Chapter IV

WATER RESOURCES EVALUATION

WATER RESOURCES EVALUATION

INTRODUCTION

Water is one of the most essential commodities for every living biological system. The occurrence, distribution and potential of water resources in any area is a function of numerous variables predominated by the geological parameters and hydroclimatological factors. The evaluation of water resource potential and utilization, especially the groundwater resource, needs an elaborate study of various factors governing the monsoon pattern, surface runoff, infiltration, various hydraulic characteristics of the aquifer systems, etc. Water is a renewable resource and greatly depends on the monsoon pattern. Due to this very fact of water resources particularly the groundwater can not be unlimited and warrants efficient management of the total water resources.

REGIONAL WATER RESOURCES

Gujarat being predominantly agrarian state and also on the forefront of industrial development; ever increasing water demand in its various sectors, further necessitates obtaining precise information on water resource potential and utilization.

Gujarat's water resources can broadly be divided as (i) surface water and (ii) groundwater resources. The surface water contribution, which substantiates the major demand to the state, is derived from 185 river basins. The available surface water resources of the state have been estimated as 82,000 MM^3 (Rathod et al, 1997). The ultimate irrigation potential of the state from surface water resources and groundwater resources has been estimated as about 6.5 Mha, which is about 52% of the total culturable command area of 12.45 Mha, out of these about 40% of the ultimate irrigation potential comes from groundwater resources (Table 4.1).

As far as hydrogeological framework of the Gujarat state is concern, its all the three major hydrogeological units, namely, the consolidated rocks, semi-consolidated rocks and un-consolidated rocks, occur in equal proportions (Phadtare, 1988). Igneous and meta-sedimentary rocks cover a larger part with in the hard rock areas and have developed shallow phreatic and deeper semi-confined aquifer systems. The semi consolidated rocks (Mesozoic rocks) support multi-aquifer systems. The Quaternary alluvial formations and semi-consolidated formations of Tertiary are characterized by granular zones, have formed potential aquifers of semi-confined to confined aquifer system. A regional hydrogeological map (Fig. 4.1) encompassing the entire state provides further details on hydrogeological aspects.

Table 4.1 Water Resources of Gujarat State.

Sr. No.	Resources	Ultimate irrigation potential	Irrigation potential created upto June 95	Maximum utilization achieved upto June 95
A. Surface water resources		(in Mha)		
1	Major & medium	1.800	1.320	1.149
2	Sardar Sarovar	1.792		
3	Minor scheme	0.348	0.205	0.110
Sub-total (a)		3.940	1.525	1.259
B. Groundwater resources				
1	Govt. tube well	0.400	0.285	0.175
2	Pvt. Tube well	2.148	1.720	1.530
Sub-total (b)		2.548	2.005	1.705
Grand Total (a+b)		6.488	3.530	2.964

(Source: Rathod et al, 1997)

SURFACE WATER RESOURCES

It is quite natural that in a high rainfall riverine area like South Gujarat, surface water has always received priority in the field of irrigation in addition to groundwater, which is well evident from a close perusal of past records. This accrues primarily from the perennial character of the rivers, the rapidly deteriorating drainage system and the necessity of intensive agriculture due to accelerating growth of population. These conditions have created the need for artificial irrigation either through total replacement by groundwater or through conjunctive use of both. The basic source of surface water in the region is rainfall. Runoff from the drains through streams and rivers is normally stored in reservoirs, tanks and ponds.

A changing scenario with regard to the sources of irrigation is observed throughout the decades. During the 1950s i.e. before Kakrapar irrigation project the primary source of irrigation was wells and tanks, also at places government canals did irrigation locally (Table 4.2).

Table 4.2 Areas Under Different Sources of Irrigation in Different Talukas Coming Under the Kakrapar Left Bank Canal Project Before Commissioning of Kakrapar Project (1953-54).

Sr. No.	Talukas	Irrigation Areas (ha)				
		Canals	Tanks	Wells	Other Sources	Total
1.	Choryasi	-	23	901	-	924
2.	Kamrej	-	-	2318	33	2351
3.	Bardoli	82	-	725	-	807
4.	Palsana	-	-	568	258	826
5.	Mahuva	44	22	148	36	250
6.	Navsari	-	324	1903	-	2227
7.	Gandevi	117	104	758	-	979
8.	Chikhli	-	9	442	-	451
9.	Valsad	-	-	315	-	315
Total		243 (2.66)	482 (5.28)	8078 (88.48)	327 (3.58)	9130 (100.00)

Figure in bracket indicates percentage to total. (Source: Mistry and Purohit, 1982)

By the late 1960s, irrigation by government canals has increased due to implementation of the Kakrapar Project i.e. 1958. Canal irrigation assumed importance in the alluvial plains of the area. Irrigation through wells and tanks has attained 2nd and 3rd preference respectively. These changing trends in irrigation made continued till late seventies, with government canals gradually replacing other irrigation sources due to the implementation of the Ukai Projects with the increase in population pressure and demand for more irrigation water. While dug wells, tube wells and other miscellaneous sources still retained their importance in part of the area (Table 4.3). The irrigation data for the last decade i.e. 1990s shows considerable increase in canal irrigated area. Almost 61% of the total irrigated area is irrigated by canal while wells come on second place with 32% and remaining area is irrigated by tanks and other sources (Table 4.4).

Table 4.3 Areas Under Different Sources of Irrigation in Different Talukas Coming Under the Kakrapar Left Bank Canal Project After Commissioning of Ukai & Kakrapar Project (1977-78).

Sr. No.	Talukas	Irrigation Areas (ha)				
		Canals	Tanks	Wells	Other Sources	Total
1.	Choryasi	9150	40	4924	-	14114
2.	Kamrej	9610	-	8726	-	18336
3.	Bardoli	12223	-	487	-	12710
4.	Palsana	9225	25	2290	-	11540
5.	Mahuva	2002	-	745	36	2783
6.	Navsari	12450	273	141	-	12864
7.	Gandevi	3826	328	1684	-	5838
8.	Chikhli	2840	900	4400	-	8140
9.	Valsad	1180	35	2562	-	3777
Total		62506 (69.37)	1601 (1.78)	25959 (28.81)	36 (0.04)	90102 (100.00)

Figure in bracket indicates percentage to total. (Source: Mistry and Purohit, 1982)

Table 4.4 Areas Under Different Sources of Irrigation in Different Talukas Coming Under the Kakrapar Left Bank Canal Project During 1991.

Sr. No.	Talukas	Irrigation Areas (ha)				
		Canals	Tanks	Wells	Other Sources	Total
1.	Choryasi	5809	220	3940	890	10859
2.	Kamrej	12396	24	11953	422	24794
3.	Bardoli	16216	136	5525	1028	22906
4.	Palsana	7103	118	5655	74	12950
5.	Mahuva	10783	96	3164	933	14976
6.	Navsari	14615	452	4281	266	19614
7.	Gandevi	3636	425	3709	125	7895
8.	Chikhli	8285	41	3830	580	12736
9.	Valsad	4649	691	2037	1481	8857
Total		83493 (61.58)	2204 (1.63)	44094 (32.52)	5799 (4.28)	135589 (100.00)

Figure in bracket indicates percentage to total. (Source: District Census Handbook of Surat & Valsad, 1991).

CANAL NETWORK

The Kakrapar irrigation system comprises a network of Main canal, branch canal, distributaries, minors, sub-minors, field drains and outlets of different dimensions and different capacities (Fig. 4.2). The region has one main canal having 64-km length and having capacity to discharge 3020 cusecs of water to irrigate total 145335 hectares area through its branch and distributaries having length 306 km and 877 km respectively.

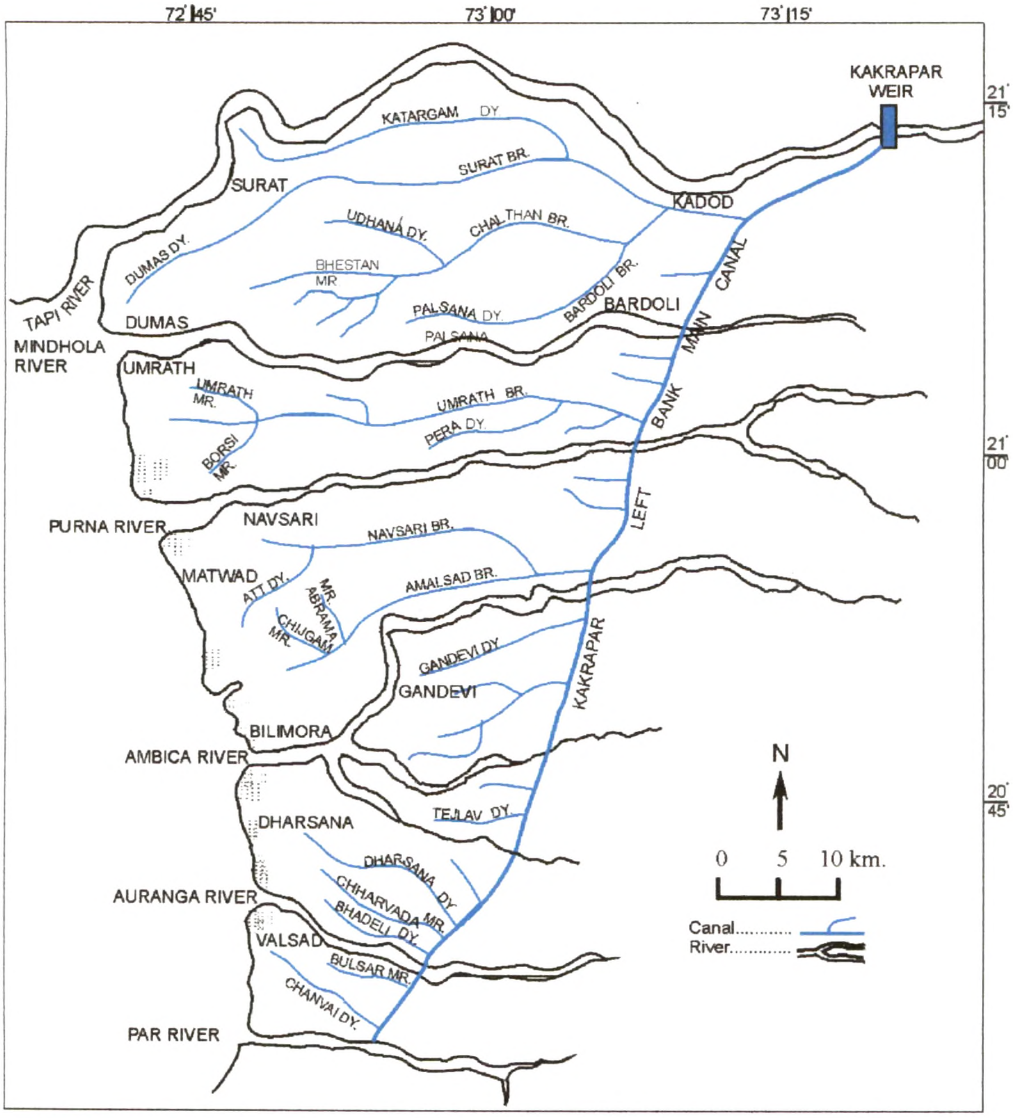

Fig. 4.2 Canal Network Map of KLBC Area.

As the major canal network is unlined, the seepage losses from canal system (Table 4.5) are bound to recharge the groundwater regime also. The estimates on

As the major canal network is unlined, the seepage losses from canal system (Table 4.5) are bound to recharge the groundwater regime also. The estimates on recharge taking in to consideration the canal seepage, returned irrigation seepage for the entire command area stand at 1788 MCM (GWRDC, 1985). The detail on estimated seepage for canal system in the command area is given in Table 4.6.

Table 4.5 The Details Regarding Lined and Unlined Canals in KLBC Area.

Sr. no.	Canals	Length in km.			Total
		Lined		Unlined	
		Before 1999	After 1999		
1	Main	0.00	35.00	29.00	64.00
2	Branch	0.00	11.00	233.32	244.32
3	Distributaries	0.00	0.00	218.80	218.80
4	Minor	50.38	0.00	360.80	411.18
5	Sub-minor	112.66	0.00	1294.73	1407.39
Total		163.04	66.00	2136.65	2345.69
Percentage (%)		6.95	1.96	91.09	100.00

Source: GWRDC (1985).

Table 4.6 Estimated Seepage Losses from the Canals in KLBC Area.

Type of Canal	Length of Canal in m.	Avg. wetted perimeter	Seepage loss in MCM
Main canal	64000.00	29.09	48.00
Branch canal	244320.00	14.72	163.93
Distributary	218000.00	5.67	55.00
Minor canal	411180.00	3.44	55.9
Total	937500.00	52.92	322.83

Source: GWRDC (1985).

Canal Water Chemistry

Chemistry of canal water is prerequisite to study the impact of irrigation on soil-water quality regimes. The available canal water quality data for the KLBC system, analyzed by the state Soil Survey Department for 48 locations suggests majority of samples fall under the good category of irrigation water quality standards, as prescribed by W.H.O. and I.S.I. A summary on various physico-chemical parameters of the canal water is given in Table 4.7.

The author has also given the graphical treatment to these available water chemistry data; using standard plots (viz. Piper Trilinear Plots, U.S.Salinity chart etc.) and classified the canal waters from the point of view of its irrigation suitability (Table4.8).

Table 4.7 Major Physico-chemical Constituents of Canal Water (premonsoon -2000).

Sr. No.	Constituents	Total no Of Samples	Range		Mean	Standard Deviation
			Min.	Max.		
1	PH	48	7.60	8.50	7.97	0.20
2	EC (mmhos/cm)	48	330.00	550.00	451.91	48.26
3	TDS (mg/l)	48	211.53	352.55	289.68	30.93
4	Hardness (mg/l)	48	162.53	262.59	217.45	24.14
5	$CO3^-$ (mg/l)	48	Nil	Nil	Nil	Nil
6	$HCO3^-$ (mg/l)	48	73.22	109.84	91.92	8.38
7	Cl^- (mg/l)	48	63.81	120.53	95.94	12.70
8	$SO4^-$ (mg/l)	48	9.61	24.02	14.51	4.31
9	Ca^{++} (mg/l)	48	20.04	52.10	34.05	7.48
10	Mg^{++} (mg/l)	48	27.34	39.49	32.18	2.51
11	Na^{++} (mg/l)	48	3.91	5.06	4.67	0.55
12	K^+ (mg/l)	48	Nil	Nil	Nil	Nil

(Source: Soil Survey Division, Surat, 1999)

Table 4.8 Various Parameter Used to Determine Irrigation Water Quality of Canal Water (Compiled after Scofield, 1933; Richards, 1954; Eaton, 1950; Ayers and Westcot, 1976).

Parameters	Max.	Min.	Category	Percentage of Samples	Water class
EC	550	330	< 250		Excellent
			250-750	100.00	Good
			750-2000		Permissible
			2000-3000		Doubtful
			>3000		Unsuitable
Na%	5.54	3.45	< 20	100.00	Excellent
			20-40		Good
			40-60		Permissible
			60-80		Doubtful
			> 80		Unsuitable
SAR	0.16	0.11	<10	100.00	Excellent
			10-18		Good
			18-26		Fair
			> 26		Poor
RSC	-2.05	-3.65	<1.25	100.00	Good
			1.25-2.50		Medium
			> 2.50		Bad
Adj.SAR	0.26	0.17	<10	100.00	Normal
			10-20.		Low sodium
			20-30		Medium sodium
			>30		High sodium

EC: Electrical Conductivity; Na%: Sodium percentage; SAR: Sodium Adsorption Ratio; RSC: Residual Sodium Carbonate; Adj.SAR: Adjustable Sodium Adsorption Ratio.

