsible for this continual enrichment. The subsequent decreasing trends in EC values i.e. 1995 and 1999 throughout the study area is on account of adopted remedial measures, viz. controlled canal water supply, change in agricultural practices etc. The observation well at Sanki shows significant and continual improvement in EC values, as the village is equally utilizing the groundwater for irrigation.

Table 7.6 Secular Variations in Electrical Conductance (pre monsoon) of Groundwater in Chalthan Command Area.

Location	Year of Observation					
	1970	1980	1985	1990	1995	1999
	Electrical Conductance in mmhos/cm					
Vihan	750	1100	1040	1200	1100	980
Alura	1000	1500	1680	1920	1540	1720
Chikhli	2500	1700	1760	2160	1760	3400
Parab	1050	2600	1280	1800	1540	1870
Haldharu	600	1800	1280	2040	1760	1900
Pali	650	1000	800	1800	1650	1870
Bharampur	1300	1200	2440	2160	1870	1500
Khoj pardi	1200	1300	2380	2520	1870	2200
Jolwa	1000	1650	880	1000	880	710
Mota	625	1800	2240	2860	4130	4600
Isanpur	650	1100	1840	2280	2090	4210
Chalthan	1000	850	730	2280	1760	950
Tantithaiya	850	1200	970	1320	1210	1450
Sanki	900	880	420	550	520	500

(Source: Soil Survey Division, Surat)

Based on the irrigation water quality classification (Christiansen, 1973) the available long term annual records on EC (Table 7.7) have been categorized in to 05 categories and annual aerial coverage of individual categories has been estimated. The EC levels show considerable change from 1970 - 1999 (both pre as well as post monsoon). The most noticeable changes can be observed in the EC categories < 1000 and 2000 - 3000 mmhos/cm.

Table 7.7 Temporal Aerial Distribution Pattern of Electrical Conductance in Chalthan Command Area.

Year	Electrical Conductivity in mmhos/cm									
	Fresh		Mod. Brackish		Brackish		Saline		Highly saline	
	< 1000		1000-2000		2000-3000		3000-4000		> 4000	
	Area*	(%)	Area*	(%)	Area*	(%)	Area*	(%)	Area*	(%)
	Pre-monsoon									
1970	6743.10	61.61	4064.25	37.13	137.25	1.25	0.00	0.00	0.00	0.00
1980	178.23	1.63	8592.59	78.51	1115.28	10.19	592.90	5.42	465.47	4.25
1985	732.12	6.69	7466.53	68.27	2163.93	19.79	572.80	5.24	1.60	0.01
1990	433.58	3.96	6363.30	58.14	3251.90	29.71	659.47	6.03	236.21	2.16
1995	231.14	2.11	9189.36	83.96	1523.98	13.92	0.00	0.00	0.00	0.00
1999	706.56	6.46	6166.44	56.34	3256.40	29.75	735.03	6.72	80.04	0.73
	Post monsoon									
1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1980	1047.87	9.57	6151.33	56.20	3061.68	27.97	646.40	5.91	37.19	0.34
1985	1917.01	17.52	6172.67	56.40	1773.65	16.21	754.13	6.89	327.01	2.99
1990	1154.21	10.55	7735.84	70.68	2054.43	18.77	0.00	0.00	0.00	0.00
1995	1000.93	9.15	9434.50	86.20	509.05	4.65	0.00	0.00	0.00	0.00
1999	387.56	3.54	4287.61	39.18	4657.43	42.56	1428.83	13.06	183.06	1.67

* Area is in Ha.

Hydrogen Ion Concentration (pH)

The pH value of water represents the overall balance of a series of equilibrium existing in solution. Dissolved substances usually alter the pH value, because some ions combine with the H^+ and OH^- ions and thus upset the chemical equilibrium (Matthess, 1982).

Natural waters usually contained dissolved CO_2 and hydrogen carbonate ions, which form a buffer system with the carbon dioxide. This is the chief reason for the small variation in the pH, generally pH between 6.0 and 8.0 is found in natural waters. High pH values (>8.5) are associated with sodium-bicarbonate-carbonate waters. Moderately high pH values are associated with waters having high bicarbonate and low pH values (<5.5) reflect waters containing free acids (Garrels and Christ, 1966; Davis and De Wiest, 1967; Schwille, 1976). The hydrogen ion concentration (pH) of water is also a measure of its acidity or alkalinity. A neutral pH, neither acid nor alkaline, is 7.0; water with pH below 7 is acidic and above 7 is alkaline (Hem, 1959).

Seasonal behaviour of pH does not show much change with in the command area (APPENDIX II, III and IV). The pH of groundwater shows marginal increase from post monsoon 1998 to pre monsoon 1999 and decreases in subsequent post monsoon 1999. This change in pH value (from pre to post monsoon season) may be attributed to the introduction of CO_2 from the soil zone through percolating rainwater and irrigation recharge during post monsoon season (Matthess, 1982).

Total Dissolved Solids (TDS)

Total dissolved solids in water sample include all solid materials in solution, whether ionized or non-ionized. It does not include suspended sediments, colloids or dissolved gases. The amount and character of the dissolved solids depend upon the chemical composition and physical structure of rocks, temperature, residence time, pH and Eh conditions (Hem, 1959).

Generally, the total dissolved solids are indicative of an overall suitability of water, and water that contains too much-dissolved solids is not satisfactory (McKee and Bacon, 1953). TDS 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 300,000 mg/l in brines (Hem, 1970; Davis and De Wiest, 1967)

In the Chalthan Branch Command Area TDS exhibits a wide range (APPENDIX II, III and IV). Although not much seasonal change in TDS values are seen but spatial distribution pattern shows it is ranging from as low as 200 to as high as 2900 mg/l. TDS records based on long term monitoring (Table 7.8) shows marked increase in TDS levels from 1970 to 1995. The TDS levels for a set of observation wells exhibits steady rise except at Sanki village. Sharp rise in TDS has also been witnessed at Isanpur from 416 to 2696 mg/l and at Mota from 400 to 2944 mg/l.

An Iso-TDS contour map prepared for pre monsoon 1970 (Fig. 7.21) indicates TDS contours are ranging between 400 and 1600 mg/l. The contour pattern depicts its increasing trend towards NW direction. However the area around Haldharu and Mota villages are characterized by low TDS (<400 mg/l) waters.

Subsequent scenario i.e. pre monsoon 1985 represents almost two fold rise in TDS levels. The prepared Iso-TDS contour map (Fig. 7.22) indicates well-developed maxima with a TDS level of 2400 mg/l at Mota village. Contrary to this the 1999 TDS levels (Fig. 7.23) shows very well developed maxima around Dastan (3200 mg/l), Mota (2600 mg/l) and north of Mota (2900 mg/l) and a minima (400 mg/l) around Sanki village.

Table 7.8 Secular Variations in TDS (pre monsoon) of Groundwater in Chalthan Branch Command Area.

Location	Year of Observation					
	1970	1980	1985	1990	1995	1999
	Total Dissolved Solids (mg/l)					
Vihan	480	704	666	768	704	627
Alura	640	960	1075	1229	986	1101
Chikhli	1600	1088	1126	1382	1126	2176
Parab	672	1664	819	1152	986	1197
Haldharu	384	1152	819	1306	1126	1216
Pali	416	640	512	1152	1056	1197
Bharampur	832	768	1562	1382	1197	960
Khoj pardi	768	832	1523	1613	1197	1408
Jolwa	640	1056	563	640	563	454
Mota	400	1152	1434	1830	2643	2944
Isanpur	416	704	1178	1459	1338	2694
Chalthan	640	544	467	1459	1126	608
Tantithaiya	544	768	621	845	774	928
Sanki	576	563	269	352	333	320

(Source: Soil Survey Division, Surat)

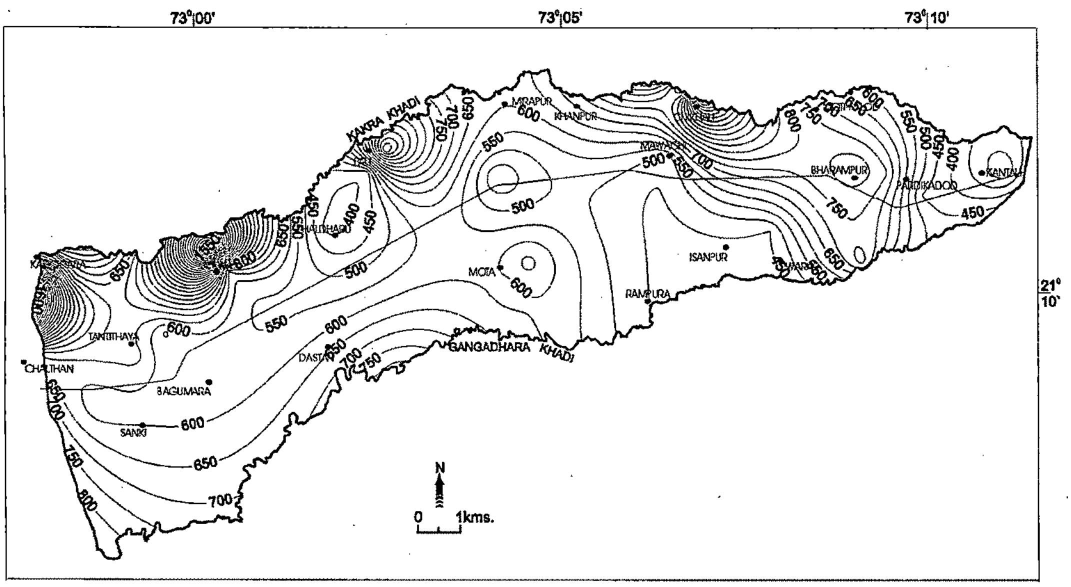

Fig. 7.21 Iso-TDS (mg/l) Contour Diagram of Groundwater in Chalthan Command Area (pre monsoon 1970).

A secular change in TDS has been estimated considering TDS levels of 1970 to 1999. Accordingly the author has prepared a contour map (Fig. 7.24). The long term changes in TDS levels show marked rise in TDS levels upto 2400 mg/l around

Mota and Dastan villages while some of the command area around Sanki, Bagumara and Jolwa villages is characterized by depletion in TDS levels upto -200 mg/l. These positive changes in TDS levels may be attributed to rise in water table and hence continual enrichment of the dissolved salts. Whereas the negative change is may be on account of better soil drainage conditions and sub-surface outflow.

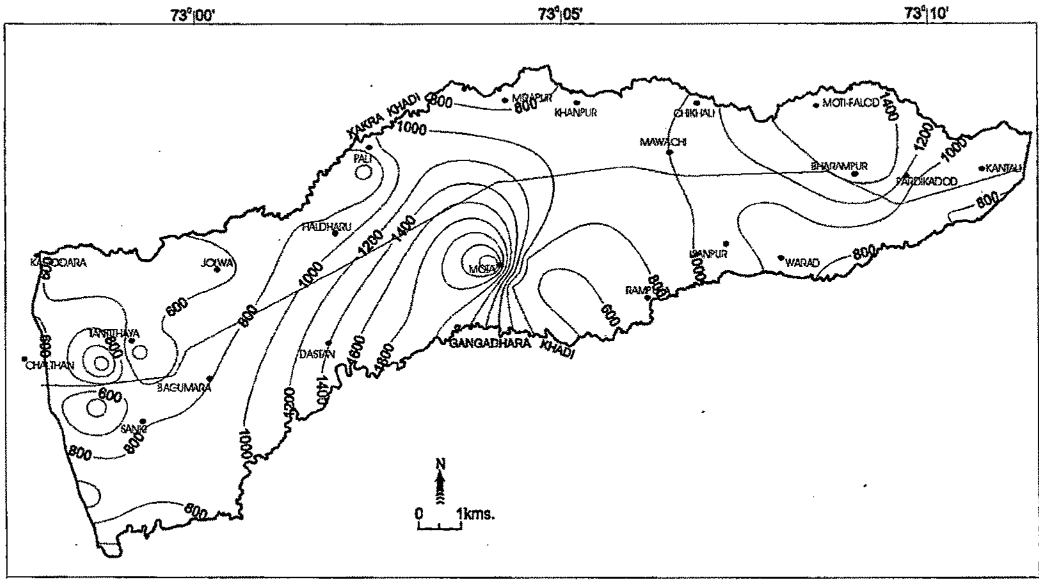

Fig. 7.22 Iso-TDS (mg/l) Contour Diagram of Groundwater in Chalthan Command Area (pre monsoon 1985).

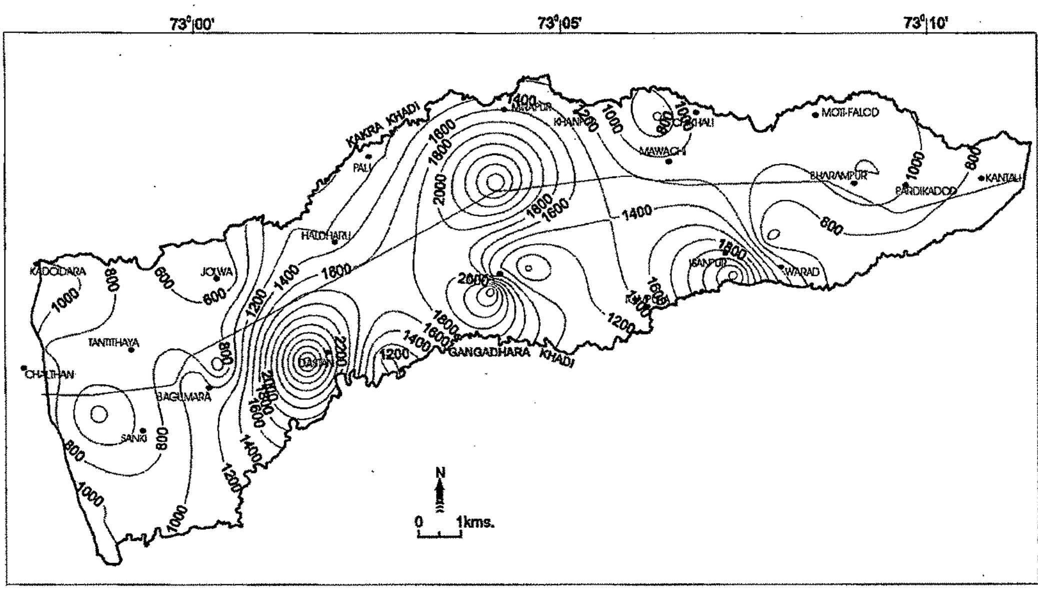

Fig. 7.23 Iso-TDS (mg/l) Contour Diagram of Groundwater in Chalthan Command Area (pre monsoon 1999).

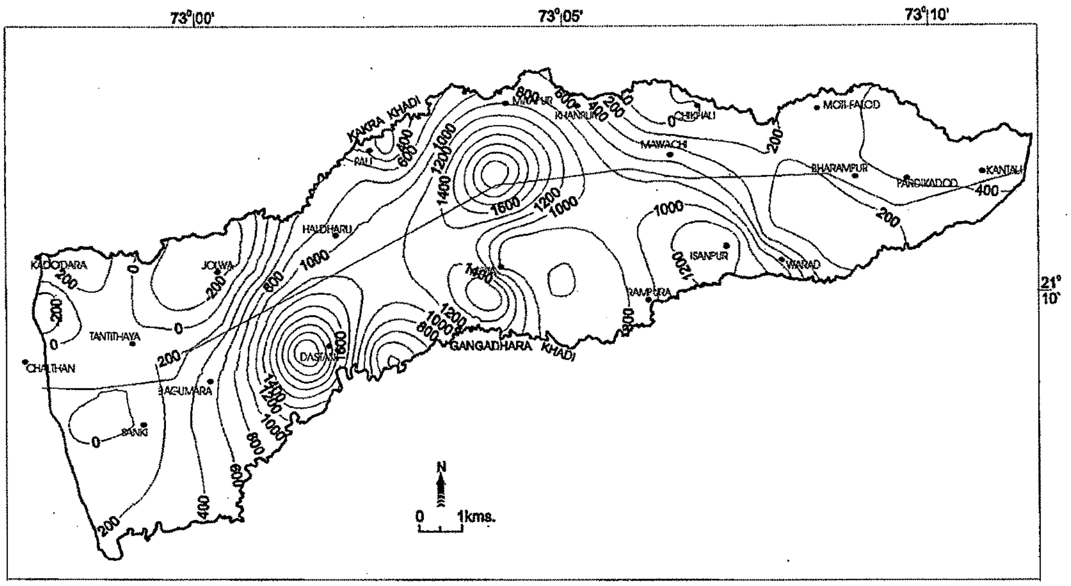

Fig. 7.24 Secular Change in TDS (mg/l) of Groundwater in Chalthan Command Area (1970-99).

Sodium (Na^+)

Sodium is by far the most important and abundant ion in mineralized groundwater with the exception of gypsiferous and many Ca-HCO_3 waters (Davis and De Wiest, 1967). It is considered to be the most injurious cation in irrigation waters (Glover, 2000).

Sodium is a dominant constituent of many igneous rocks and of rock salt. The important sodium bearing minerals are albite and other members of plagioclase feldspars, nepheline, sodalite, glaucophane, aegerine etc. Sodium is liberated during the weathering of these minerals. In addition to this certain precipitates of sodium present in the soils, clay minerals and zeolites are also considered as the important sources of sodium (Hem, 1959; Matthess, 1982).

Most sodium salts are readily soluble in the groundwater but take no active part in the chemical reactions like alkaline earths. Sodium like other cations, when applied to the soil in the irrigation water, it precipitates in the base exchange reaction of the clay minerals (Sharma and Chawla, 1977; Matthess, 1982).

The sodium content of groundwater ranges from about 1 mg/l in humid regions to over 100,000 mg/l in brines. Groundwater in well-drained areas with good amount of rainfall usually has 10 to 15 mg/l Na (Hem, 1991).

The sodium ion concentration estimated for three seasons viz. post monsoon 1998, pre and post monsoon 1999 (APPENDIX II, III and IV) shows a wide range. There is also an observed perceptible increase in sodium content during post monsoon period. Important locations where high sodium levels have been observed are Mota (802 mg/l), Tanti (682 mg/l), Motiphalod (494 mg/l) and Umbhel (434 mg/l) during post monsoon 1998 period. While during pre monsoon 1999 some of the wells show rise in sodium content specifically a well located around Mota, Khoj Pardi, Motiphalod villages etc. This overall rise in sodium content and its location specific enrichment in the groundwater may be ascribed to numerous reasons i.e. (i) rise in water table and hence continual enrichment of the dissolved salts containing sodium and (ii) sodium bearing water may under conditions participate in base exchange reactions whereby sodium replaces other cations in clay minerals (Hem, 1970, Matthess, 1982).

Potassium (K^+)

Potassium is found in many rocks, but is more abundant in igneous than sedimentary rocks. It is a constituent of many of the complex silicates making up the soil. The common sources of potassium are the silicate minerals like orthoclase, microcline, nepheline, leucite and biotite from igneous and metamorphic rocks and sylvite and niter from sedimentary rocks (Hem, 1970). Although potassium occurs abundantly in the rocks its concentration in groundwater is hundred times less than Na (Pawar, 1996). Because of lower geochemical mobility in groundwater, potassium is seldom found in groundwater (Matthess, 1982). The potassium concentration in water ranges from 1 mg/l to 10 mg/l in groundwaters and from 100 mg/l to several thousand mg/l in brines (Davis and De Wiest, 1967; Hem, 1970). Because of seldom occurrence in groundwater, potassium is used as agricultural fertilizers, and this can lead to significantly higher potassium concentrations in groundwater below cultivated areas (Harth, 1965).

Potassium is essential in plant nutrition and is removed from soil solution or from exchange media in the soil where plants are growing. The potassium in the plant structure is returned to the soil, unless the plant is removed (Hem, 1959).

In the study area potassium concentration show a wide range from 0.00 to 15.1 mg/l during post monsoon 1998, while pre monsoon 1999 data shows that potassium is in the range from 0.10 to 24.63 mg/l. The locations like Mota, Mavachhi, Dastan and Chalthan shows high potassium levels. However its overall concentration is found to be less than 0.10 mg/l. The minor seasonal fluctuations in potassium is due to its lower geochemical mobility in groundwater and also because of its act, as solution exchange media between plants and soils, which replenishes potassium in soil.

Calcium (Ca^{++})

Calcium is one of the most abundant cation, but is never found in nature uncombined (Sharma and Chawla, 1977). Because of wide spread occurrence in all types of rocks and soils and its ready solubility, calcium is present in nearly all types of waters (Matthess, 1982). Principal sources of calcium in the groundwater are silicate group of minerals like plagioclase feldspar, pyroxene and amphibole group of minerals in the igneous and metamorphic rocks. In the sedimentary rocks limestone, dolomite and gypsum are the chief sources of calcium (Davis and De Wiest, 1967).