From the potability point of view, majority of canal water samples fall under field VI in Piper Trilinear diagram, indicating canal water is characterized by non carbonate hardness and of Calcium-chloride types (Ca-Mg-Cl-SO_4) (Fig. 4.3).

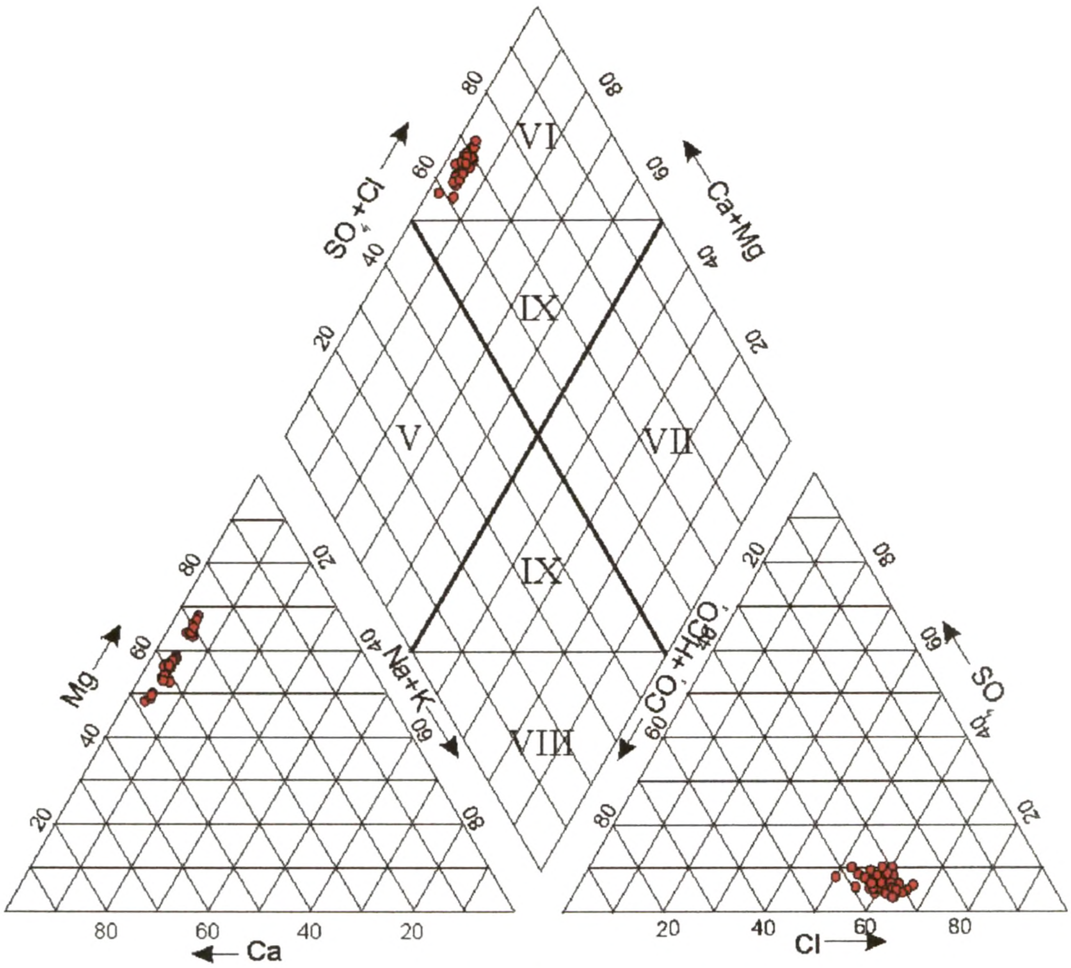

Fig. 4.3 Piper-Trilinear Plots of Canal Water.

Fig 4.4 shows the Wilcox diagram of canal water. The diagram reveals that the all the samples fall in field of excellent to good (class I) waters suitable for irrigation. Based on U.S. Salinity chart (Fig. 4.5), the canal water, fall under the C2-S1 class indicating its suitability for irrigation water.

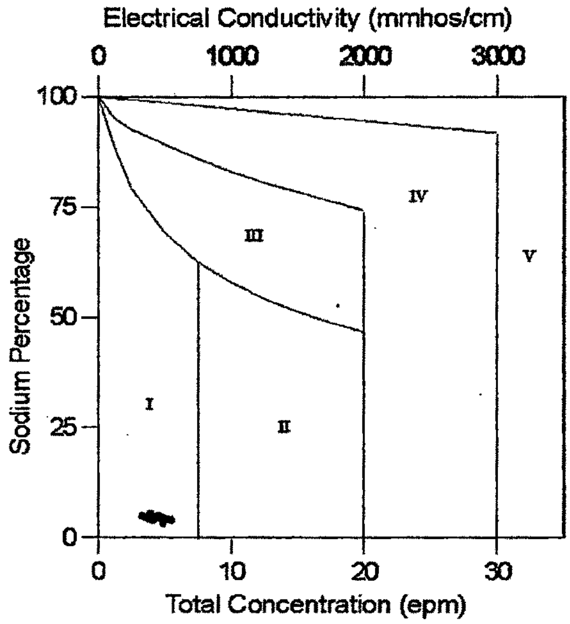

Fig. 4.4 Irrigation Water Quality of Canal Water (after Wilcox, 1955).

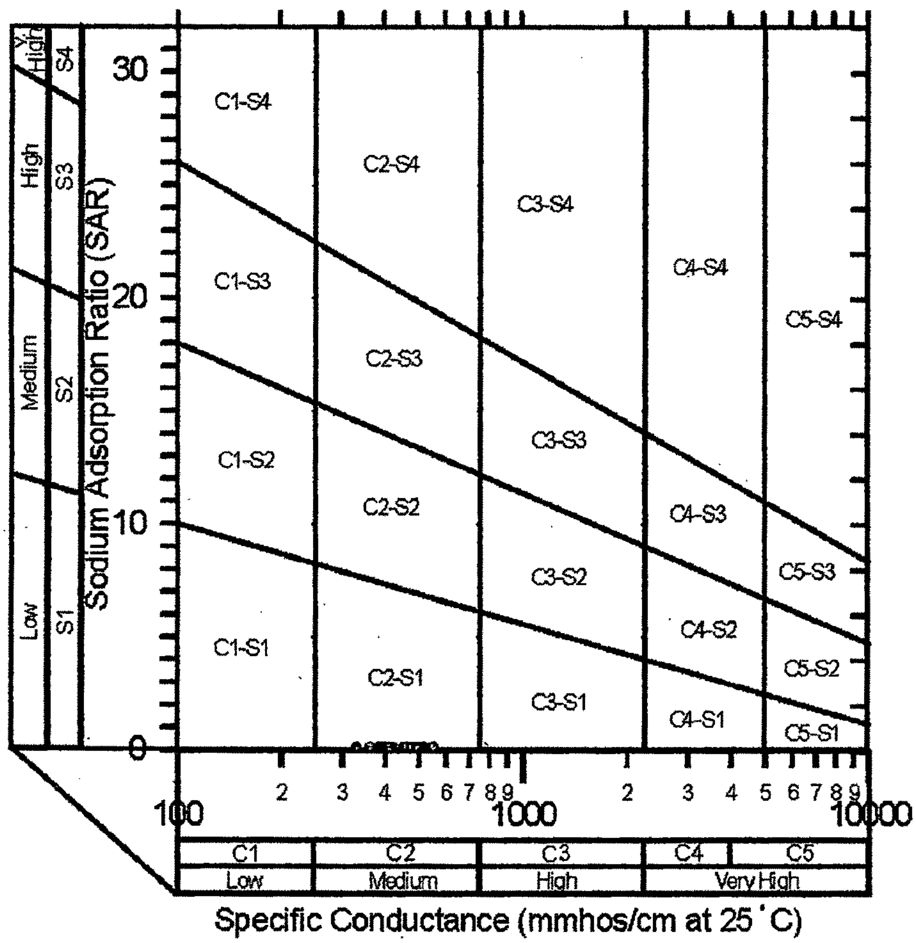

Fig. 4.5 U.S.Salinity Chart for Irrigation Water Quality of Canal Water (after Richards, 1954).

GROUNDWATER RESOURCES

The spatial pattern of seasonal groundwater depth provides a base for classifying it into low, medium and high potential zones. In reality, the distribution of groundwater resources is compatible with the incidence of several environmental factors, predominant amongst them being rainfall and soil texture. Micro-level variations accrue from differences in relief, vicinity of surface water bodies, and underground seepage as well as groundwater movement.

The groundwater studies of the KLBC area has been carried out with a view to understand, (i) Hydrogeological setup of the area, (ii) Aquifer nature and extent, (iii) Groundwater level and its fluctuation, movement, gradient etc., (iv) Anthropogenic impact of irrigation on groundwater level and (v) Groundwater quality and its behavioral pattern with time. Systematic monitoring of groundwater in the command area is carried out by the State Soil survey division and Gujarat Water Resources Development Corporation (GWRDC). The author has carried out a critical review of available data for the entire command area. A critical appraisal on the hydrogeological aspects of the KLBC area is given as under.

HYDROGEOLOGICAL SETUP

From the hydrogeological point of view major geological formations in the area can be categorized as consolidated and unconsolidated sediments (Fig. 4.6).

a) **Consolidated formation**: The Deccan trap comprising the fissured, jointed vesicular & massive basalts and numerous dykes of dolerite are by and large the important consolidated formations in the area. Basalts in its original form is compact and devoid of any significant primary porosity except vesicular flow which has a pitted surface (vesicles) formed in the upper surface of a flow due to escape of gases during cooling and crystallization of magma. Compact or massive basalts as such do not hold or transmit much water. The weathered product of basalt known generally as "murum" however is granular in texture and having developed sufficient secondary porosity in them can hold and transmit sufficient quantity of water to act as very good aquifers. Consolidated formation, which covers about 15 to 20 % of the command area; groundwater occurs under water table condition in the weathered zone i.e. the aquifer. These aquifers are major source of water, particularly in the eastern part of the command area where irrigation efficiency is less. Here the water table shows high order of seasonal fluctuation. These basaltic aquifers are characterized by the wide range of, transmissibility i.e. 478 to 2.35 m^2/day; permeability 7.08 to 0.03 m/day; and specific capacity 0.83 to 0.1 lps/m.

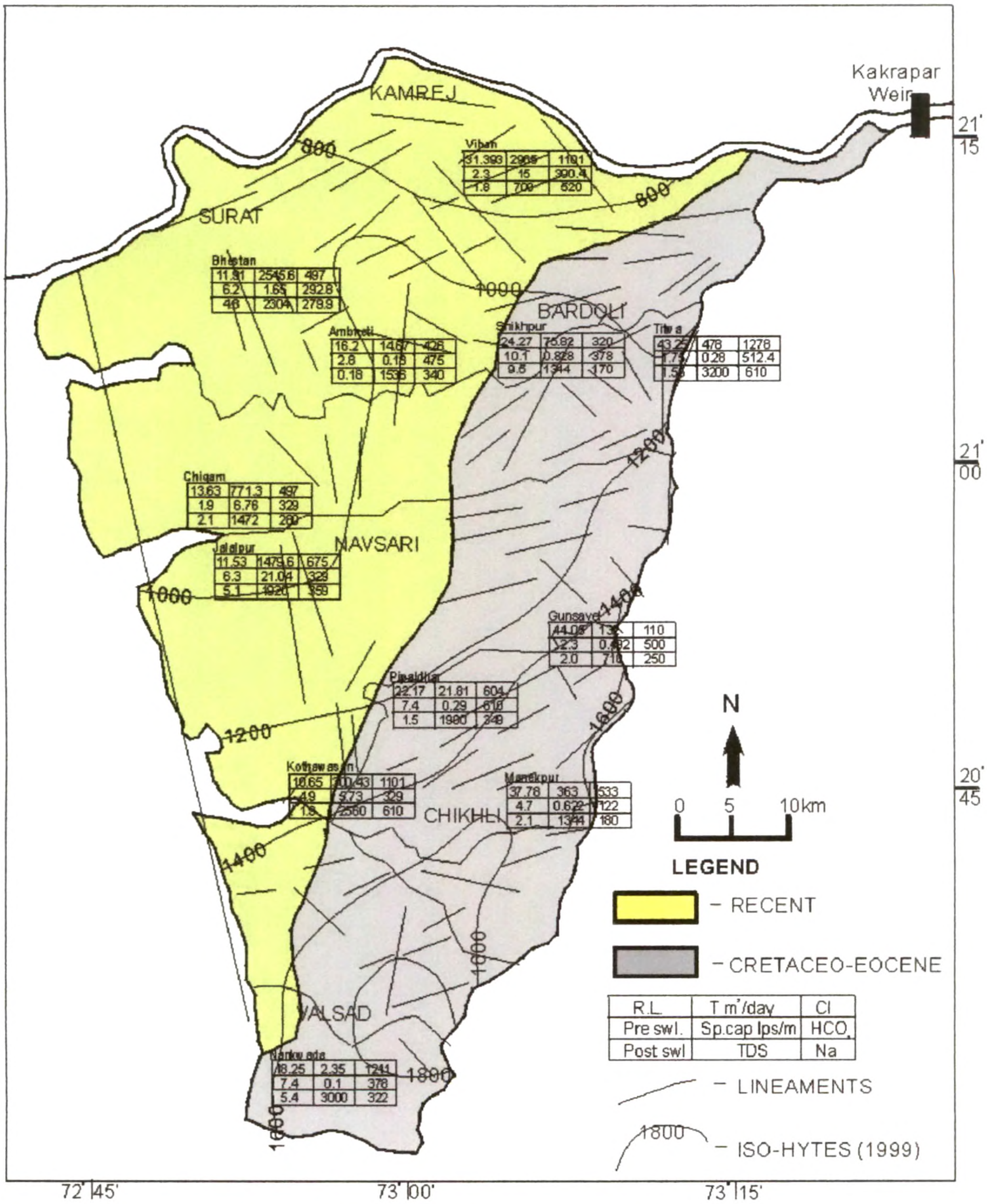

Fig. 4.6 Geohydrological Map of KLBC Area.

b) **Unconsolidated Formation:** The Quaternary sediments comprising the recent alluvium, older alluvium, and coastal alluvium plains are the unconsolidated formations. These sediments are essentially composed of clays, silts, sands, gravels, calcareous nodules etc. Study of bore hole data suggests the thickness of these sediments is more than 100 to 150 m. These sediments show intercalation of clay and sand lying over Tertiary sediments or Deccan trap. Groundwater in alluvium occurs under unconfined and confined conditions. Geohydrological map of the command area (Fig. 4.6) shows that groundwater potential is good in alluvial terrain. It is a major source in the central part of the command area where surface irrigation efficiency is less. Aquifer characteristic data (Table 4.9) based on aquifer performance tests, show transmissibility values ranging between 2965 and 11.47 m^2/day; permeability values ranging between 148.25 and 0.31 m/day; specific capacity varies between 23.88 and 0.18 lps/m and discharge on an average 1440 lpm, indicative of high groundwater potential.

Table 4.9 Hydraulic Characteristics of Alluvium and Basaltic Aquifers.