Presence of large amount of calcium and bicarbonate in solution is possibly on account of large amount availability of carbon dioxide (Hem, 1959).

$$CaCO_3 + H_2O + CO_2 = Ca^{++} + 2HCO_3^-$$

In this condition fresh water can have 20 to 30 mg/l of Ca at saturation level. However, in soil-air through which water has to pass before reaching the groundwater, the percentage of CO_2 is several times high and hence, the Ca content can be as high as 70 to 110 mg/l. In certain chloride brines the Ca content can reach over 70,000 mg/l (Hem, 1959, Matthess, 1982).

Water with high calcium or magnesium is considered hard and is not desirable for domestic water supplies, but hard water is considered good for irrigation (Matthess, 1982). A calcium soil is friable and easily worked, which favors good water penetration and easy tilling. In irrigated areas this condition is favorable when the salts of the irrigation water are predominated by calcium. Calcium is essential to normal plant growth and is abundantly supplied through most irrigation waters (Sharma and Chawla, 1977).

Calcium content in the command area is ranging between 4.8 and 90.8 mg/l during post monsoon 1998, while during pre monsoon 1999 it is ranging between 10.0 to 82.40 mg/l (APPENDIX II, III and IV), which does not show much seasonal change in the calcium. Exceptionally higher values of calcium have been observed during pre monsoon 1999 around Karan (60 mg/l), Dastan (62.4 mg/l) and Mota (82.4 mg/l) villages. Certain wells specifically around Warad, Mota, Kantali, Motiphalod, Bagumara, and Karan villages show change in calcium levels from low during post monsoon to high during pre monsoon. This observed fluctuation in calcium content from post monsoon to pre monsoon season may be attributed to the rising trend of the groundwater and continuous enrichment of the salts, which may contain some amount of calcium salts. The reduction in calcium content during post monsoon may be attributed to the flushing action as well as replacement by Na under base exchange reaction in clay minerals.

Magnesium (Mg^{++})

Magnesium is abundant in nature and forms a normal constituent of dolomite in sedimentary rocks and biotite, hornblende, and augite in basic igneous rocks. It also occurs in metamorphic rocks like talc and tremolite schists. Most limestones also contain some magnesium carbonate. In the volcanic and metamorphic rocks magnesium occurs in the form of insoluble silicates, which on weathering forms soluble carbonates. In the study area the basalts seems to be the only source of Mg. In the presence of carbonic acid in water, magnesium carbonate is converted into more soluble bicarbonate (Sharma and Chawla, 1977; Hem, 1959).

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

The reaction of magnesium is much like 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 plant (Sharma and Chawla, 1977).

Dissolved concentrations of magnesium in groundwaters range between 1 to 40 mg/l. Groundwaters from rocks rich in magnesium may have as much as 100 mg/l but concentrations of more than 100 mg/l are rarely encountered except in sea water and brines (Davis and De Wiest, 1967).

In the study area magnesium has higher value than calcium because like calcium, magnesium normally is present in ionic form in solution and once in solution, magnesium has a stronger tendency to remain in that state than does calcium. In the study area magnesium concentration is ranging between 0.0 and

126.27 mg/l during post monsoon 1998, while during pre monsoon 1999 it is ranging between 2.56 and 140.42 mg/l (APPENDIX II, III and IV). Exceptionally higher values have been observed around Khoj Pardi (140.42 mg/l), Tanti (128.10 mg/l), Mota (98.45 mg/l) and Parab (87.35 mg/l) villages during pre monsoon 1999. However, it does not show any significant seasonal change.

Carbonates (CO_3^{-})

Carbonate in the form of limestone and dolomite and iron carbonate is widely distributed on the earth surface (Davis and De Wiest, 1967). When pH of groundwater is below 4.3, the carbonate species exists as H_2CO_3, however on crossing the limits of the pH above 8.5, the carbonate form changes to the bicarbonate (Hem, 1970).

On application of soluble carbonate (alkali) rich water in the irrigation, the response given by soil may be of two types (i) in the absence of soluble calcium or magnesium in the soil, it becomes alkaline and takes on the unfavourable characteristics described under sodium and (ii) if an excess soluble calcium is present such as gypsum, calcium carbonate is precipitated and little adverse effect on the soil is noted. Alkali carbonate such as sodium carbonate is undesirable in irrigation water and the soil solution is extremely toxic to plants (Sharma and Chawla, 1977).

In the Chalthan Branch Canal Command Area the carbonate content is very less, and hardly exceeds beyond 18 mg/l (APPENDIX II, III and IV). Exceptionally higher values have been observed in the wells located at Mota (36.0 mg/l) and Tanti (42.0 mg/l) villages. This high carbonate content, in the groundwater may be attributed to the release of the carbon dioxide under the higher water table conditions and/or the presence of large amount of sodium in proportion to calcium and magnesium (Hem, 1959).

Bicarbonates (HCO_3^{-})

Bicarbonate is not found to any extent in nature except in solution in the groundwater. It is generally derived from complex atmosphere-hydrosphere-lithosphere interaction by two different ways viz. (i) solubility of CO_2 in the water and (ii) chemical weathering of rocks by CO_2 saturated water (Davis and De Wiest, 1967). Carbon dioxide given off by plant roots and decaying organic matter adds to the bicarbonate content when dissolved in the soil water (Sharma and Chawla, 1977).

The concentration of bicarbonate ions in rainwater is below 10 mg/l, often below 1 mg/l while in normal groundwater it ranges from 50 - 400 mg/l (Davis and De Wiest, 1967). The bicarbonate occurring in irrigation water probably is of little direct importance in plant nutrition.

In the study area the hydrochemical data (APPENDIX II, III and IV) of post monsoon 1998 indicates the bicarbonate content is ranging between 51.23 and 173.20 mg/l, while during pre monsoon 1999 it is ranging between 58.54 and 279.38 mg/l. This observed marginal change in bicarbonate content, may be attributed to the change in amount of carbon dioxide either released from soil or added from the atmosphere. Exceptionally higher levels of bicarbonate are observed during 1999 around Khoj Pardi (279.38 mg/l), Haldharu (219.60 mg/l), Mota (219.60 mg/l) and Sevni (207.40 mg/l) villages.

Chloride (Cl^-)

Chloride is present in all natural waters. In groundwater the presence of chloride is attributed to the chloride bearing minerals such as sodalite, chlor-apatite, occurring as constituents of igneous and metamorphic rocks. Solutions of halite and other evaporite minerals may give rise to high chloride content in the groundwater (Walton, 1970). The chloride occurrence in the groundwater is also due to atmospheric sources or seawater contamination (Matthess, 1982).

The chloride in the groundwater varies from a few mg/l to several thousand mg/l in certain desert brines. The chloride content of rainwater is normally less than 10 mg/l and is of the order of 13,000 mg/l in the seawater. Therefore, in the groundwater the availability of chloride can be as high as the seawater or very less like the rainwater (Hem, 1959; Matthess, 1982).

Chloride is an essential element for plants and animals in a very limited amount or as traces in the soil solution, and both may constitute secondary or cyclic source of chloride in water. It inhibits the growth of most plants at the higher concentrations and for some plants has definite toxic effect (Sharma and Chawla, 1977).

Among the anions present in the command area chloride is the most dominant anion. The analytical data (APPENDIX II, III and IV) of groundwater indicate that chloride content is ranging between 25.03 and 1358.20 mg/l during post monsoon

1998. During pre monsoon 1999 it is ranging between 65.07 and 1309.24 mg/l, while during post monsoon 1999 it is between 67.45 and 1207.00 mg/l, thereby indicating minor seasonal change in chloride content.

Exceptionally higher values of chloride are observed around Mota (1309 mg/l), Tanti (897.80 mg/l), Parab (597.47 mg/l) and Motiphalod (577.23 mg/l) villages. High chloride content in groundwater may be attributed to the higher amount of electrical conductivity and use of chloride containing fertilizers (Matthess, 1982; Chhabra, 1996). Wells located in command area specifically around Kantali, Khoj Pardi, Kareli, Dastan, Haldharu, and Karan villages. point to an overall rise in chloride content from post monsoon 1998 to post monsoon 1999 and may be ascribed to an overall rise in groundwater levels due to over irrigation as returned irrigation seepage which is in addition to monsoonal recharge (Hem, 1970).

Sulfate (SO_4^{--})

Sulfur occurs in water largely in oxidized form as sulfate. The sources of sulfate in the groundwater are sulfur minerals, sulfides of heavy metals from igneous and metamorphic rocks, and gypsum and anhydrite from the sedimentary rocks (Hem, 1959).

Considerable amount of sulfate is added to the hydrologic cycle through precipitation (Goreham, 1955; Rankama and Sahama, 1960). A wide variation in the sulfate content of groundwater is on account of various ongoing geochemical reactions like reduction, precipitation, solution and concentration (Hem, 1959). Addition of sulfate to groundwater has been advocated from the breakdown of organic substance in the soil, from the addition of leachable sulfates in fertilizers, and other anthropogenic factors (Matthess, 1982). Sulfur is an essential element in plant nutrition and in the form of sulfate in groundwater it is readily available to plants (Sharma and Chawla, 1977).

In the study area sulfate content is seen ranging between 14.99 and 249.80 mg/l during post monsoon 1998 while during pre monsoon 1999 it is from 16.32 to 428.64 mg/l (APPENDIX II and III). This slight increase in sulfate content during pre monsoon season may be attributed to the enrichment of salts because of evaporation, such as calcium sulfate, magnesium sulfate etc. The study area wells around Kantali, Motiphalod, Vihan, Mota, Mavachhi, Dastan and Haldharu villages. shows annual decline in sulfate content which may be attributed to increase in irrigation supply and gradual leaching of the soluble salts, through surface drainage as well as the subsequent flow, appearing in the streams.

GROUNDWATER QUALITY EVALUATION

The use of a water as a public supply entails a combination of all the three main types of utilization viz. (i) domestic use, (ii) agricultural use and (iii) industrial use. However in case of study area domestic and agricultural uses are of the fore most importance.

Drinking Water Quality Evaluation

The water that is used for drinking purpose must meet high standards of physical, chemical and biological purity. The importance of the knowledge of geochemistry of drinking water and its relation to water quality and hence to human health cannot be under estimated. It is therefore, desirable that the water available should be of a desired quality suitable for different kinds of human uses. For this purpose, minimum quality standards have been formulated by the World Health Organization (WHO), the Indian Council of Medical Research (ICMR) and the Indian Standards Institution (ISI) (Table 7.9).

Hardness

Natural waters contain varying proportions of lime and other mineral salts and the relative hardness or softness of groundwater depends on the amount of these mineral salts. Water hardness is a traditional measure of the capacity of water to react with soap and is caused by dissolved polyvalent metallic ions. In fresh waters, the principal hardness causing ions are - calcium and magnesium; strontium, iron, barium and manganese (USEPA, 1976). The hardness is an important criterion for determining the usability of water for domestic, drinking and many industrial supplies. Although hardness may have significant aesthetic effects, a maximum acceptable level has not been established because public acceptance of hardness may vary considerably according to the local conditions (Fetter, 1990). Accordingly the water hardness has been divided into various classes Table 7.10 gives detail on water hardness scale. However, according to WHO, ICMR AND I.S.I. (IS: 10500) norms for evaluating the total hardness of the water, the dissolved solids up to 600 mg/l categorise as permissible for the drinking purpose.

Table 7.9 Summary of Drinking Water Quality Standards vis-à-vis Groundwater Quality in Chalthan Branch Command Area.

Substance	WHO. (1993)	I.C.M.R. (1975)	I.S.I. (1983)	Chalthan Command (1999)	
				Pre monsoon	Post monsoon
Colour (hazen)	5 (50)	5 (25)	10	Colourless	Colourless
Odour	Not desirable	Not desirable	Unobject-ionable	Odorless	Odorless
Taste, JTU	Not desirable	5 (25)	Agreeable	Normal	Normal
TDS (mg/l)	500 (1500)	500 (1500)	2000	275 - 2944	294 - 2835
PH	7-8 (6.5-9.2)	7-8.5 (6.5-9.2)	6.5-8.5	7.32 - 8.80	7.90 - 8.50
TH (mg/l)	300 (600)	300 (600)	300	85.46 - 702.11	72.20 - 699.88
Calcium (mg/l)	75 (200)	75 (200)	75	10.0 - 82.4	6.4 - 64.0
Magnesium (mg/l)	50 (150)	50 (100)	30	2.56 - 140.42	2.44 - 131.15
Chloride (mg/l)	200 (600)	200 (1000)	250	65.07 - 1309.24	67.45 - 1207.0
Sulfates (mg/l)	200 (400)	200 (400)	150	16.32 - 428.64	19.20 - 297.60

Figure in bracket indicate maximum permissible limit of constituent.

Table 7.10 Classification of Water Based on Hardness.

Type of water	Klut-Olszewski (1945) meq/l	Kass (1965) meq/l	Sawyer and McCarty (1967) mg/l
Very soft	0 - 1.43	0 - 1	< 60
Soft	1.43 - 2.86	1 - 3	
Avg. hardness	2.86 - 4.28	3 - 5	60 - 120
Moderately hard	4.28 - 6.42		
Hard	6.42 - 10.72	5 - 10	120 - 180
Very hard	> 10.72	> 10	> 180

The analytical data on groundwater hardness in study area for the pre and post monsoon periods of 1999 suggests that the hardness do not exceed the permissible limit (i.e. 600 mg/l) except few locations such as Khoj-Pardi (702.11 mg/l), Mota (611.19 mg/l) and Tanti (613.41 mg/l).

Genetic Classification of Groundwater

One of the most useful graphs for representing genetic classification of groundwater and comparing water quality analysis is the Trilinear Diagram given by Piper in 1953 and it is commonly used for the evaluation of the overall distribution of groundwater quality within an area. In this diagram anionic and cationic values are expressed as percentages of total cation and anion in milliequivalent per liter and plotted in the right and left triangles respectively. Then these plotted points from the respective triangles are projected into the central diamond-shaped area as the intersection points, representing total chemistry of groundwater. The central diamond shaped field is subdivided into different genetically governed fields (Fig. 7.25).

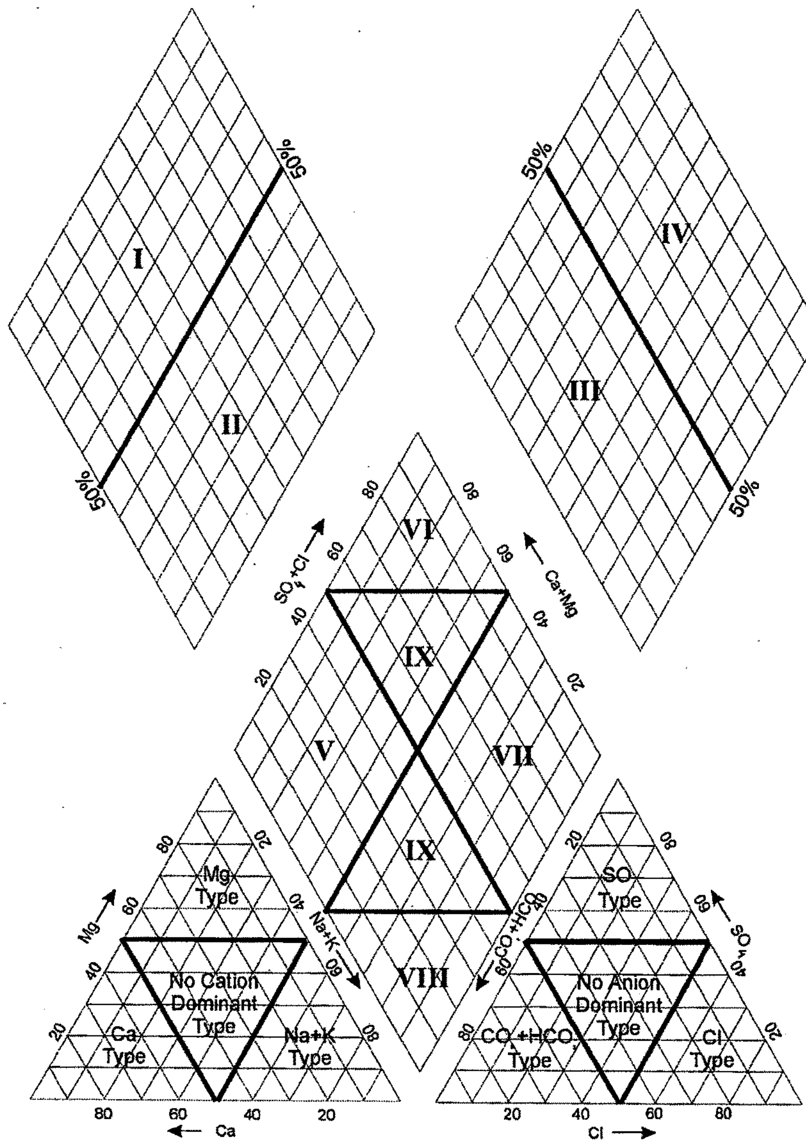

Fig. 7.25 Geochemical Fields in Piper Trilinear Diagram.

Depending upon the position of the point in these fields, different types of groundwater and their geochemical characteristics are evaluated as shown below:

Field 1: Alkaline earth exceed alkalies

Field 2: Alkalies exceed alkaline earths.

Field 3: Weak acids exceed strong acids.

Field 4: Strong acids exceed weak acids.

Field 5: Carbonate hardness exceeds 50%, i.e. chemical properties of the groundwater are by alkaline earths and weak acids.

Field 6: Non-carbonate hardness exceeds 50%.

Field 7: Non-carbonate alkali exceeds 50% i.e. chemical properties of ground water are dominated by alkalies and strong acids.

Field 8: Carbonate alkali exceeds 50% - very soft waters with low TDS content.

Field 9: No one cation anion pair exceeds 50%.

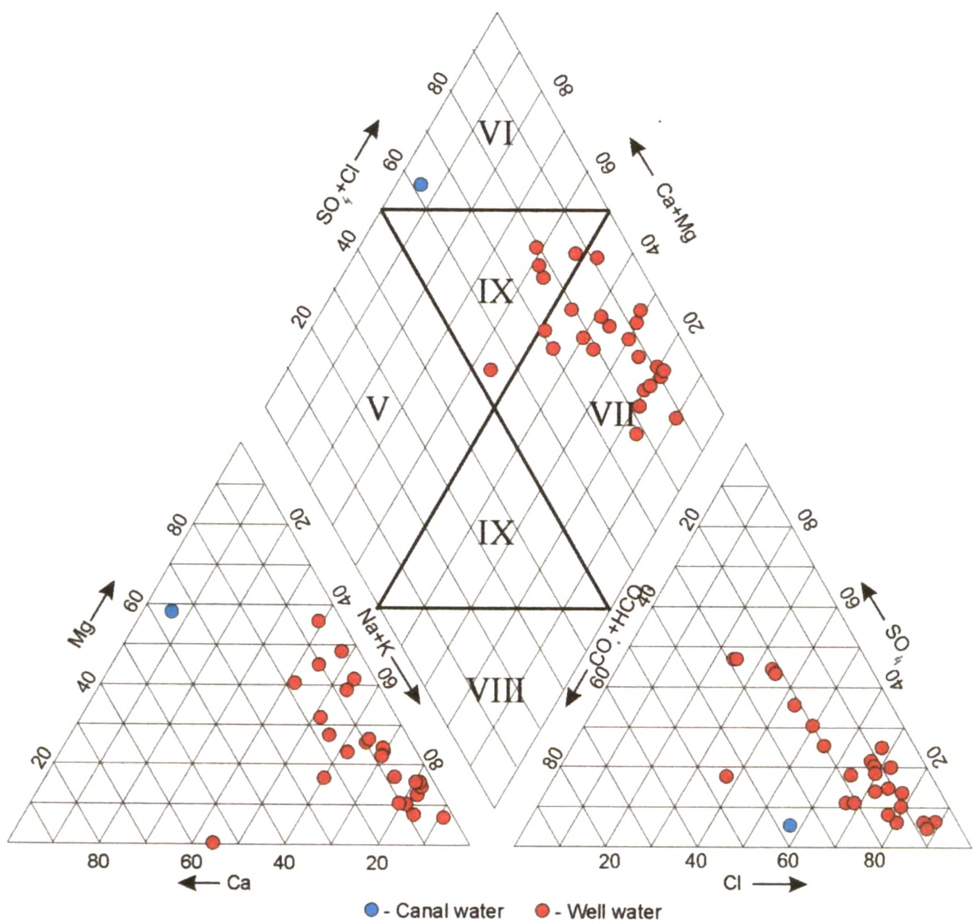

Fig. 7.26 Piper Trilinear Plots of Groundwater Samples in Chalthan Command Area (post monsoon 1998).