Aquifer character	Productivity	Value	Discharge (yield) lpm	T m^2/day	Sp. Cap. lps/m	K m/day
Alluvium	High	High	3156.2	2965	23.88	148.25
		Low	12.1	11.47	0.18	0.31
		Average	1440.58	598.81	4.9	17.34
Hard Rock	Low	High	627	478	0.83	7.085
		Low	113.4	2.35	0.1	0.03
		Average	313.18	128.15	0.35	2.17

(After: GWRDC, 1985)

Geomorphological Controls

The term 'Hydrogeomorphology' designates the study of landforms as caused by the action of water (Scheidegger, 1973). The terrain configuration, landform patterns and drainage play an important role in the development of groundwater regime. The terrain configuration imparts varied topographic shapes, which are closely related to the nature of lithology. The detailed hydrogeomorphological map of South Gujarat prepared by Department of Space using landsat data of March 1986 (Fig. 4.7). The major geomorphic units identified in the area are given in Table 4.10.

Alluvial plain is the major geomorphic unit in the area. It comprises the prominent and innumerable paleochannels mainly between Tapi and Purna Rivers. These paleochannels occupy low-lying topographic position on the landscape and are believed to be the remnants of the old active channels. From groundwater prospect point of view they are high potential zones, as such features are predominated by sand and gravels, which are highly porous and permeable.

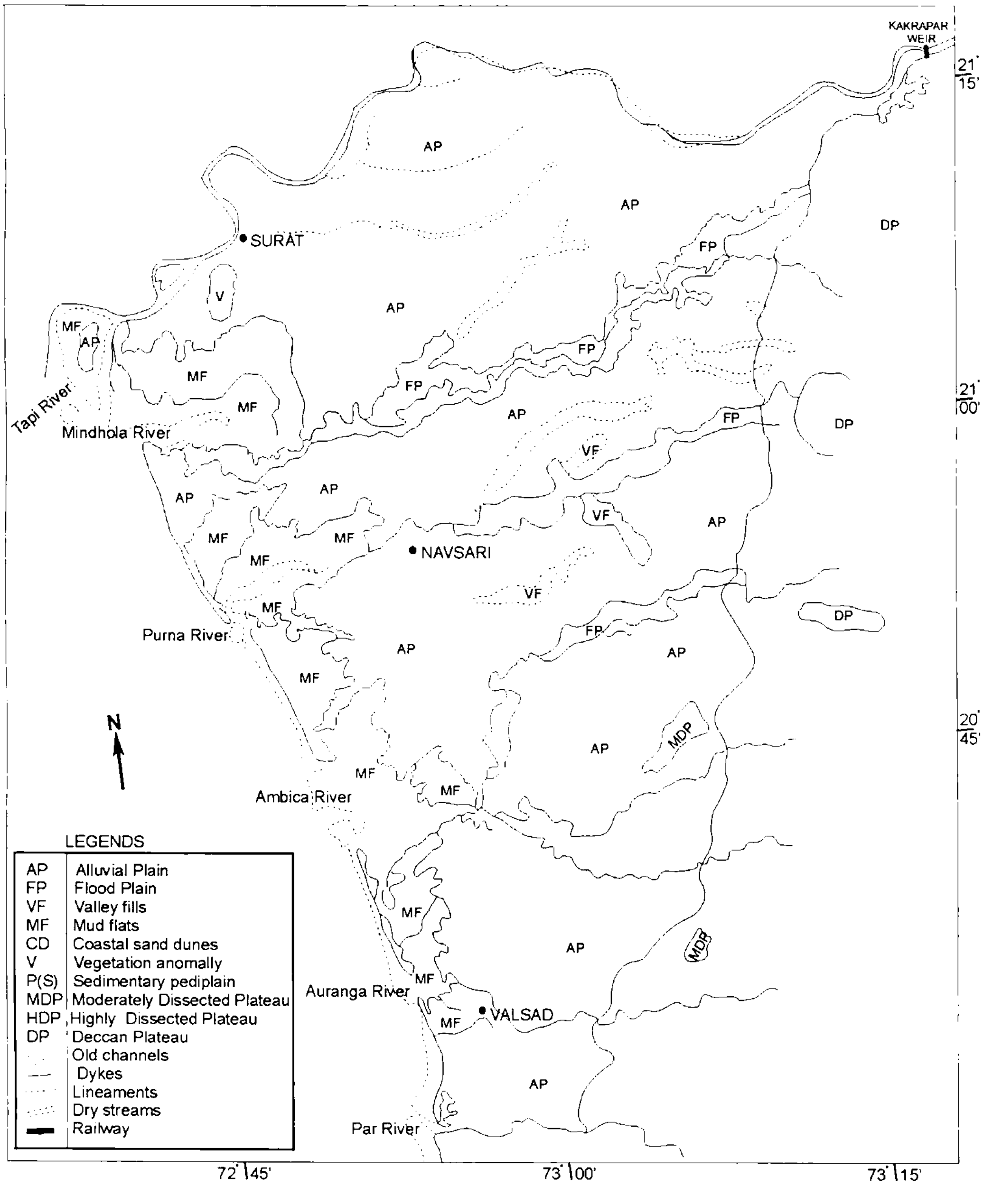

Fig. 4.7 Hydrogeomorphological Map of KLBC Area (based on Landsat – March, 1986).

Flood plain deposits are restricted upto the bank of the westerly flowing rivers and it is more pronounced along Tapi, Mindhola, Purna and Ambica rivers. Groundwater point of view this unit is characterised by high potential. Another potential geomorphic unit in the area is valley fill deposits, seen occurring along the course of Purna river.

Table 4.10 Hydrogeomorphic Units and Groundwater Prospects in KLBC Command Area (Based on landsat data of March 1986).

Geomorphic Units	Description	Groundwater prospects
Alluvial plain (AP)	Composed of clay, silt, sand, flat terrain, cultivated except coastal area.	Excellent except coastal area.
Flood Plain (FP)	Composed of sand, gravel, pebble, boulder, clay and silt, gentle slope normally cultivated.	Excellent subject to water level and thickness of material.
Valley Fills (VF)	Digressional area, normally controlled by fractures, composed of unconsolidated weathered material, more thick at center and tapering at the periphery normally cultivated.	Good to very good subject to depth of the field material.
Mud Flats (MF)	Composed of fine clays, very gentle slopping, and marsh vegetation.	Negligible, usually saline
Coastal Sand dunes (CD)	Mainly composed of sand and silt, undulating, gentle to moderately slopping, vegetated at places.	Poor to moderate.
Moderately Dissected Plateau (MDP)	Comparatively low to moderate relief, moderately jointed and fractured with thin weathered cover.	Poor to moderately good along lineaments and weathered zones.
Deccan Plateau (DP)	Low relief, undulating topography, normally cultivated.	Poor to Moderate, along weathered zones and depressions.
Paleochannels	Mainly composed of sand and gravel, normally cultivated, gently slopping.	Excellent.

Ref: Atlas of Hydrogeomorphological maps of India- Gujarat, Dadra Nagar Haveli and Diu & Daman, Department of Space, Govt. of India, July 1990.

Mud flats are developed along the western margin of the area and are generally composed of fine clays having negligible permeability with very gentle slope towards west. The meagre groundwater resources are restricted within the stabilized dunal ridges, which are severely influenced by the encroachment of the saline water, particularly during post monsoon period i.e. January onwards.

The eastern margin of the area is demarcated by the development of the important geomorphic units are Deccan plateau and moderately dissected plateau of basalt. Such features are found near Chikhli and Mahuwa. These features reflect moderate to low relief and are moderately jointed and fractured as seen on the satellite picture (Fig 4.8). Runoff is very high in this area because of less porosity and permeability.

AQUIFER NATURE AND EXTENT

Apart from general lithological and geomorphological control of groundwater, bore hole data study is very much important to study the subsurface hydrologic profile and for preparing panel and fence diagrams. Based on these data author has constructed four different subsurface profiles and evaluated the hydrologic regime, whose details are as follows.

1) Bhada - Vihan subsurface profile (A-A'): This section is drawn along the villages Bhada – Wav – Jokha – Vihan (Fig. 4.9). Section comprises intercalated sequence of clay and sand. The highest thickness i.e. 26 m. of the single clay bed is encountered in borehole located at Bhada and is gradually pinching towards Vihan. Clay beds being highly porous but less permeable indicating its aquiclude nature. The most remarkable feature in the subsurface profile is presence of basalt i.e. bedrock, encountered at a depth of 44 m. in the bore hole at Vihan. Here the traps are representing the eastern Cambay basin marginal fault, as further west the traps have not been encountered up to 101 m depth at Bhada. In this section in all three sand layers are encountered out of that the first two are promising zones of the groundwater. In Wav, sandy bed is encountered at a depth of 10.6 m. while in Bhada and Vihan it is 29 and 21 m respectively, indicating the sandy beds are sloping from center towards east as well as in west direction i.e. lensoidal form. Groundwater table shows its gradient towards west (Fig. 4.9). The observed discharge in the exploratory bore holes located at Vihan and Bhada; is 2808 and 2162 lpm respectively, indicating high potential groundwater prospect.

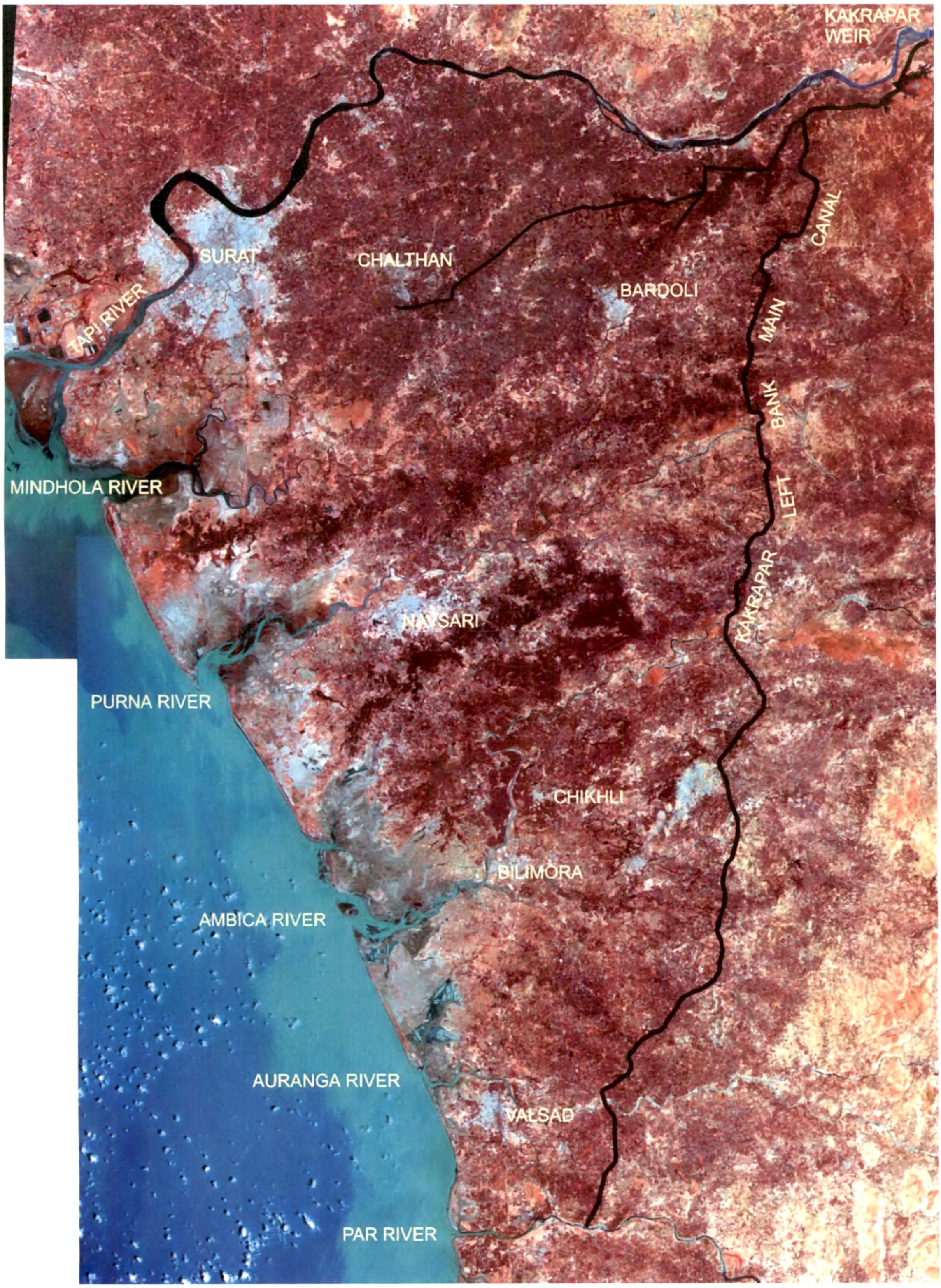

Fig. 4.8 Satellite Imagery (LISS – III) of KLBC Area.

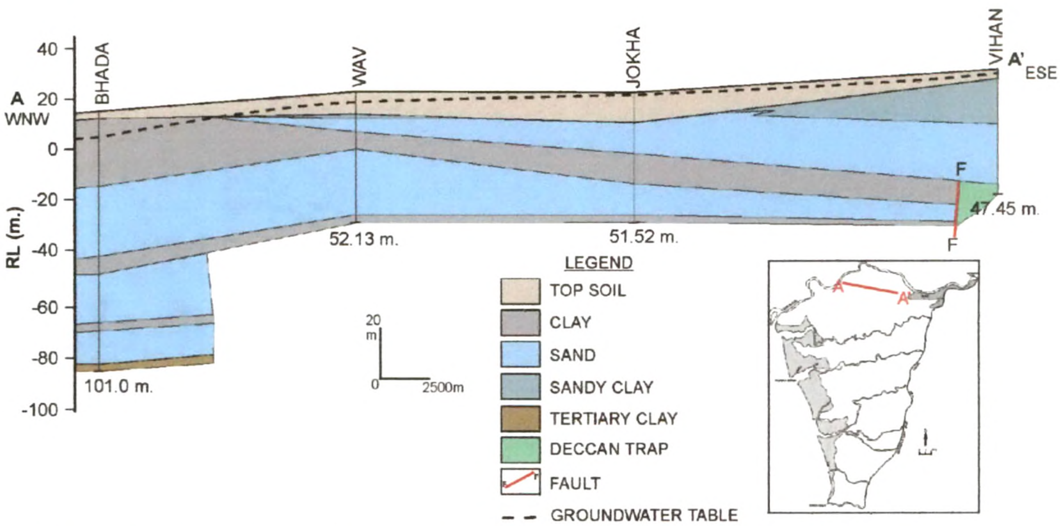

Fig. 4.9 Subsurface Geological Profile Along Bhada - Vihan (A-A') Section Line.

2) Bhestan - Titwa subsurface profile (B-B'): This section is drawn along Bhestan – Makhinga – Dastan – Tajpure – Titwa villages (Fig. 4.10). The characteristic feature of this section is presence of weathered basalt at a depth of 2.13 and 10.03 m in Tajpure and Titwa village respectively. Here groundwater occurs under unconfined condition in the basaltic weathered zone having moderate to poor groundwater yield. Another important feature is the presence of Tertiary clay encountered in the boreholes at Bhestan, Makhinga and Dastan villages. The absence of Tertiary sequence in Tajpure and Titwa marked the fault between village Tajpure and Dastan. The subsurface profile display the presence of total three different sand bodies, coalescing in to one single unit east of Dastan and are of promising groundwater potential zone.

3) Asundar - Tajpure subsurface profile (C-C'): This section is drawn along Asundar – Ambheti – Vadoli – Tajpure villages (Fig. 4.11). The important features of this profile are (i) the presence of Tertiary sequence on which the Quaternary sediments are overlying unconformably and (ii) the presence of bed rock in bore hole at Vadoli and Titwa, encountered at a depth of 20 and 10.3 m respectively. This section display an intercalated sequence of clay and sand layers, representing two aquifers at the depth of 35 and 51 m; with an aggregate thickness of 22 m and 27 m at Asundar and Ambheti villages respectively.