Irrigation Water Quality Evaluation

In irrigation, water quality is related to effects on soils, crops and management necessary to compensate for problems linked to water quality. The importance of water quality with special emphasis on irrigation has been intensely explored by the workers viz. Taylor et al (1937), Kelly, et. al. (1940), Kelley (1941), 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), Puri (1967), van Hoorn (1971), Bhumbala and Abrol (1972), Rhoades, (1972), Environmental Protection Agency (1973), Ayers and Westcot (1976), Christiansen et al. (1975, 1977), Westcot (1979), Bhatti (1986), Suarez, (1990), Gupta and Gupta (1997 a), Hoffman (1997), Datta et al. (1998) etc.

Assessment of the suitability of water for agricultural purpose requires a detail ionic chemistry of water. There exist numerous parameters and indices for evaluating the water chemistry impact on soil and crop due to irrigation. Some important one, which is currently in vague, are as follows:

a) Electrical Conductance,
b) Sodium Absorption Ratio,
c) Wilcox Irrigation Water Classification,
d) Permeability Index,
e) Residual Sodium Carbonate,
f) Soluble Sodium Percentage,
g) Schoellar Index,
h) Kelley's Ratio,
i) Adj. SAR,
j) Specific Ion Effect.

Electrical Conductance (EC)

Salinity is usually reported as electrical conductance (EC) and it affects the availability of water to crops due to reduction in soil permeability (Ayers, 1977). Various classifications on EC for use of irrigation water are given in Table 7.12.

The study of electrical conductivity and its seasonal variations does not show any marked changes. However, the ground water samples from Khoj Pardi, Mota and Tanti villages fall under Doubtful - Unsuitable category (Fig. 7.29).

Table 7.12 Classification of Irrigation Water Based on Electrical Conductance (EC).

<table>
<tr><th rowspan="2">Water Class</th><th>Scofield (1933)</th><th>Wilcox & Magistad (1943)</th><th>Richards (1954)</th><th>Christiansen et al (1973)</th><th>Ayers (1977)</th></tr>
<tr><th colspan="5">Electrical Conductance (mmhos/cm)</th></tr>
<tr><td>Class 1, Excellent</td><td>< 250</td><td rowspan="2">< 1000</td><td>100 - 250</td><td>< 500</td><td rowspan="2">< 750</td></tr>
<tr><td>Class 2, Good</td><td>250 -750</td><td>250 - 750</td><td>500 - 1000</td></tr>
<tr><td>Class 3, Permissible</td><td>750 - 2000</td><td rowspan="2">1000 - 3000</td><td>750 - 2250</td><td>1000 - 2000</td><td rowspan="2">750 - 2750</td></tr>
<tr><td>Class 4, Doubtful</td><td>2000 - 3000</td><td>2250 - 5000</td><td>2000 - 3000</td></tr>
<tr><td>Class 5, Unsuitable</td><td>> 3000</td><td>> 3000</td><td>> 5000</td><td>> 3000</td><td>> 2750</td></tr>
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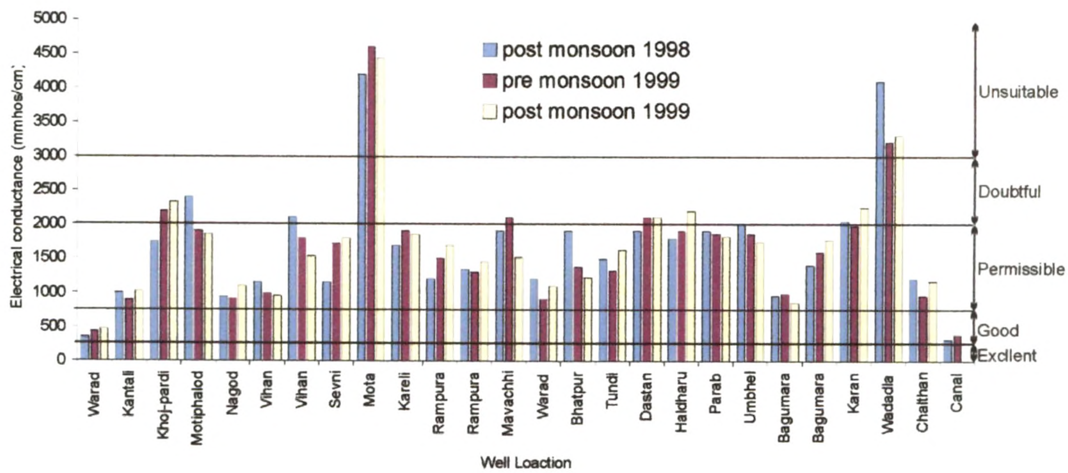

Fig. 7.29 Classification of Groundwater for Irrigation in Chalthan Command Area (Based on Electrical Conductance).

Sodium Adsorption Ratio (SAR)

In 1954, the U.S. Salinity Laboratory proposed that sodium percentage idea be replaced by a significant ratio termed as the sodium adsorption ratio (SAR) because it has a direct relation with the adsorption of sodium by soils. This ratio is calculated from the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

where Na, Ca and Mg concentrations are in milliequivalents per liter.

The permissible value of the SAR is a function of salinity. High salinity levels reduce swelling and aggregate breakdown (dispersion), promoting water penetration. High proportions of sodium, however, produce the opposite effect. Fig. 7.30 represents the approximate boundaries where chemical conditions severely reduce infiltration of water into soil, where slight to moderate reductions occur and where no reduction is expected in most soils (Hoffman, 1997).

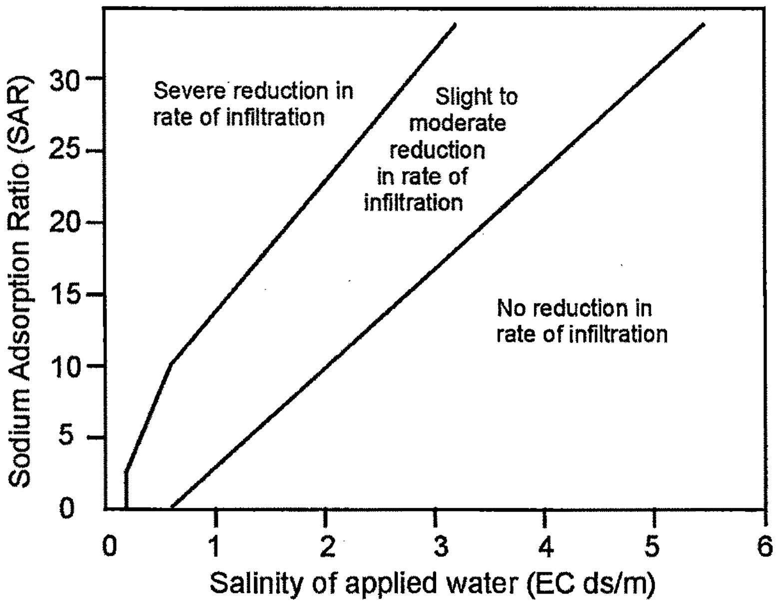

Fig. 7.30 Relative Rate of Water Infiltration as Affected by Salinity and Sodium Adsorption Ratio (Hoffman, 1997).

In order to evaluate the relationship of water constituents in terms of its quality, the conductivity of water is plotted on the x-axis and the SAR on the y-axis of the U. S. Salinity diagram, 1954. The diagram is used for locating a point on it; the position of this point gives the quality classification of water in terms of salinity and alkalinity hazards.

The U. S. Salinity diagram is divided into eight different classes such as C_1, C_2, C_3 and C_4 as salinity classes and S_1, S_2, S_3 and S_4 as sodium hazard or alkalinity classes. The significance and interpretation of the quality ratings on the diagram are summarized in Table 7.13 and 7.14.

Based on the plotted data on U. S. Salinity diagram (Fig. 7.31) it is inferred that the majority of well waters for all the three seasons are falling in Class C_3 - S_2 and C_3 - S_1 (Table 7.15), indicating of moderate class of water.

Table 7.13 Salinity Classification Based on EC.

Salinity Class		Remarks
Class C_1	Low Salinity	Good for irrigation and used for all soils.
Class C_2	Moderate Salinity	Good for irrigating extremely salt-sensitive plants if grown on soils of high to medium permeability.
Class C_3	High Salinity	Used for plants with good salt tolerance.
Class C_4	Very High Salinity	Undesirable for irrigation.

Table 7.14 Alkalinity Classification Based on SAR.

Salinity Class		Remarks
Class S_1	Low Sodium	Good for irrigation and used for all soils.
Class S_2	Medium Sodium	Used on coarse grained soils.
Class S_3	High Sodium	Good drainage, high leaching, and organic matter additions for improving the physical conditions of the soil are necessary for success with the water.
Class S_4	Very High Sodium	Undesirable for irrigation.

Table 7.15 Details of Groundwater Samples Belonging to Different Class of U. S. Salinity Diagram in Chalthan Command Area.

Class		Number of Groundwater Samples		
		Post monsoon 1998	Pre monsoon 1999	Post monsoon 1999
Good	C_2 -S_1	2	2	1
Moderate	C_3 - S_1	8	8	6
	C_3 - S_2	8	7	9
Bad	C_4 -S_2	0	1	1
	C_3 -S_3	3	5	5
	C_4 -S_3	1	0	1
	C_3 - S_4	1	1	1
	C_4 -S_4	2	1	1

Well located at Mota and Warad villages fall under Class C_3 - S_4 and C_4 -S_4 respectively, indicating non-suitability of groundwater for irrigation. The exceptionally higher values of SAR viz. Mota (18.20), Umbhel (19.85) and Motiphalod (13.99) indicate that use of such irrigation water may create alkalinity or sodium hazard problems.

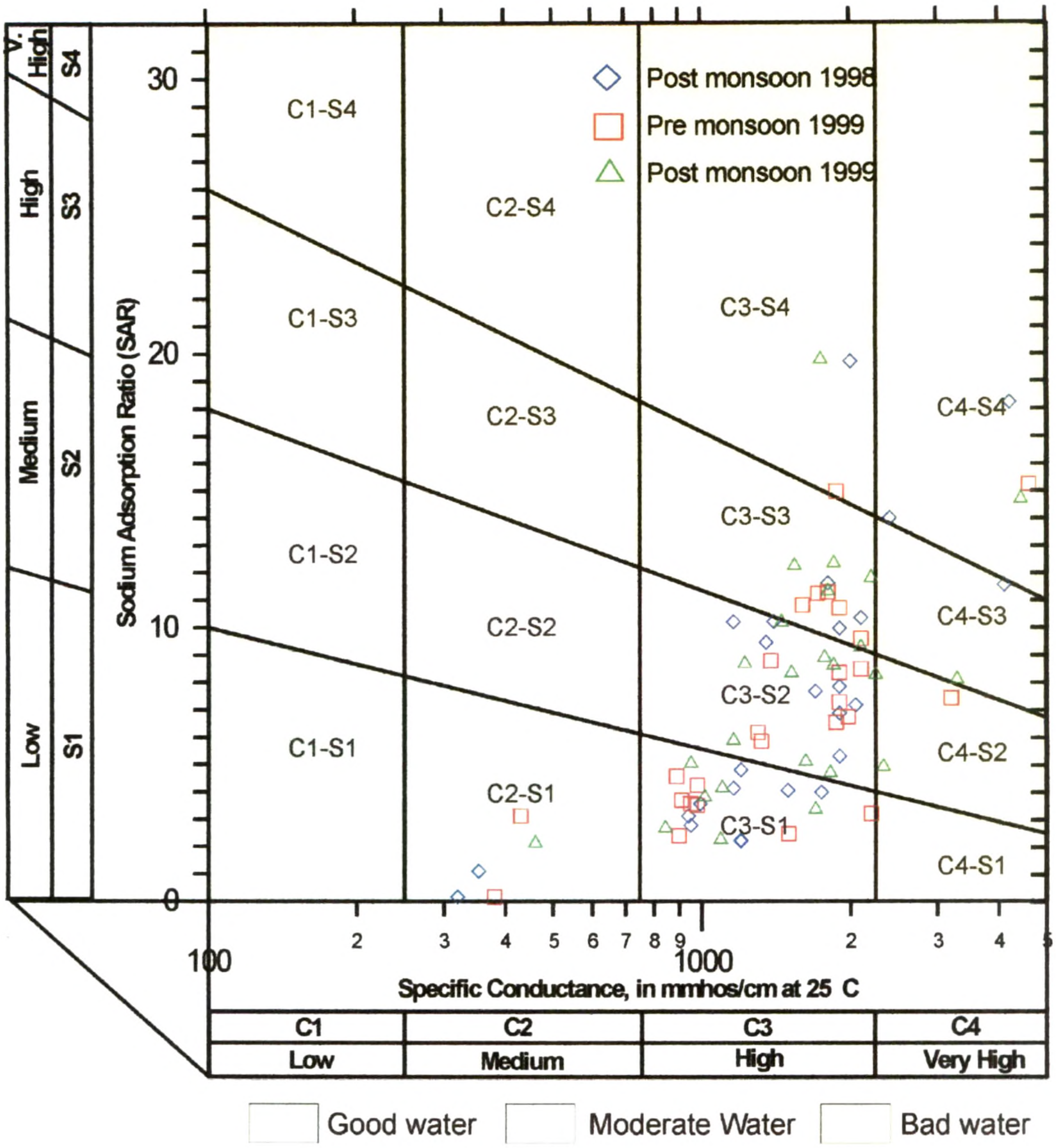

Fig. 7.31 U. S. Salinity Diagram Showing Seasonal Change in Quality of Groundwater (after Richards, 1954).

Wilcox Irrigation Water Classification

Wilcox diagram (Wilcox, 1955) is also helpful in evaluation of the water quality for irrigation. The plotted diagram (Fig. 7.32) shows majority of the samples for all the three seasons fall in the field of Permissible to Doubtful (Class - III) and Doubtful to Unsuitable (Class - IV) classes for irrigation purpose. The diagram also reveals that the number of well water samples reduces in case of Class - II i.e. 6 number of wells (post monsoon 1998) to 2 wells (post monsoon 1999), indicating deterioration in irrigation water quality.

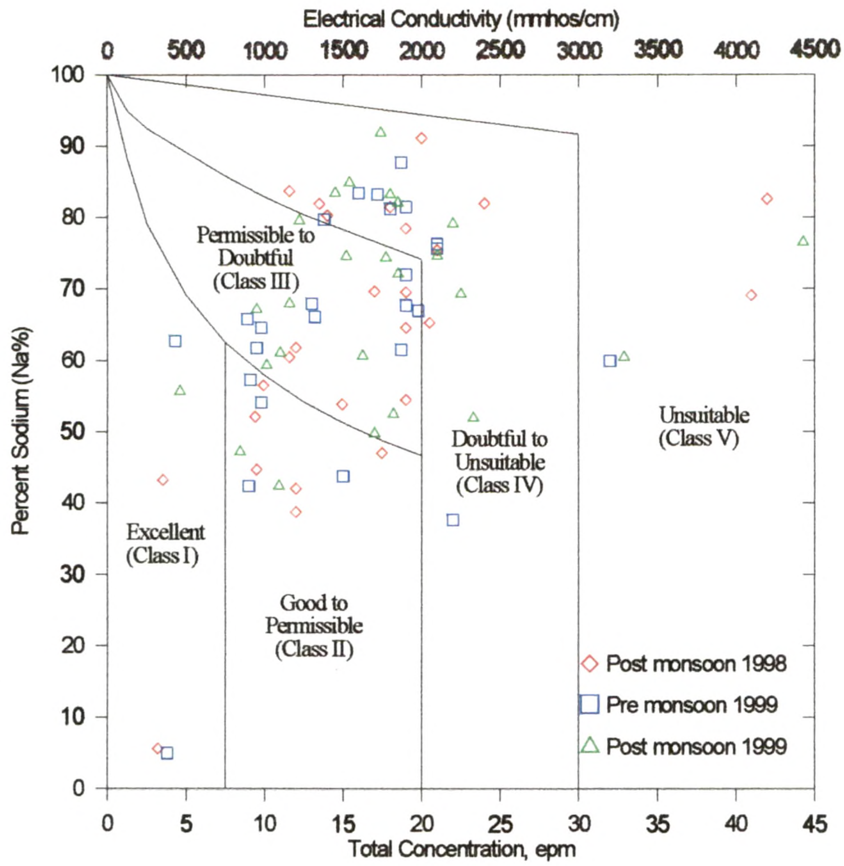

Fig. 7.32 Irrigation Water Classification in Chalthan Command Area (after Wilcox, 1955).

Permeability Index (PI)

Doneen (1964) has evolved a modified criterion for determining PI, based on the solubility of salts and the reaction occurring in the soil solution from cation exchange thereby, estimating the quality of agricultural waters. According to him, soil permeability, as affected by long-term use of irrigation water, is influenced by (i) total dissolved solids, (ii) sodium content, (iii) bicarbonate content, and (iv) the soil. To incorporate the first three items Doneen has empirically developed a term called "Permeability Index" (PI).

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100$$

Ionic concentration in meq/l

The PI values above 75 indicate excellent, between 25 and 75 good and less than 25 reflect bad quality of water for irrigation.

Fig. 7.33 indicates that almost 50% of the measured well water samples are having permeability index (PI) more than 75 for all the three seasons, indicating good quality of groundwater.

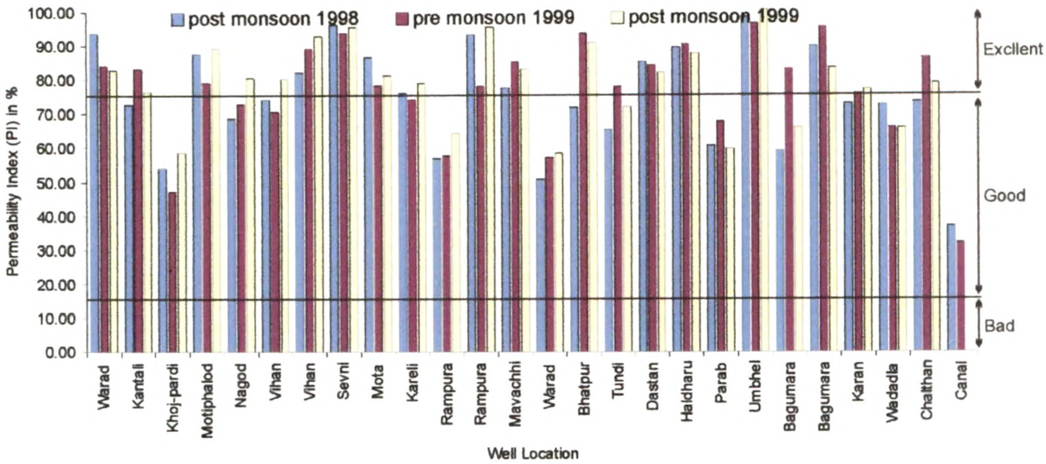

Fig. 7.33 Irrigation Water Classification Based on Permeability Index in Chalthan Command Area (after Doneen, 1964).

Residual Sodium Carbonate (RSC)

Waters containing a carbonate plus bicarbonate concentration greater than the calcium plus magnesium concentration have what is termed "Residual Sodium Carbonate". Residual Sodium Carbonate is very deleterious to the physical properties of soils. It creates what is known as a "black alkali" because Na_2CO_3 dissolves organic matter in the soil, which leaves a black stain on the soil surface when it dries. Soils containing high sodium carbonate or sodium bicarbonate are characterized by high pH i.e. 8.5 to 10.0. Such soils are referred to as sodic and have poor tilth, being very hard with large cracks when dry and very sticky when wet (Christiansen et al, 1975).

The potential for a sodium hazard is increased as RSC increase, and much of the calcium and sometimes the magnesium is precipitated out of solution when water is applied to the soil (Hoffman, 1997). Waters having high chlorides and sulfates do not cause as much change in the RSC, as chlorides and sulfates are more soluble than carbonates and bicarbonates.

If the water contains carbonate and bicarbonate in excess of calcium and magnesium, then it is likely to precipitate the calcium that is displaced by the exchange reaction. This excess quantity of carbonate and bicarbonate is denoted by Residual Sodium Carbonate (RSC) as proposed by Eaton (1950).

$$RSC = (CO_3^{2-} + HCO^{3-}) - (Ca^{2+} + Mg^{2+})$$

Ionic concentration in meq/l

According to Eaton (1950) water with RSC more than 2.5 meq/l - Unsuitable; between 1.25 to 2.5 meq/l - Permissible; and less than 1.25 meq/l - Safe for irrigation purpose. Measured RSC values for all the three seasons; with in the study area indicates that no well water is having values more than 1.25 meq/l (Fig. 7.34) thereby indicating safe nature of irrigation water from bicarbonate hazards.