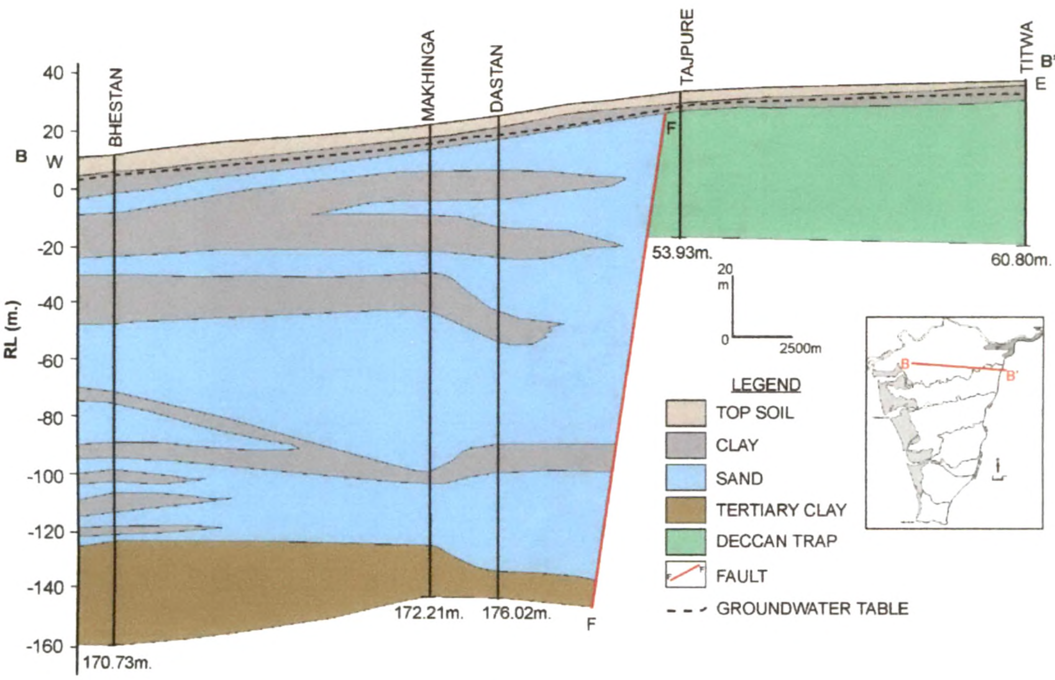

Fig. 4.10 Subsurface Geological Profile Along Bhestan - Titwa (B-B') Section Line.

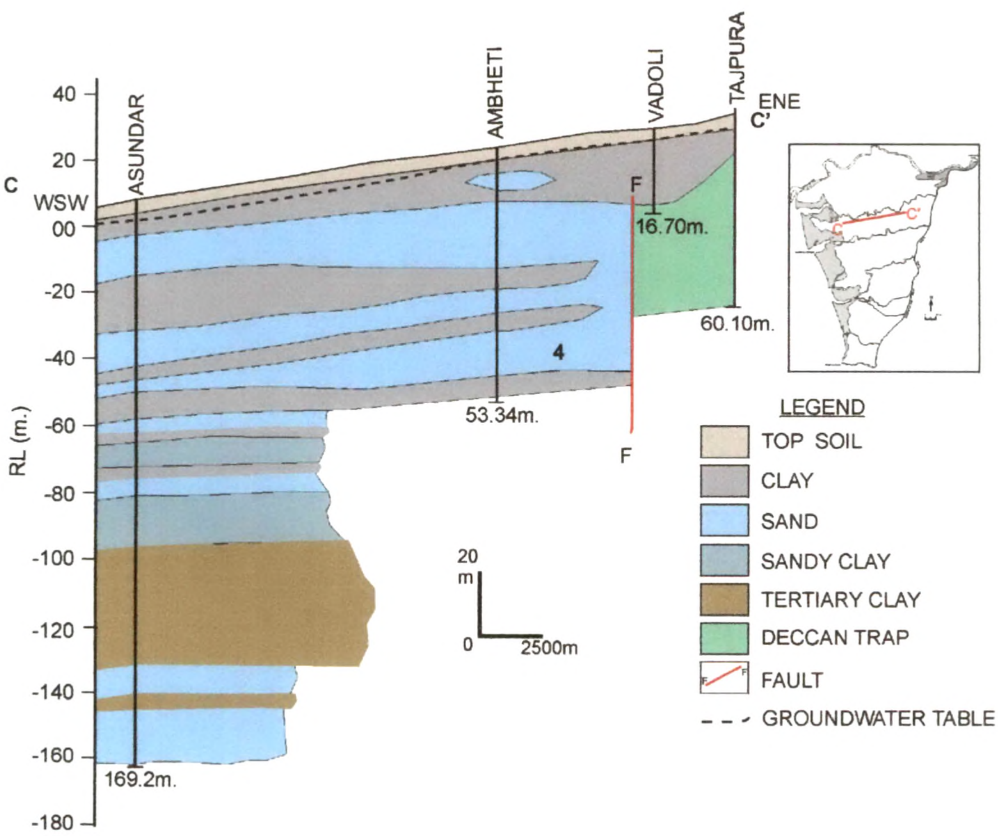

Fig. 4.11 Subsurface Geological Profile Along Asundar-Tajpure (C-C') Section Line.

4) Kothavasan - Gunsavel subsurface profile (D-D'): This section is drawn along the Kothawasan – Pipaldhara – Sarpore – Gunsavel villages (Fig. 4.12). In this profile all the bore holes are seen terminated at an average depth of 50 m, on encountering the basaltic bed rock. The bed rock which is representing a typical erosional paleo topographic profile show general slope due west. The subsurface profile is marked by the presence of two sand beds sandwiched within the clay units, except the bore hole located at Gunsavel. The thickness of the bottom sand bed is tapered towards east, indicating their low potential. The geohydrological characteristics observed in various exploratory tube wells included under various hydrogeological subsurface profiles are given in Table 4.11.

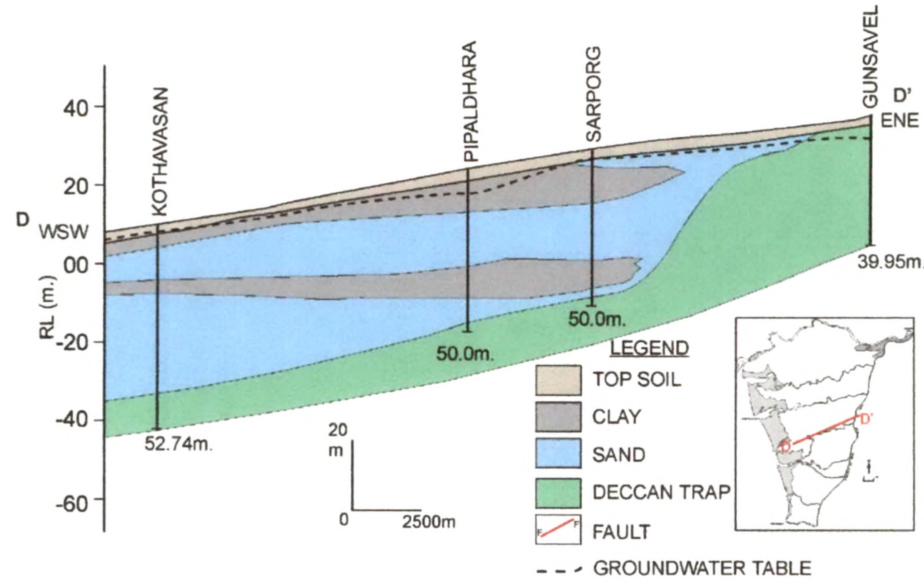

Fig. 4.12 Subsurface Geological Profile Along Kothavasan-Gunsavel (D-D') Section Line.

GROUNDWATER LEVEL FLUCTUATION

Water table fluctuation is by far a function of the recharge factors either in the form of rainfall or irrigation and/or discharge factors either through dugwells or tubewells (Walton, 1970). The water-table fluctuations and their correct interpretation are very important for economic utilization of groundwater resources in crop production. Water level contour for any area, not only presents a spatial distribution of the water levels but also indicates groundwater flow direction, gradient and overall utilization pattern in terms of recharge and discharge.

Table 4.11 Geohydrological Data of Various Aquifers in Kakrapar Left Bank Canal Command Area.

Sr. no.	Village (Taluka) R.L. mts	Total Depth (m)	Aquifer depth & thickness (m)	SWL in m.	PWL in m.	D.D. in m.	Discharge lpm	T m^2 /day	Sp.cap lps/m	Rem-arks*
1	Vihan (Kamrej) 31.33	47.45	20.00 – 40.00	1.75	5.04	3.29	2808	2965	15.00	ALL/T
2	Bhada (Kamrej) 15.77	157.62	34.28 – 55.44 61.97 – 81.25	10.10	26.22	16.12	2162	1037.91	1.37	ALL
3	Jokha (Kamrej) 24.48	51.52	12.60 – 24.10 36.30 – 45.44	1.19	13.79	12.60	485	84.23	0.64	ALL
4	Wav (Kamrej) 15.22	52.13	10.00 – 15.28 23.15 – 46.05	4.88	25.91	21.03	441	12.828	0.34	ALL
5	Titwa (Valod)	60.80	Based on Lithological data	2.35	18.55	16.20	272.40	478	0.28	ALL/T
6	Bhestan (Surat) 11.91	170.73	59.96 – 83.82 90.52 – 104.1 109.7 – 114.9	7.20	25.24	18.04	1787	2545.60	1.65	ALL
7	Makhinga (Palsana) 15.67	172.21	63.77 – 82.99 86.0 – 107.1 109.3 – 125.9	8.40	21.70	13.30	1625	2145	2.04	ALL
8	Dastan (Palsana) 25.69	176.82	32.42 – 42.90 55.00 – 75.37 83.0 – 117.69	7.25	9.73	2.48	2702	1219.54	18.15	ALL
9	Ambheti (Palsana)	5335	15.48 – 36.95 43.07 – 49.21	3.65	21.18	17.53	189	14.67	0.18	ALL
10	Bardoli (Bardoli) 32.02	47.25	13.04 – 19.15 31.29 – 43.42	4.21	12.71	8.50	441	34.75	0.86	ALL/T
11	Tajpura (Bardoli) 23.41	53.93	Based on lithological Data	5.89	16.69	10.80	113.40	11.089	0.175	ALL/T
12	Gunsavel (Mahuva) 44.05	39.93	Based on Lithological Data	6.51	27.70	21.20	627	132	0.492	ALL/T
13	Kothawasan (Gandevi) 10.65	52.72	22.48 – 39.91 41.91 – 49.82	1.80	10.00	8.20	2288	300.43	5.73	ALL/T
14	Pipaldhara (Gandevi) 22.17	50.00	11.72 – 26.71	6.50	13.51	7.01	126	21.81	0.29	ALL/T
15	Jalapur (Navsari) 11.53	283.53	45.05 – 62.98 65.98 – 71.88 74.88 – 84.31 87.34 – 106.9	8.10	10.15	2.05	2525.04	1479.68	21.04	ALL
16	Asundar (Navsari) 7.10	169.20	35.00 – 49.02 51.02 – 59.33	6.00	18.90	12.90	1871	310.97	2.41	ALL
17	Telada (Navsari) 16.19	188.90	25.00 – 28.12 48.40 – 52.40 55.40 – 66.83	9.50	23.27	13.77	2116	410	2.56	ALL
18	Ethan (Navsari) 10.96	185.97	16.26 – 28.18 35.43 – 53.23	5.20	7.68	2.48	2744	2261.17	18.40	ALL

* ALL = Alluvium, T = Trap (Source: GWRDC, 1985)

A water level contour map prepared for both pre and post monsoon periods, not only gives the quantitative scenario of seasonal fluctuations but also indicate the groundwater gradient and movement direction through contour patterns and their spacing. As it has been already stated that the GWRDC and State Soil Survey Department is carrying out a close and long term monitoring on the groundwater aspects through a network of observation wells. For evaluating the seasonal and long-term groundwater level fluctuations the author has divided the entire command area into 25 sq. km equal area grids and selected a representative observation wells at each node (Fig. 4.13) by carefully scrutinizing the well performance records.

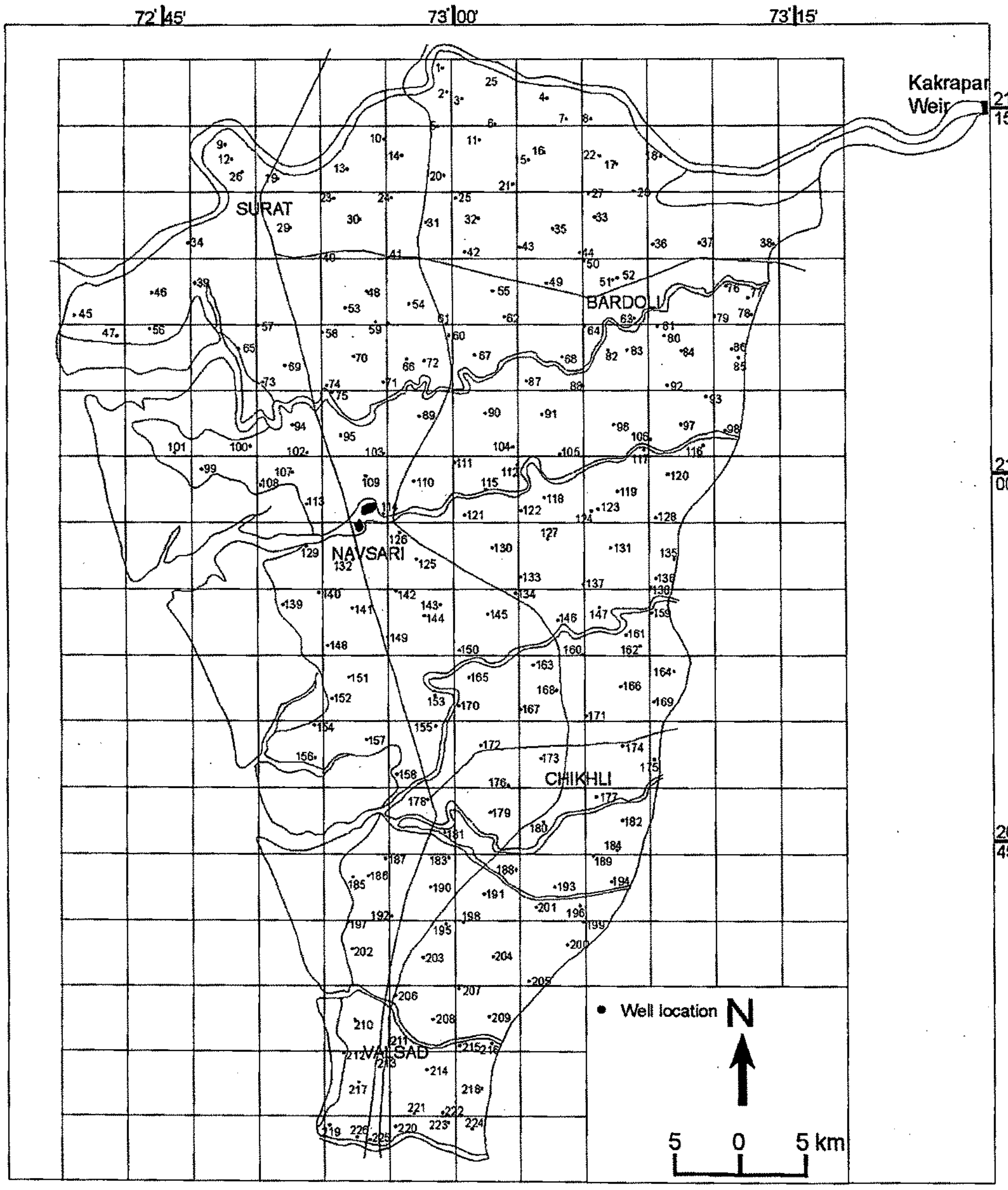

Fig. 4.13 Observation Well Locations in KLBC Area.

Pre Canal Irrigation Scenario

Prior to the inception of canal irrigation the groundwater was one of the major source for irrigation, accounting for almost 88% of the irrigation need. For the purpose of evaluation of groundwater regime in the command area, the water table data for the year 1950 have been utilized. Based on these data, the Static Water Level (SWL) and Reduced Water Level (RWL) maps were prepared. The SWL map (Fig 4.14) indicates the existence of moderate to shallow groundwater conditions with an average depth, ranging between 4 and 10 m. The pediment zones and the pediment plains are characterized by moderate groundwater depths, while the coastal alluvium tract having shallow groundwater depths. Development of large numbers of maxima and minima clearly indicates strong controls exercised by the local topographical features.

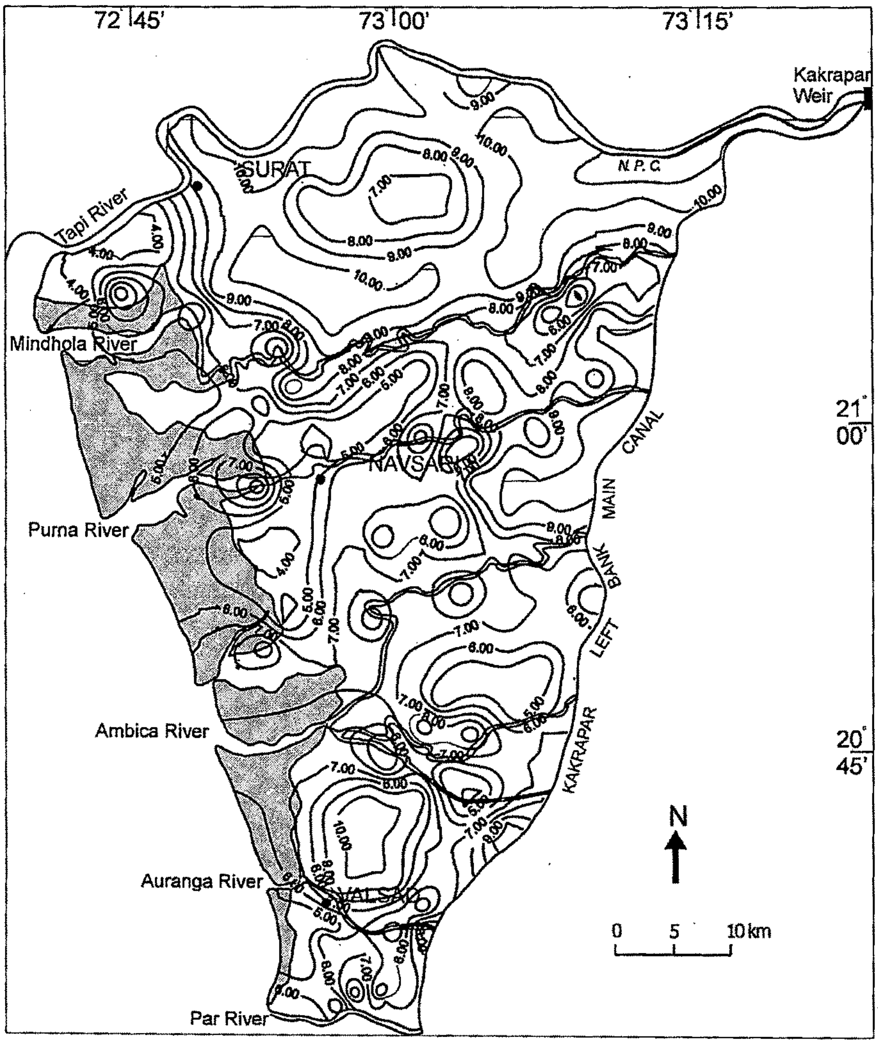

Fig. 4.14 Static Water Level Contour Map of KLBC Area for the Pre Monsoon 1950.

Contrary to this, the Reduced Water Level map (Fig 4.15) drawn for the same period, categorically suggests strong influence of the topography. The overall groundwater movement direction remains westerly, so as the surface drainage. However, local variations in groundwater movement may be attributed to lithological controls. In the proximity of river valleys, almost all the rivers are characterized by their affluent nature.

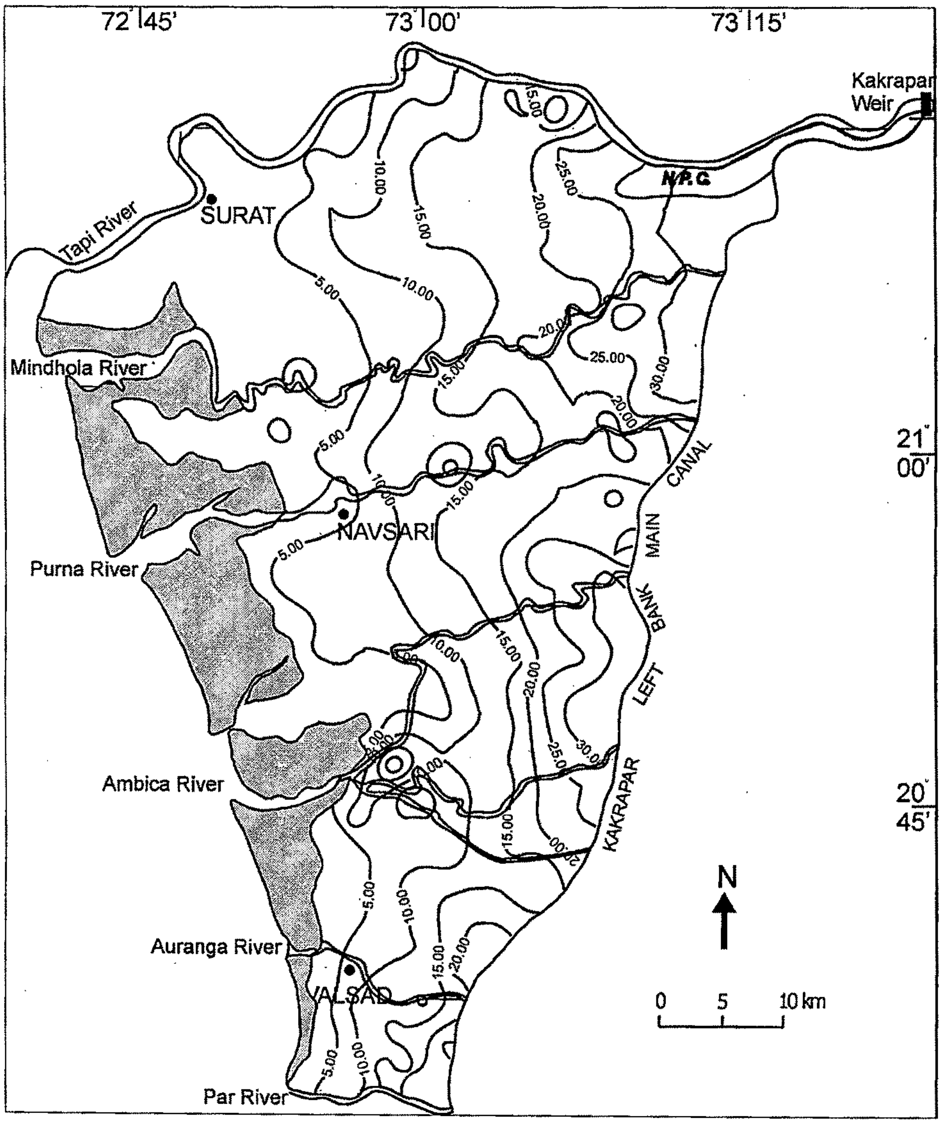

Fig. 4.15 Reduced Water Level Contour Map of KLBC Area for the Pre Monsoon 1950.

Similarly, the groundwater gradient also depicts strong lithological control. Here the surface outcrop pattern of the basalt seems to have governed the gradient characteristics.

The bedrock exposures from Tapi in the north gradually extend southwesterly, and almost reaches to the coastline further south of Ambica River. The groundwater gradient within the rocky aquifers display steep nature i.e. 1:433 - 1:555 (between Par and Ambica rivers); 1:773 - 1:1000 (between Ambica and Purna rivers). The Tapi interstream area, which is characterized by the thick pile of alluvium; the groundwater gradient is within the range of 1:866 - 1:1200 (Table 4.12). This observed variations in the groundwater gradient clearly indicates the strong lithological controls.

Table 4.12 Groundwater Gradient and Movement Direction During Pre and Post Canal Irrigation Scenario.

Area	Pre canal irrigation scenario (1950)		Post canal irrigation scenario (1999)	
	Gradient	Direction	Gradient	Direction
Between Tapi R. and Mindhola R.	1:866 to 1:1200	due W	1:466 to 1:1090	due W
Between Mindhola R. and Purna R.	1:1000	due W	1:908	due W
Between Purna R. and Ambica R.	1:773	due W	1:622 to 1:778	due WSW
Between Ambica R. and Kharera R.	1:433	due W	1:420	due W
Between Kharera R. and Par R.	1:555	due W	1:544 to 1:907	due W

Post Canal Irrigation Scenario

Rising trend in water table and consequent waterlogging of the area is a common phenomenon in any canal irrigation command. This is attributed to the returned irrigation seepage and reduction in the groundwater abstraction. In order to evaluate the net effects of the canal irrigation on groundwater regime, the author has taken into account pre monsoon (1999) water level data and has prepared the Reduced Water Level (RWL) map (Fig. 4.16).

As one can see there is no significant change in the contour pattern as well as the ground water movement direction from pre canal irrigation contours. But there is an indicative change has been noticed in the groundwater gradient. The gradient shows marked increase, almost in all the interstream areas of the various watersheds. A comparative account on the gradient change during the pre and post canal irrigation scenario is gives in Table 4.12. This change in groundwater gradient can be attributed to two main factors i.e. (i) the basement topographic configuration and (ii) the disposition pattern of the aquifers, which are having sizable volume in central and western parts and gradually get coalesced east ward near mountain front i.e. eastern margins of the command. The seepage and leakage from the unlined canal has created innumerable groundwater mounds there by, change in groundwater gradient.

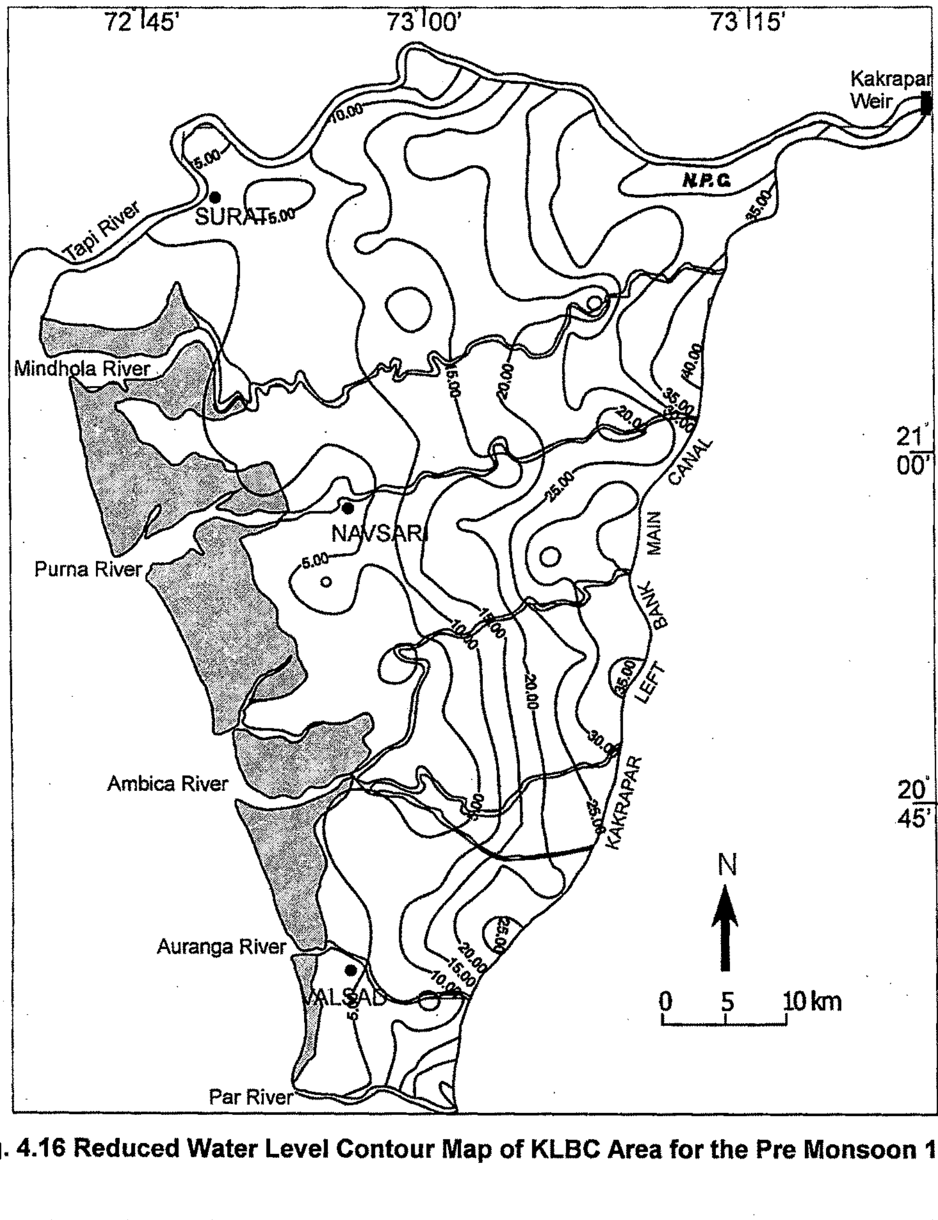

Fig. 4.16 Reduced Water Level Contour Map of KLBC Area for the Pre Monsoon 1999.

In order to have the assessment on the influence of topography over the groundwater regime, the author has plotted the graph by taking the Reduced Water Levels v/s the altitudes (Fig. 4.17). As majority of the plots displaying a linear trend, giving strong indication of topographical controls.