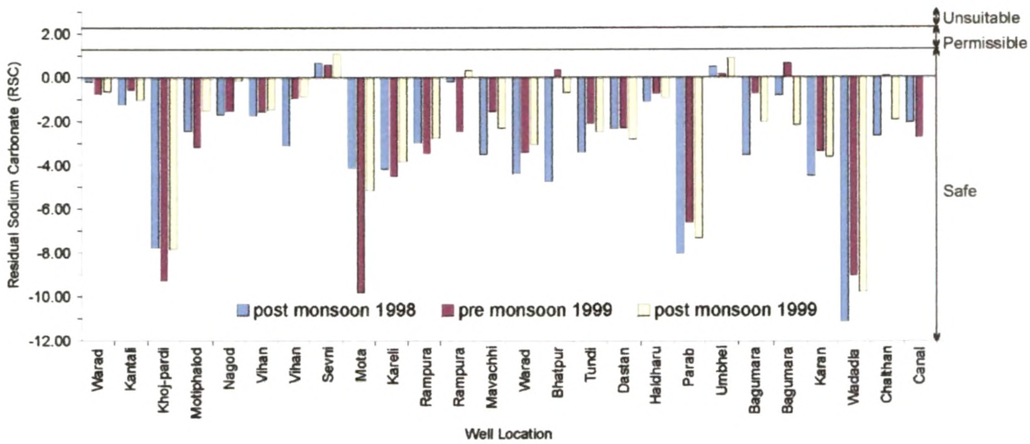

Fig. 7.34 Irrigation Water Classification Based on RSC (Eaton, 1950) in Chalthan Command Area.

Soluble Sodium Percentage (SSP)

If the irrigation water contains calcium and magnesium ions in quantity that equals or exceeds the quantity of sodium, a sufficient concentration of calcium and magnesium will be retained on the clay particles of the soil to maintain good tilth and permeability. Such waters serve well for irrigation even though the total mineral content may be quite high. This fact leads to the adoption of a factor called the sodium percentage i.e. the ratio of the sodium ions to the total sodium, calcium and magnesium ions (Hoffman, 1997). Scofield (1933) has proposed classification scheme for rating irrigation water on the basis of Soluble Sodium Percentage (SSP).

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

Ionic concentration in meq/l

Various classification schemes have been proposed to evaluate irrigation water quality based on Soluble Sodium Percentage are given in Table 7.16.

Table 7.16 Water Classification Based on Sodium Percentage.

Water Class	Quality	Sodium (Na^+) Percentage		
		Scofield (1933)	Christiansen (1975)	Wilcox (1948)
Class I	Excellent	< 20	< 40	< 60
Class II	Good	20 - 40	40 - 60	
Class III	Permissible	40 - 60	60 - 70	60 - 75
Class VI	Doubtful	60 - 80	70 - 80	> 75
Class V	Unsuitable	> 80	> 80	

In general Soluble Sodium Percentage exceeding 50 percent is considered to be the warning for sodium hazard. The SSP values of groundwater in study area are ranging between 45 and 85% (Fig. 7.35). Almost 70% of the wells water fall under Class - IV i.e. Doubtful - Unsuitable for irrigation purpose and may create problem to soils such as reduction of permeability & infiltration and increased sodicity, that ultimately reduces the crops yield.

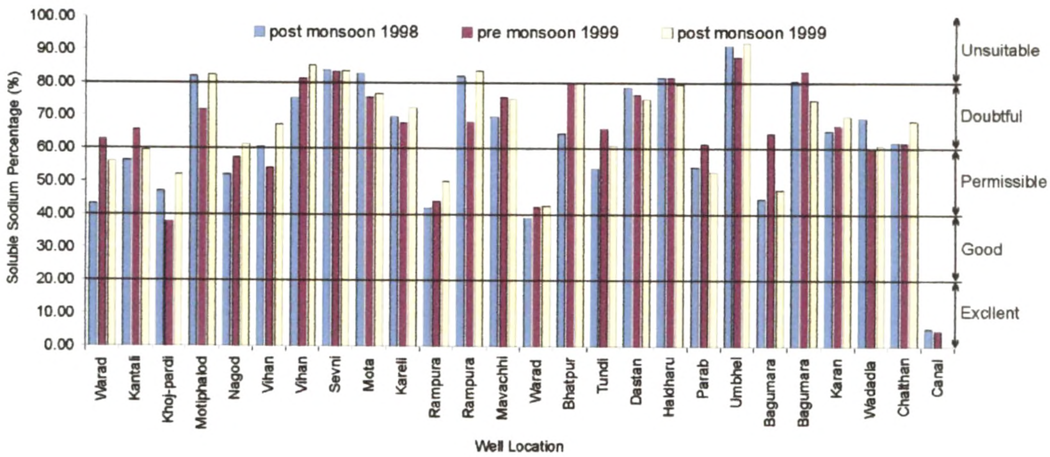

Fig. 7.35 Irrigation Water Classification Based on SSP (Wilcox, 1948) in Chalthan Command Area.

Schoeller Index (SI)

Schoeller (1959) used an index 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 SI is indicative of base exchange reaction i.e. Na+K in water being exchanged with Mg and Ca; whereas negative value of the SI 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 Chalthan Command Area indicates that about 20% of well samples are showing the positive values indicating the base exchange for all the three seasons, where as about 80% of the well water shows the negative values (Fig. 7.36). The above data also indicates that the Base Exchange is more pronounced during the post monsoon 1998 while cation and anion exchange is more pronounced during pre monsoon 1999.

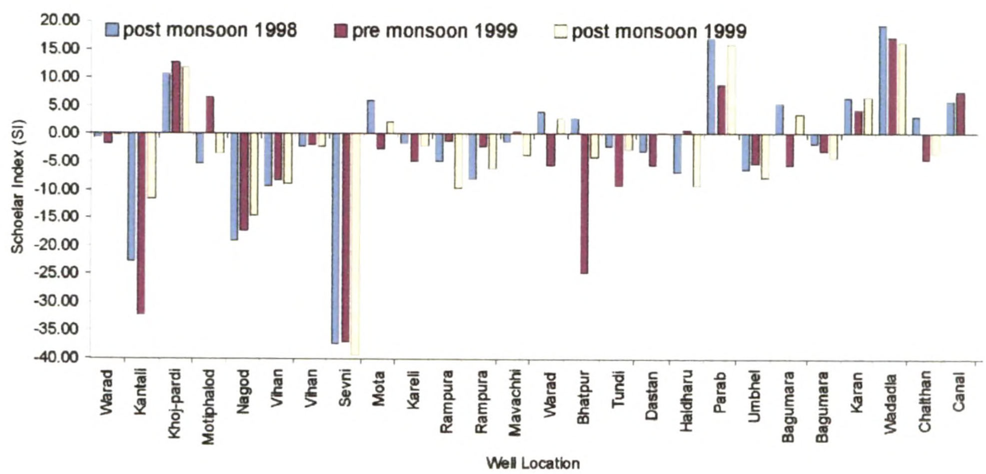

Fig. 7.36 Irrigation Water Classification Based on Schoeller Index (Schoeller, 1959) in Chalthan Command Area.

Kelley's Ratio (KR)

This parameter gives an idea regarding possible alkali hazards in the soils due to adverse groundwater quality. To evaluate alkali hazards of groundwater Kelley et al (1940) proposed a following equation

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

Ionic concentration in meq/l

Based on this ratio if the KR is one or less than one, indicates that the water is good for irrigation and is free from alkali hazards while the value of KR is more than one then it is indicative of alkali hazards. The calculated values of KR in Chalthan Command Area indicate that groundwater in major part of the command area has > 1 KR (Fig. 7.37), particularly well water at Umbhel has recorded almost 12 KR thereby groundwater is by and large prone to cause alkali hazards if applied in irrigation. However, certain locations like Khoj-Pardi, Rampura, Warad and Bagumara; the groundwater is free from alkali hazards.

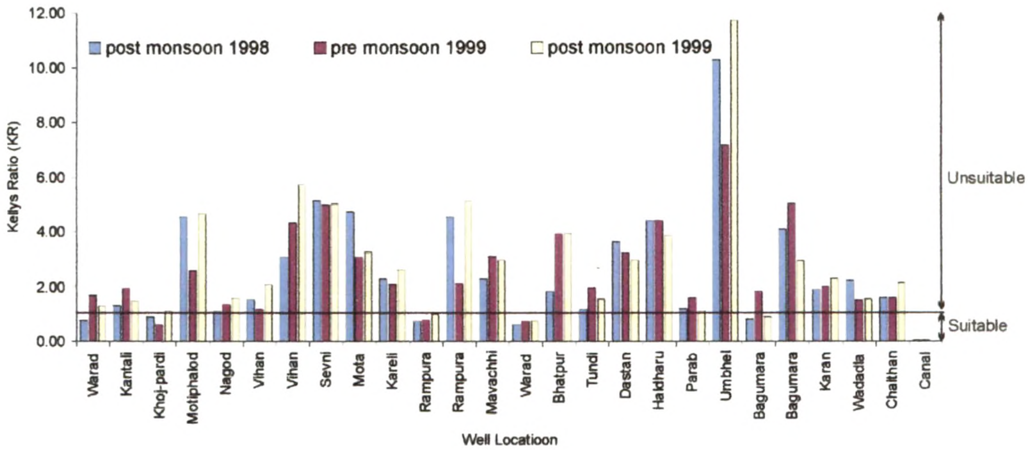

Fig. 7.37 Irrigation Water Classification Based on Kelley's Ratio (Kelley et. al, 1940) in Chalthan Command Area.

Adjusted Sodium Adsorption Ratio (adj. SAR)

The SAR indicates the tendency for the soil to become higher in exchangeable sodium; higher SAR value means higher exchangeable sodium percentage and lower soil permeability. If the water contain bicarbonate and carbonate ions, these will precipitate with calcium and magnesium, which increases the SAR (Miller and Donahue, 1995). The adj. SAR (Ayers and Westcot, 1976) is defined as

$$adj.SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}\left[1 + (8.4 - pHc)\right]$$

The ionic concentration of sodium, calcium and magnesium (in meq/l) are taken directly from the water analysis. The pH_c is calculated by the following formula

$$pH_c^* = (pK_2' - pK_c') + p(Ca + Mg) + pAlk$$

where *p(Ca + Mg)* and *pAlk* are the negative logarithms of the molar concentration of *Ca+Mg* and of the equivalent concentration of titratable base $(CO_3+HCO_3,)$ respectively and pK'_2 and pK'_2 are the respective logarithms of the second dissociation constant of H_2CO_3 and the solubility constant of calcite, respectively, both corrected for ionic strength (Wilcox, 1966). Values of *pHc* above 8.4 indicate tendency to dissolve lime from soil through which water moves; values below 8.4 indicate tendency to precipitate lime from water applied (Wilcox, 1966). Classification of irrigation water (Table 7.17) based on adj. SAR is given as under.

Table 7.17 Water Classification Based on Adj. SAR.