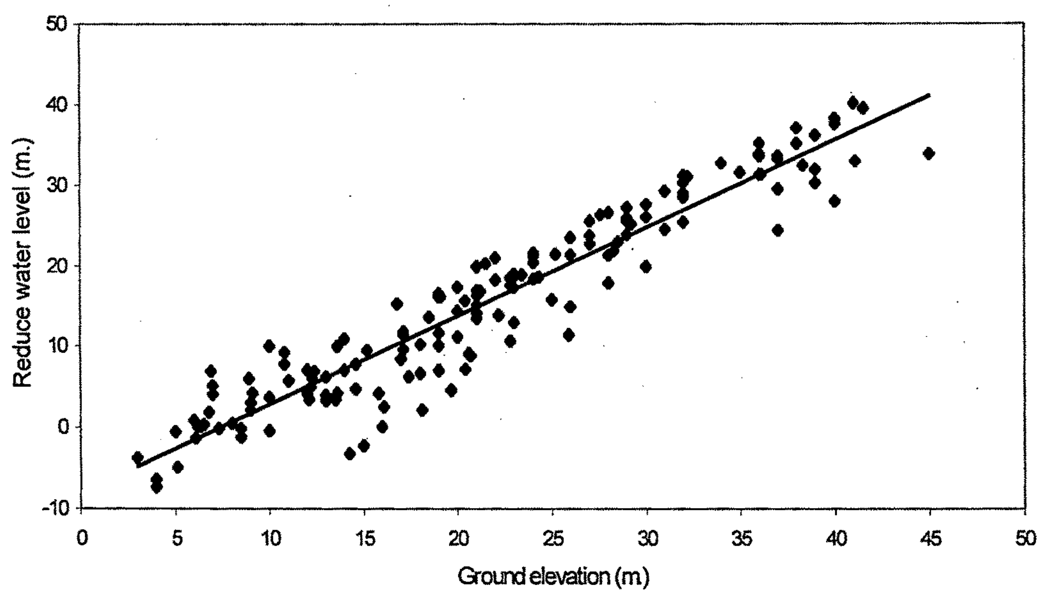

Fig. 4.17 Plots of Reduced Water Levels v/s Ground Elevations of Pre Monsoon 1999.

Seasonal Water Level Fluctuations

Apart from the minor diurnal changes that affect the groundwater levels it is also subjected to the seasonal fluctuations, which are conspicuous and directly correspond to the changes in the groundwater storage, which in turn can be related to the variations in annual precipitation and prevailing irrigation practices. Therefore rise and fall of water levels directly represents the net increase and depletion in the groundwater storage respectively.

To study the seasonal behavioral pattern of the water table in the command area, Reduced Water Level (RWL) maps for the pre and post monsoon seasons (1999) have been utilized. Based on the obtained contour patterns, annual change in groundwater storage was determined, by superimposing the pre and post monsoon water level contours (Fig. 4.18). The obtained change in water regime has provided following inferences:

1) Average seasonal groundwater level fluctuations are to the tune of 1.8 m.
2) The highest observed positive fluctuation in water table is more than 11 m around the Dived village. There is significant fall in water level i.e. upto –5.0 m around Pipala village.

3) The water table fluctuation is more pronounced in the hard rock terrain than in alluvial area.

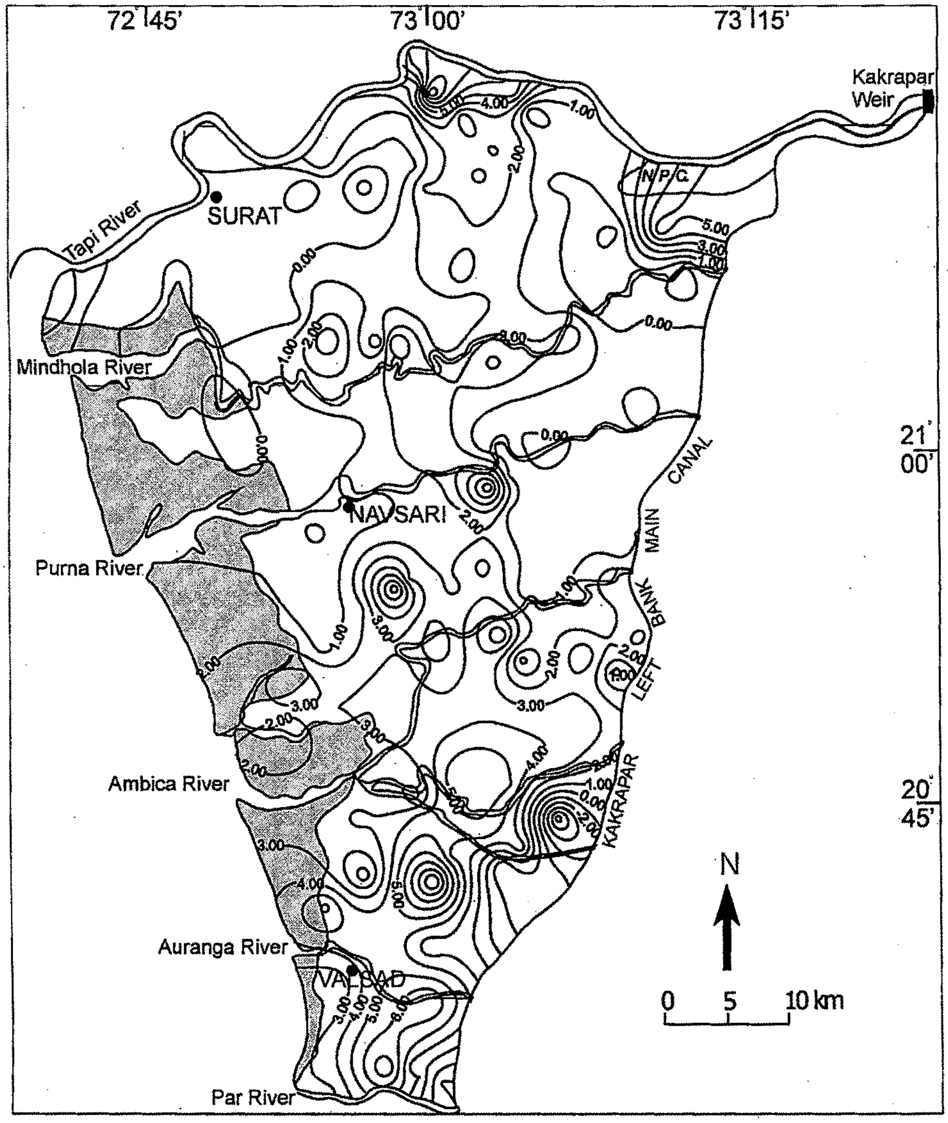

Fig. 4.18 Net Seasonal Change in Water Table in KLBC Area (Pre to post monsoon 1999).

Secular Behaviour of Water Levels

Information on long term monitoring on the water level fluctuation is very vital for the performance and evaluation of irrigation command. In Kakrapar Left Bank Canal Command area, a close network of observation wells exists for monitoring the behavioral pattern of water table. For the evaluation of secular changes in groundwater storage, the observation well hydrographs have been prepared, by considering the pre and post monsoon water levels between 1975 and 1999 at 05 years interval. For this the best performing representative observation wells, distributed in the entire command area were selected on unit grid basis.

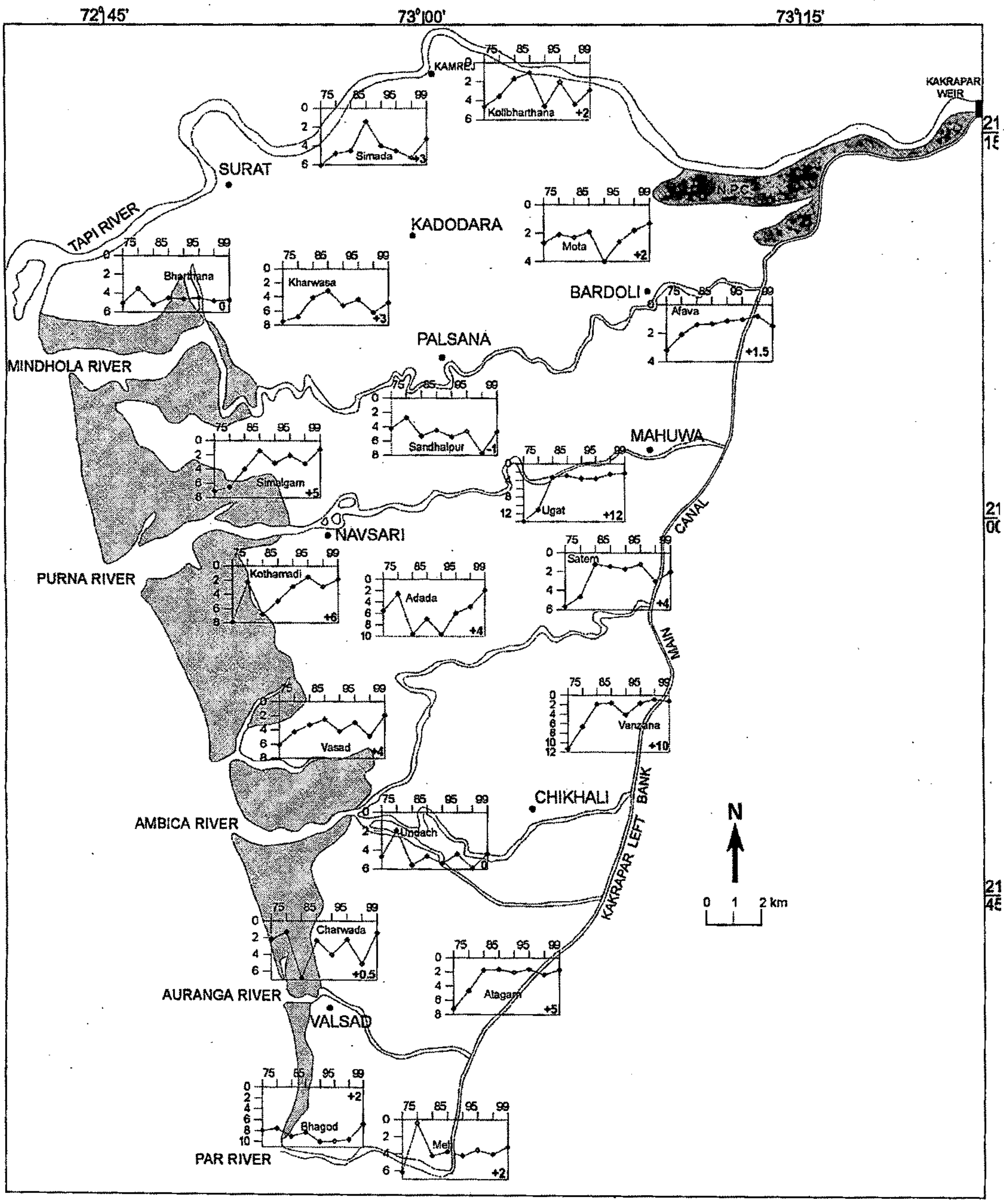

Fig. 4.19 Well Hydrographs Depicting Secular Behaviour of Water Levels in KLBC Area.

Based on the study of these well hydrographs (Fig 4.19) the following inferences have been drawn:

1) During the last 30 years spell of irrigation, majority of the command area shows positive response (i.e. rise in water levels) to the canal irrigation.

2) Majority of the observation wells point to sudden rise in water levels between 1975 and 1985. The period between 1985 - 95 is by and large marked with stabilization in water levels. The hydrographs also depicts steep fall in water levels during pre monsoon 1999 period. This indicates restricted use of canal water and scanty rainfall in the previous years there by less recharge to the groundwater regime.
3) The response to returned irrigation seepage as recharge to the groundwater regime vary from area to area.
   i. In the eastern parts of the command i.e. along the main canal; the rise in water levels is in the range of 3 - 10 m. By and large the interstream area between Ambica and Par rivers, is characterized by higher rise than the interstream area between Ambica and Tapi rivers.
   ii. The response to the canal irrigation in terms of recharge to the groundwater regime in central and western parts of the command is in the range of 2 - 6 m.
   iii. Certain observation wells also display declining trend in groundwater levels particularly at Sandhalpur (Purna River), Undach (Kharera River) and Bhagod (Par River). This may be attributed to more dependability on well irrigation as well as higher rate of subsurface flow.

The Hydro-Iso-Bath (HIB) maps prepared by the Soil survey division, Surat for the periods 1957, 1985, 1995 and 1999 categorically point out to the fact that inception of canal irrigation has made a serious impact on the soil and groundwater regimes of the command area. The statistical data complied through these maps (Table 4.13) demonstrates that prior to the inception of canal irrigation no area has groundwater table above 3.0 m, whereas the post irrigation phase has greatly modified the recharge pattern to the groundwater storage accountable to rise in water table. Now almost 37661 ha. (15.77%) command area fall under the groundwater level rise category of more than 3 m. Almost 99% of the area has witnessed 3 m rise in water levels in the past 50 years time span. There is sharp depletion has been observed in

HIB pattern between 1985 and 1999 in 3 - 6 m category. This may be attributed to the imposed restriction on availability of the canal water during early nineties.

Table 4.13 Secular Behaviour of Hydro-Iso-Bath (HIB) vis-à-vis Affected Command Area (pre monsoon).

HIB (in m.)	1957-58		1985		1995		1999	
	Area (ha.)	%	Area (ha.)	%	Area (ha.)	%	Area (ha.)	%
0.0 – 1.5	0	0.00	5498	2.30	5486	2.30	3327	1.39
1.5 – 3.0	0	0.00	34416	14.41	33716	14.12	34334	14.38
3.0 – 6.0	1348	0.56	135953	56.93	113425	47.50	97510	40.83
> 6.0	237446	99.44	62927	26.35	86167	36.08	103623	43.39
TOTAL	238794	100.00	238794	100.00	238794	100.00	238794	100.00

(Source: Soil Survey Division, Surat)

GROUNDWATER CHEMISTRY

Quality of groundwater is as important as the quantity. In irrigation, water quality is relevant to its effects on soil and crop. In the command area the groundwater chemistry has been monitored since 1990 on regular basis. Prior to this period the available data are very scanty. Furthermore, for the last few years the water quality has been monitored only for those wells, which has EC more than 2000 mmhos/cm. Owing to these practical difficulties and in consistency in available data, the author has attempted an overall quality evaluation based on 1981 and 2000 premonsoon data. A summary of important quality parameters, encompassing the lowest and highest values observed in the command area is given in Table 4.14.

Total Dissolved Solids (TDS): This parameter forms an important basis to evaluate the soil and water quality and can broadly described as, the amount of total salts present in solution in a water sample at normal temperature and pressure (Hem, 1959). The command area shows considerable rise in TDS during a time span of 20 years i.e. from 280 - 4550 mg/l (1981) to 1282 - 7051 mg/l (2000). The highest TDS 7051 mg/l has been observed in a well located at Munsad, while the lowest TDS, 1282 mg/l in a well located at Khaparwada during pre-monsoon 2000.

Table 4.14 Major Physico-chemical Constituents of Groundwater, KLBC Area.

Premonsoon 1981 (total 35 samples)

Sr. No.	Constituents	Min	Max	Mean	Std. Dev.
1	pH	7.6	8.2	7.8	0.18
2	EC (mmhos/cm)	443	6420	2311.97	1518.28
3	TDS (mg/l)	280	4550	1506.06	980.67
4	Hardness (mg/l)	112.54	2125.68	587.17	533.99
5	CO_3^- (mg/l)	Nil	Nil	Nil	Nil
6	HCO_3^- (mg/l)	61.62	850.36	424.9	213.37
7	Cl^- (mg/l)	42.54	2827.85	602.08	672.3
8	SO_4^- (mg/l)	0	249.76	59.69	65.21
9	Ca^{++} (mg/l)	14.03	454.91	82.59	114.84
10	Mg^{++} (mg/l)	15.19	288.56	92.58	67.34
11	Na^{++} (mg/l)	5.98	1074.78	326.92	240.96
12	K^+ (mg/l)	Nil	Nil	Nil	Nil

Pre monsoon 2000 (total 85 samples)

Sr. No.	Constituents	Min	Max	Mean	Std. Dev.
1	pH	7.1	8.6	7.83	0.336
2	EC (mmhos/cm)	2000	11000	3970.24	1769.404
3	TDS (mg/l)	1282	7051	2544.92	1134.188
4	Hardness (mg/l)	225.02	2550.36	837.61	409.74
5	CO_3^- (mg/l)	Nil	60	20.5	14.435
6	HCO_3^- (mg/l)	170.86	683.42	355.8	100.199
7	Cl^- (mg/l)	425.4	3261.4	1032.69	547.914
8	SO_4^- (mg/l)	9.61	1757.9	192.71	195.298
9	Ca^{++} (mg/l)	15.03	235.47	84.45	40.284
10	Mg^{++} (mg/l)	21.26	476.89	170.39	78.455
11	Na^{++} (mg/l)	210.82	1299.39	478.57	223.507
12	K^+ (mg/l)	1.17	200.12	17.45	31.086

(Data source: Soil Survey Division, Surat)

The prepared Iso-TDS contour map (Fig. 4.20) for the entire command area corroborates higher TDS values in alluvial aquifers than the hard rock areas. This is attributed to better porosities in alluviums and very flat gradient, governing slow movement of groundwaters. Further the salts added through chemical fertilizers, ultimate percolating to the groundwater regime in solution, as returned irrigation seepage, also accounted for higher TDS in alluvium aquifers.