Water Class	Adj.SAR	Problem
I	< 3	No problem for toxicity
II	3 - 6	No problem for permeability
III	6 - 9	Increasing problem
IV	> 9	Severe problem

The calculated *pHc* values for the study area suggests that almost all the samples shows pHc value less than 8.4 thereby indicative of lime precipitation from irrigation water. Where as measure adj. SAR values shows considerable variation throughout the study area (Fig. 7.38). Almost 60% of well waters are falling under Class - IV (i.e. > 9 adj. SAR), indicating severe problem of toxicity and permeability.

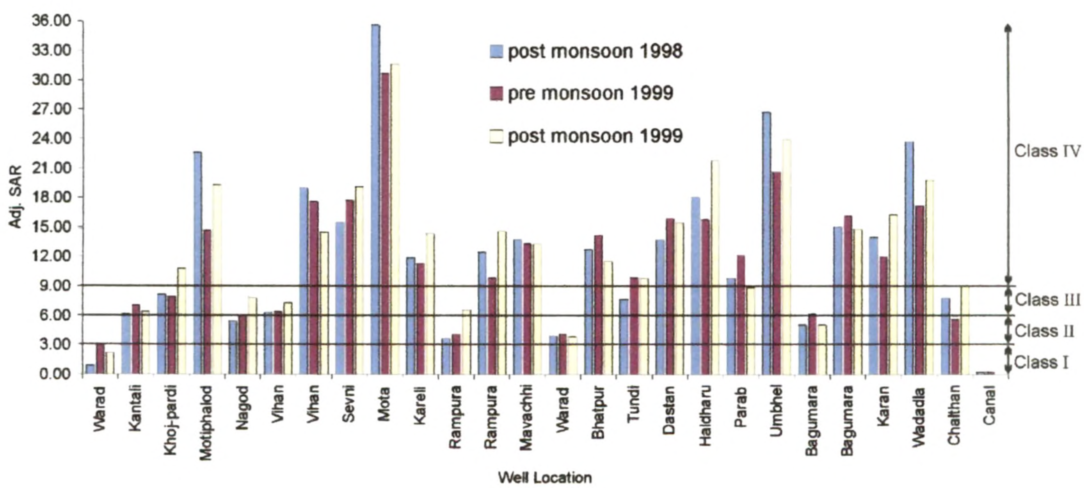

Fig. 7.38 Irrigation Water Classification Based on Adj. SAR (Ayers and Westcot, 1976) in Chalthan Command Area.

Specific Ion Effect

In addition to salinity, permeability and sodicity hazards, crop's growth may get affected by low to moderate and high concentration of certain specific solubles (ions) that may have a direct toxic effect. Toxic solubles includes sodium, chlorides, sulphate and boron. Some important ions whose concentration may become hazardous to plant growth are discussed here under:

Chloride (Cl^-): Chloride ions represent a hazard because they are absorbed by plant tissues and accumulate in the leaves resulting in leaf burns when present in excessive amounts. This has sometimes been referred to as chloride toxicity. For high chloride waters the rating for Cl^- may be higher than for EC and / or ES and for low Cl^- waters the reverse may be true (Christiansen et al, 1975). Scofield (1933) and Christiansen (1973) have proposed classification for irrigation water based on chlorides concentration (Table 7.18).

Table 7.18 Irrigation Water Classification Based on Chloride Content.

Water Class	Quality	Chloride (Cl) meq/l	
		Scofield (1933)	Christiansen (1973)
Class I	Excellent	< 4	< 3
Class II	Good	4 - 7	3 - 6
Class III	Permissible	7 - 12	6 - 9
Class VI	Doubtful	12 - 20	9 - 12
Class V	Unsuitable	> 20	> 12

In the study area chloride concentration is ranging between 0.71 and 38.26 meq/l during post monsoon 1998 and during post monsoon 1999 it is ranging between 1.9 and 34.0 meq/l. Fig. 7.39 shows that 9 well water samples are falling under Class - IV and 2 in class V indicative of non suitability of water in irrigation.

Some scientists have considered the chloride ion Cl^- twice as toxic as the sulfate ion SO_4^{--}. Doneen (1963) introduced the term "potential salinity" (PS), which he defined as the sum of the Cl^- and half of the SO_4^{--} (Table 7.19). The Potential Salinity can be determined as

$$PS = Cl + \frac{1}{2} SO_4$$

Ionic concentration in meq/l

For e.g. Ca^{++} and Mg^{++} facies indicate that water having over 90% $Ca^{++} + Mg^{++}$ and $Na^{+} + K^{+}$ is less than 10%. On the other hand, $Na^{+} + K^{+} - Ca^{++} + Mg^{++}$ facies indicate that $Na^{+} + K^{+}$ is the dominating ions in comparison to $Ca^{++} + Mg^{++}$. Based on detailed ionic concentrations, the groundwaters in Chalthan Command Area can broadly be classified into 2 hydrochemical facies (Table 7.21). The identified hydrochemical facies in the study area clearly indicates that alkalies predominate the alkaline earths among the cation, while amongst the anions the chloride and sulfate are dominant over bicarbonates.

Table 7.21 Hydrochemical Facies of Groundwater in Chalthan Branch Canal Command Area.

Hydrochemical Facies	No. of groundwater samples		
	Post monsoon 1998	Pre monsoon 1999	Post monsoon 1999
Na+K - Ca+Mg -- Cl+SO_4 - HCO_3	20	22	22
Ca+Mg - Na+K -- Cl+SO_4 - HCO_3	5	3	3

HYDROGEOLOGICAL INFERENCES

Based on the fore going account on the water regime of the Chalthan Branch Canal Command Area the following inferences can be derived:

- In the absence of any reservoir body, the canal (i.e. Chalthan Branch of Kakrapar Left Bank Canal System) is the only and vital source of surface water for irrigation.
- In the study area productive aquifers occur both under unconfined and confined conditions. The thicknesses of confined aquifers tend to increase with depth and are located in the depth range of 32 to 117 m below the surface.
- The aquifers represent an intercalated sequence of sand-silt-clays show s geohydrologic characters viz. transmissibility (79 - 1219 m^2/day), specific capacity (0.088 - 18.15 m^3/min/m) and discharge (200 - 3156 lpm), thereby signifying moderate to high potential of aquifers.
- Depth to water level in the study area ranges between 0.4 and 16.5 b.g.l. during pre monsoon 1999, while during post monsoon it is between 0.3 and 13.6 b.g.l.

- The overall groundwater movement is westerly with variable hydraulic gradient.
- Seasonal water level fluctuations in the study area show no significant change in the groundwater depth contour patterns as well as the groundwater movement for prior to inception of canal irrigation and the present scenario. However there exists marked change in seasonal fluctuation i.e. 2.5 m (1950) to 1.0 m (1999).
- Secular data on water level fluctuations in the study area (since 1950) has clearly revealed, a continuous rise in water table. The average rate of rise has been estimated to the order of 15 cm/year. The rise in water levels is more pronounced in the upper and middle parts of the command than the lower command area
- The canal irrigation, which is meant for kharif season, has greatly neglected the groundwater abstraction. The returned irrigation seepage coupled with monsoon recharge is primarily responsible for the ultimate rise in water level.
- The groundwater flow, with relation to the bordering Kankra Khadi and Gangadhara Khadi is of effluent in nature. Thereby indicating its shallow and near surface nature.
- The groundwater quality shows considerable variation. The continual rise in water table and upward migration of dissolved salts are possibly the causative factors for deterioration in the groundwater quality.
- Taking the bases of Drinking Water Quality Standards, majority of the groundwater samples have established the potability and water is safe for drinking purpose.
- Irrigation water classification of groundwater samples shows that almost 50% of the groundwater samples fall under the category of permissible to unsuitable categories and remaining 50% under Excellent - Good categories.
- A common chemical attribute of groundwater samples for all the three seasons suggest that the groundwater is characterized by the dominance of alkalies ($Na+K$) exceeds alkaline earth ($Ca+Mg$) and strong acids ($Cl+SO_4$) exceeds weak acids (CO_3+HCO_3).
- In terms of hydrochemical facies, groundwater of the study area mainly belongs to $Na+K$ - $Ca+Mg$ -- $Cl+SO_4$ - HCO_3 hydrochemical facies.

Based on above salient characteristics the author had prepared the hydrogeological map of the Chalthan Branch Canal Command Area (Fig. 7.43). The parameters considered for this are geology, geomorphology, pre and post monsoon water level, hydraulic conductivity, transmissibility and chemical content of pre monsoon 1999 i.e. TDS, Cl, HCO_3 and Na.

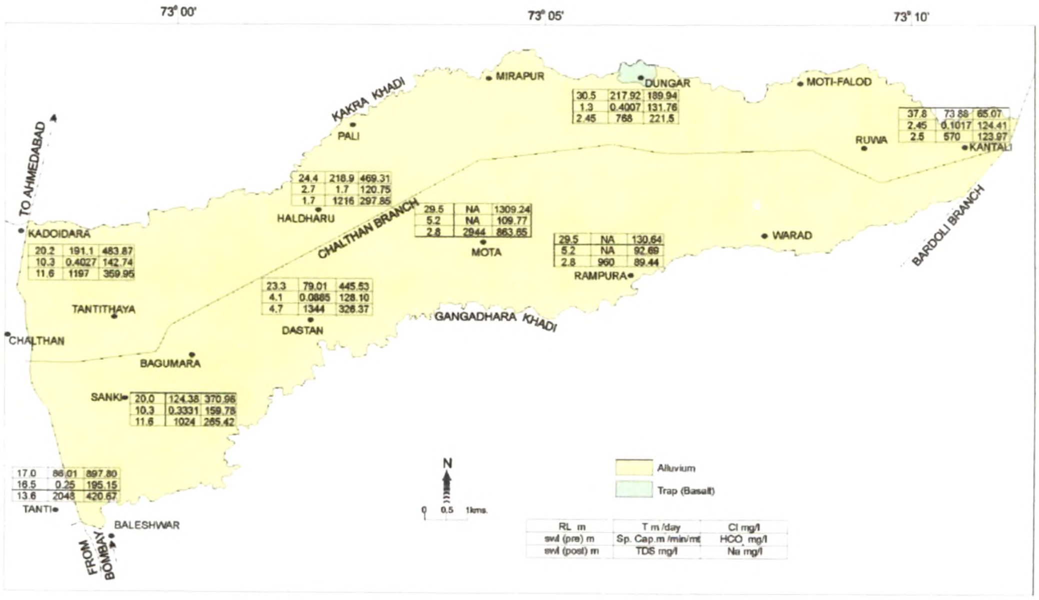

Fig. 7.43 Hydrogeological Map of Chalthan Branch Canal Command Area.