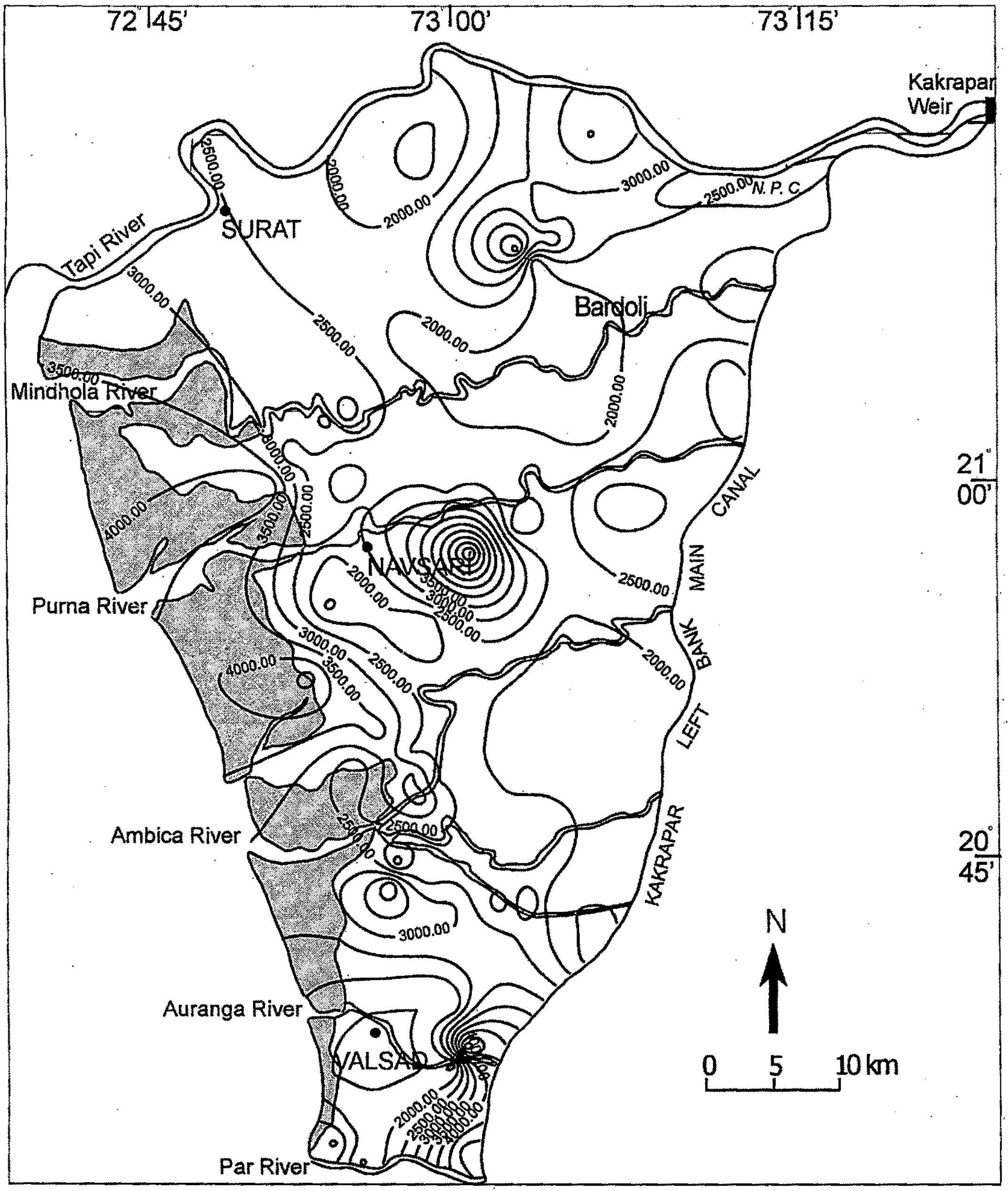

Fig. 4.20 Iso-TDS Contour Map, KLBC Area (pre-monsoon 2000).

Hydrogen Ions Concentration (pH): Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. The pH of water measured as negative logarithmic value of hydrogen ion concentration and is indication of acidity or alkalinity of water. Neutral water measures a pH value of 7. Water with pH value less than 7 are acidic in reaction and those greater than 7 are alkaline (APHA, 1976).

In the command area pH of groundwater indicates slight increase from 7.6 – 8.2 during 1981 to 7.1 to 8.6 during pre-monsoon 2000. The groundwater thus may be said to be slightly alkaline. Highest alkalinity 8.6 has been observed in wells located at Adada and Mota villages.

Anionic Concentration

Chloride (Cl): The most dominant anion in most groundwaters in the area is chloride. The chloride ion has a direct toxic effect on some plants (chloride toxicity), and also contributing to the salinity of the soil solution. In the command area the chloride content was found to be increased with time. The observed range of chloride concentration shows marked rise from 42.54 - 2827.85 mg/l (1981) to 425.4 - 3261.4 mg/l (2000). According to irrigation water quality classification (Scofield, 1933), almost entire groundwater resource of the KLBC area fall within Class-4 (Doubtful) to Class-5 (Unsuitable); which is very much similar to that of the TDS. Some of the localities in command area where exceptionally high chloride content has been observed are Meh (2212 mg/l), Munsad (3261.4 mg/l), Simalgam (2091 mg/l) and Bhathala (1871 mg/l). This exceptional rise in chloride content may be attributed to annual cyclic addition of salts through natural recharge to the aquifers, returned irrigation seepage carrying salts used as fertilizers and an inherent sediment salinity.

Bicarbonate (HCO_3): Amongst the anions, bicarbonate is the second major constituent in groundwaters. In the command area the concentration of bicarbonate shows significant change in its observed values of lower range i.e. from 61.62 to 850.36 mg/l (1981) to 170.86 to 683.42 mg/l (2000). Some of the important localities characterized by high bicarbonate concentration are Mirjapur (683.42 mg/l), Vadagam (597 mg/l), Rahej (622 mg/l), Hespur (512 mg/l), Pansara (610 mg/l) and Vankaner

(512 mg/l). By and large the groundwater associated with the alluvium aquifers shows high concentrations, than the rocky aquifers. Lower concentration of bicarbonates in rocky aquifer may be attributed to high order of flushing during monsoon period.

Carbonate (CO_3): The concentration of carbonate is found to be Nil during 1981. Where as year 2000 data show surprising higher concentration i.e. upto 60 mg/l. Some of the localities showing conspicuous rise in carbonate are Sultanpur (60 mg/l), Nanderkhan (48 mg/l) and Khaparwada (48 mg/l). These exceptionally higher carbonate values are indicative of the presence of hydrolyzate sediments i.e. clay dominated, capable of base exchange replacing Ca and Mg by sodium under alkaline pH conditions (Hem, 1959).

Sulfate (SO_4): The presence of sulfate in groundwater in command area ranges between Nil and 249.76 mg/l (1981), which have increased from 9.61 to 1757.9 mg/l (2000). Groundwater in all most entire coastal belt is characterized by the higher concentration of sulfates viz. Molyan (326 mg/l), Masa (230 mg/l), Sultanpur (220 mg/l), Masad (221 mg/l) and Kapletha (221 mg/l). In addition to these some of the inland aquifers show high sulfate content e.g. Meh (662 mg/l), Soyani (268 mg/l), and Bhadel (1757.9 mg/l). Higher sulfate content observed around Meh and Bhadel villages may be attributed to leaching of top oxidized soil surface, containing high sulfides which ultimately gets converted into sulfate and carried by groundwaters. Also, through the process of bacterial disintegration of organic matters (Hem, 1959).

Cationic Concentration

Sodium (Na): Excess sodium in irrigation water can gradually render the soil unproductive through increased alkalinity. Study of 1981 and 2000 data points to considerable rise in sodium particularly in lower range. Concentration of sodium ions ranges between 5.98 and 1074.78 mg/l (1981), and from 210.82 to 1299.39 mg/l (2000). Some important locations that are characterized by high sodium are Delad (699 mg/l), Dastan (999 mg/l), Simalgam (789 mg/l), Pali (609 mg/l), Munsad (1299.39 mg/l), Sultanpur (869 mg/l), Vasan (659 mg/l), Sari-bujrang (659 mg/l) and Palan (1199 mg/l). The increase in concentration of sodium from 1981 to 2000 may be attributed to inherent sediment composition i.e. hydrolyzate sediments, enhancing base exchange. By and large groundwaters in alluvium aquifers show higher Na content, which tend to increase towards the coastal plains.

Calcium (Ca): Groundwater show significant decline in calcium content during 20 years. The data of 1981 reveals that Ca content was ranging from 14.03 to 454.91 mg/l, while in year 2000 the observed range is from 15.03 to 235.47 mg/l. Almost about 28% sampled locations have recorded high calcium i.e. more than 100 mg/l, and it is by and large restricted along the coastal. Some of the localities identified with higher concentration are Delad (155 mg/l), Dastan (180 mg/l), Mota (110 mg/l), Munsad (235.47 mg/l) and Tigara (125 mg/l). The decline in Ca ions strongly point to replacement of Ca by Na ion under base exchange reaction (Hem, 1959).

Magnesium (Mg): Magnesium being bivalent has a higher solubility than calcium thus contributing greater to hardness of water. Magnesium content in normal groundwater is less than 50 mg/l. In the command area magnesium concentration is seen ranges from 15.19 to 288.56 mg/l (1981) and 21.26 to 476.89 mg/l (2000).

Potassium (K): Potassium is a minor element in irrigation waters; consequently, potassium determination is no longer a routine part of irrigation water analysis. In the area potassium concentration show range between 1.17 and 100.12 mg/l (2000). While as many as 9.5% sampled location recorded high potassium concentration i.e. more than 50 mg/l, which may be attributed to the rise of potash fertilizers.

GROUNDWATER QUALITY EVALUATION

Drinking Water Quality Evaluation

The chemical composition of groundwater is dependent of geological environment of the area. Therefore, a vast variation in its chemistry is observed. Also, the anthropogenic factors greatly modify the chemistry through its utilization. Due to this very fact, no rigid and uniform standards can be formulated for prescribing the quality norms. This is also an established fact that human being needs certain balanced level of dissolved salts for the proper functions of various metabolic activities and same are amply available in groundwater. However relative deficiency or abundance of any salts causes adverse effect on the metabolism, thereby health hazards.

Therefore, in order to eliminate such adverse effects caused through the consumption of groundwater, certain standard norms have been recommended by the World Health Organization (WHO), Indian Council of Medical Research (ICMR) and the Indian Standards Institution (ISI) encompassing minimum desirable and maximum permissible limits, defining potability characteristics of water (Table 4.15).

Table 4.15 Drinking Water Quality Standards.

Substance	W.H.O. (1993)	I.C.M.R. (1975)	I.S.I. (1983)	KLBC Groundwater
Colour (hazen)	5 (50)	5 (25)	10	-
Odour	Not Desirable	Not Desirable	Unobject-ionable	-
Turbidity	5 (25)	Not desirable	10	-
Taste, JTU	Not Desirable	5 (25)	Agreeable	-
TDS, mg/l	500 (1500)	500 (1500)	2000	1282 -7051
PH	7-8 (6.5-9.2)	7-8.5 (6.5-9.2)	6.5-8.5	7.1 - 8.6
TH, mg/l	300 (600)	300 (600)	300	225 -2550
Calcium, mg/l	75 (200)	75 (200)	75	15 - 235
Magnesium, mg/l	50 (150)	50 (100)	30	21 - 476
Copper, mg/l	1.0 (1.5)	0.05 (1.5)	0.05	-
Iron, mg/l	0.3 (1.0)	0.3 (1.0)	0.3	-
Manganese, mg/l	0.1 (0.5)	0.1 (1.5)	0.1	-
Zinc, mg/l	5.0	5.0	5.0	-
Chloride, mg/l	200 (600)	200 (1000)	250	425 - 3261
Sulfates, mg/l	200 (400)	200 (400)	150	9.0 - 1757
Nitrate, mg/l	-- (50)	20 (50)	45	-
Fluoride, mg/l	-- (1.5)	1.0 (1.5)	0.6 (1.2)	-

Figure in bracket indicate maximum permissible limit of constituent.

Hardness

Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater. Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions (USPEA, 1976). The general permissible limit for the hardness is 300 mg/l. The data of 1981 shows that the groundwater hardness in the command area has ranging from 112.54 to 2125.65 mg/l whereas during pre-monsoon 2000 the hardness is marked with slight increase and ranges between 225 mg/l and 2550 mg/l with an average value of 917 mg/l, that is indicative of its unsuitability for the domestic, drinking as well as industrial supplies. Exceptionally higher values of hardness have been observed around Meh (1850 mg/l), Bhthala (1425 mg/l), Vasan (1463 mg/l), Sultanpur (1750 mg/l), Munsad (2550 mg/l), Simalgam (1750 mg/l), Dastan (1862 mg/l) and Delad (1600 mg/l).

Genetic Characteristics of Groundwater

The Piper Trilinear Plots (Piper, 1953) are commonly used for the evaluation of the genetic characteristics of groundwater chemistry. In this diagram major anionic and cationic contents are expressed as percentages of total ions in meq/l and plotted in the right and left triangles respectively. Then these plotted points from their respective triangles are projected into the central diamond-shaped area as an intersection point, representing total chemistry of groundwater.

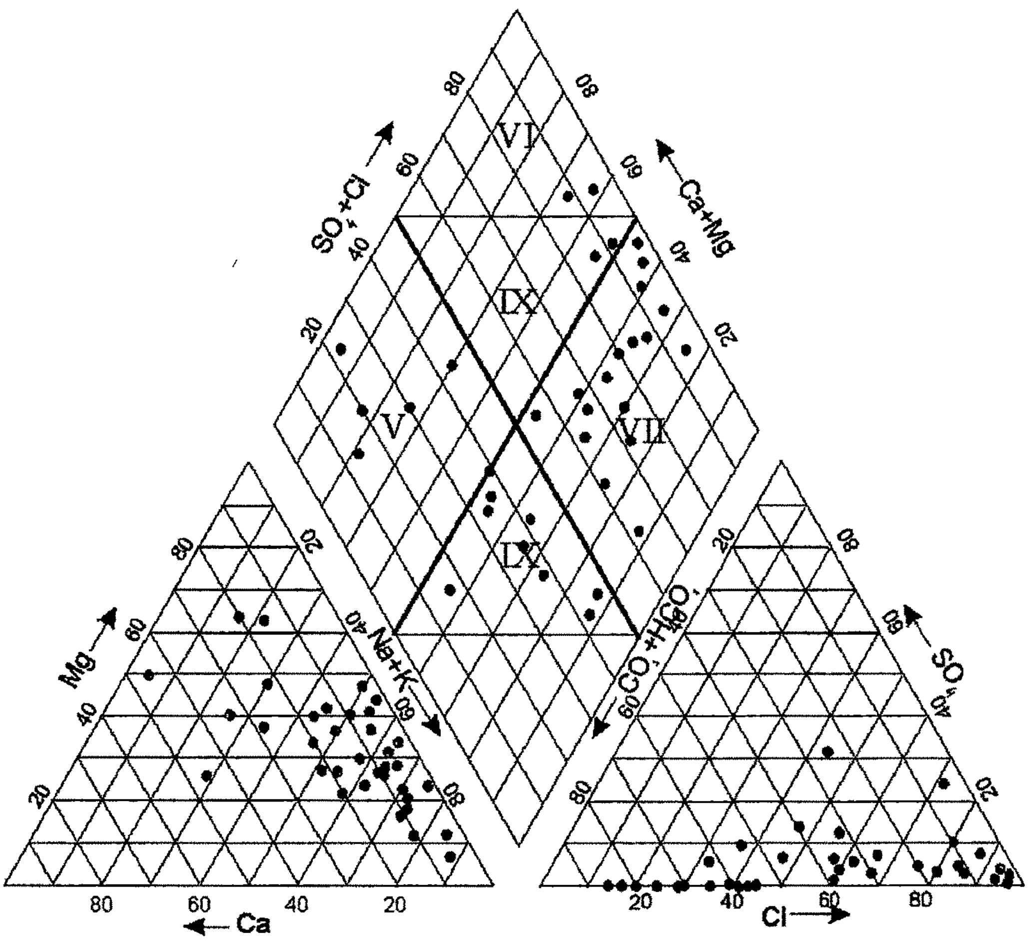

Fig. 4.21 Piper Trilinear Plots of Groundwaters in KLBC Area (pre-monsoon 1981).

Piper Trilinear diagram for the pre-monsoon 1981 (Fig. 4.21) shows that the majority of the well waters are influenced by primary salinity that is chemical properties are dominated by alkalis and strong acids (field VII), while some of the well waters shows good quality of water (field IX). Few locations such as Eru, Telada, Kaliari, Bhunwadi and Khajod fall under field V indicating secondary alkalinity (carbonate hardness) of groundwater.

On the other hand Fig. 4.22, based on pre-monsoon 2000 data, indicate that the majority of the well waters fall under the field VII, which indicate primary salinity, except few location of the well shows good quality of water (field IX) the plots are scattered throughout the area.

This observed shift in ionic plots is suggestive of considerable change in the quality of groundwater with in a time span of 20 years.

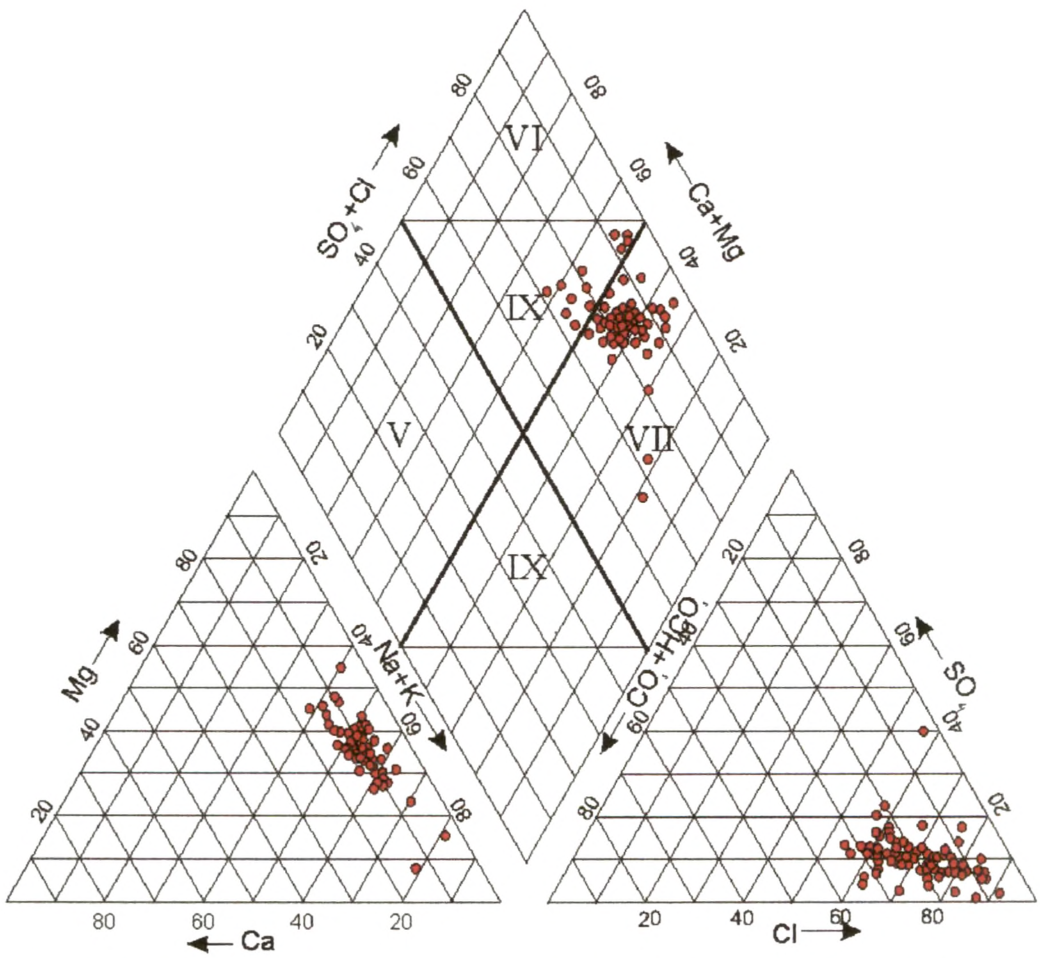

Fig. 4.22 Piper Trilinear Plots of Groundwaters in KLBC Area (pre-monsoon 2000).

Irrigation Water Quality Evaluation

The general quality evaluation of irrigation water can be made to determine and monitor the problems such as development of soil salinity, permeability, specific ion toxicity and the problems related to crop growth. Evaluation may be useful because during low rainfall or when the canal water supply is not sufficient, water from wells or tubewells is used for supplemental irrigation. The quality aspects may also be useful in adopting special management approach in irrigation practices; such as frequent irrigation crop selection, suitable irrigation method, establishment of artificial drainage system, blending in water supply, use of organic residue etc. This also helps to maintain the soil productivity (Ayers and Westcot, 1985).

It is important that all evaluation regarding irrigation water quality is linked to the evaluation of soils to be irrigated. Low quality irrigation waters might be hazardous on heavy, clayey soils, while the same water could be used satisfactorily on sandy and /or permeable soils (Ayers and Westcot, 1985).

For the determination of suitability of water for irrigation purpose, author has considered the parameters such as Electrical Conductivity (EC), Sodium Percentage (Na%), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Potential Soil Salinity (PS). The detail classification of groundwater for these parameters for the pre-monsoon season 1981 and 2000 is given in Table 4.16. These all parameters of water quality may be termed as hazardous in one or another way, to the soil and there by the plant growth.

a. **Electrical Conductivity (EC)**: The electrical conductivity is considered as measure of salinity, which greatly affects the plant growth. Salinity is caused by high solubility of salts, which rapidly accumulate in the soil (Richards, 1968). The low solubility salts precipitate in the soil as the soil solution is enriched in salinity therefore such salts does not play any role in the salinisation of the soil. According to Indian Standards water having values less than 2000 mmhos/cm of electrical conductivity, has been assigned permissible for irrigation. In the command area during 1981, 45 % of the total samples have been falling under the permissible limit (Table 4.16). However data for pre monsoon (2000) show EC values above 2000 mmhos/cm, hence unsuitable (Table 4.16).

Table 4.16 Range of Irrigation Water Quality Parameters for Pre monsoon 1981 (35 samples) and 2000 (84 samples), KLBC Area.

Parameters								
	Min	Max	% of Sample	Min.	Max.	% of Samples	Category	
E.C. (mmhos/cm)	443	10440		2000	11000		< 250	Excellent
			8.57				250-750	Good
			37.14				750-2000	Permissible
			28.57			35.71	2000-3000	Doubtful
			25.71			64.29	> 3000	Unsuitable
Na %	4.71	88.36	2.86	38.1	81.35		< 20	Excellent
			17.14				20-40	Good
			37.14			84.52	40-60	Permissible
			37.14			14.29	60-80	Doubtful
			5.71			1.19	> 80	Unsuitable
SAR %	0.16	19.8	80.0	3.4	13.2	90.48	< 10	Excellent
			17.14			9.52	10-18	Good
			2.86				18-26	Fair
							> 26	Poor
RSC	-50.9	8.94	68.57	-44.4	3.8	97.62	< 1.25	Good
			8.57				1.25-2.5	Medium
			22.86			2.38	> 2.5	Bad
PS	1.2	115.4	14.29	13.8	97.7		< 3.0	Excellent to Good
			11.43				3.0-5.0	Good to Injurious
			74.29			100	> 5.0	Injurious to Unsatisfactory

(Compiled after Scofield, 1933; Richards, 1954; Eaton, 1950; Ayers and Westcot, 1976; Doneen, 1964).

b. **Sodium Hazards (Na%)**: Sodium concentration forms an important basis in classifying the irrigation water. As sodium by the process of base exchange, replace calcium and reduces the permeability of soil which in turn effects the plant growth (Wilcox, 1953). In the command area sodium concentration is found to be ranging from 4.71 to 88.36% during 1981. In all 20% of the studied samples fall under the excellent to good category and 37% samples within the permissible to doubtful category of irrigation water classification (Table 4.16). While samples collected for pre-monsoon 2000 are showing significant deterioration in groundwater quality. In all 84% of the samples fall under the permissible limit of irrigation water, and 14% of the samples fall under the doubtful category of the irrigation water (Table 4.16). This may be attributed to increase in EC values, enhancing the base exchange capacity.

c. **Sodium Adsorption Ratio (SAR)**: The sodium or alkali hazards for irrigation water are determined by the absolute and relative concentration of cations and is expressed as Sodium Adsorption Ratio (SAR). High SAR values in groundwater indicate the risk of displacement of the soils' alkaline earths. It also adversely affects the soil structure owing to dispersion of the clay minerals (Wilcox, 1953). The data obtained on SAR for the periods 1981 and 2000 (Table 4.16) does not show any significant change in SAR. Almost more than 80% of the collected samples fall under excellent category.

d. **Residual Sodium Carbonate (RSC)**: Groundwater enriched in carbonate and bicarbonate in excess of calcium and magnesium, likely to precipitate the calcium due to displacive exchange reaction. The abundance of carbonate and bicarbonate ions is denoted by Residual Sodium Carbonate (RSC). The data on RSC (Table 4.16) indicates that during 1981 pre-monsoon season 46 percentage of water samples have been belonging to the category, which is free from bicarbonate hazards, while 64 percentage of total sample falls under medium to bad bicarbonate hazards category. Other side the data for the year 2000 (Table 4.16) show 97.5 % of total samples falls under the category, which is free from bicarbonate hazards. This drastic improvement in RSC attributed to dilution of groundwater by the applied canal irrigation water, containing high Ca and Mg content.

e. **Potential Salinity (PS)**: This parameter of quality index is based on the salinity and toxicity of irrigation water, normally affecting the soil permeability. Salinity is defined by the measures of electrical conductivity while potential salinity is defined as the concentration of chlorides and half of the sulfate ions, where concentration of ions are expressed in epm (Doneen, 1964). The data on PS in groundwater are presented in Table 4.16. The PS data for 1981 show, out of 74 percentage of total samples fall under injurious to unsatisfactory class of irrigation water. While data for 2000, almost all samples fall under the injurious to unsatisfactory class of irrigation water. This may be attributed to increase in Cl and SO_4 content in the groundwater.

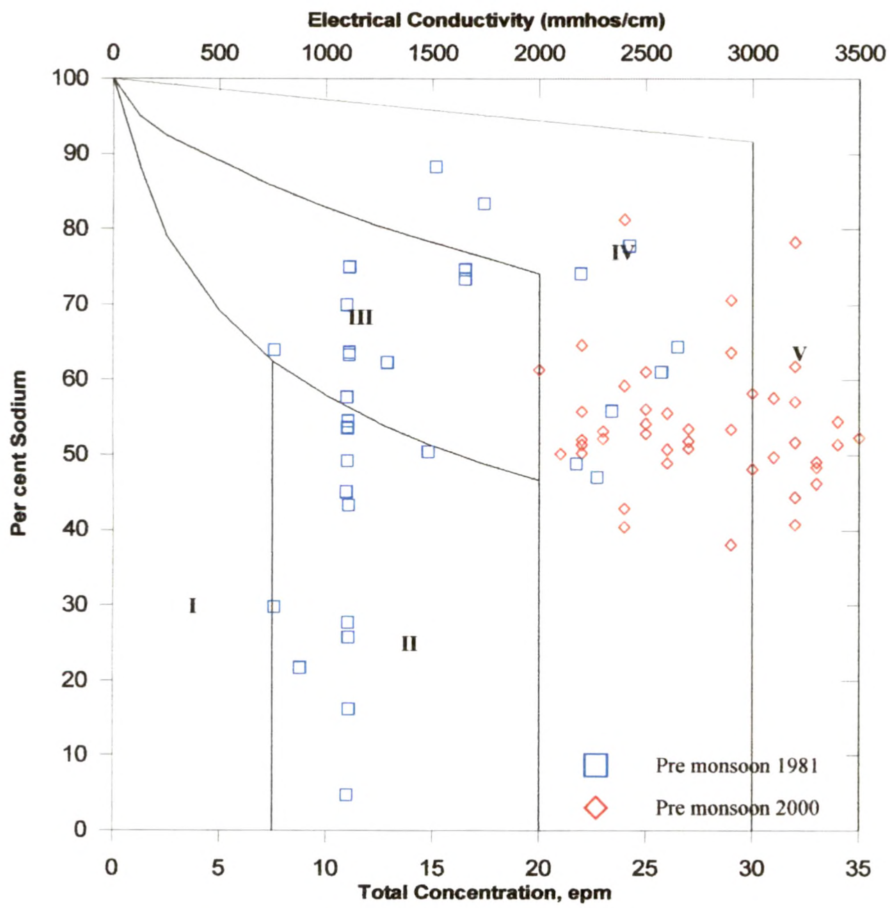

Fig. 4.23 Irrigation Water Quality Classification, KLBC Area (after Wilcox, 1955).

Majority of groundwater samples (2000) fall within the moderate groundwater category specifying C4-S2, C4-S3 and C5-S3 classes of U.S. Salinity Chart. However the groundwater samples (1981) are also of moderate category but falling under C3-S1, C3-S2 and C3-S3 classes. In the case of 2000 groundwater are characterised by increase in salinity and needs adequate treatment.

Hydrochemical Facies

The concept of hydrochemical facies has often been used to provide a model for explaining the distribution and genesis of principal types of groundwater in an area (Seth and Singhal, 1994). Taking into account the ionic concentrations of major constituents the groundwater facies have been constructed. In the KLBC area the groundwaters are dominated by three major facies viz. (i) Na-Mg-Ca-K – Cl-HCO_3-SO_4-CO_3, (ii) Mg-Na-Ca-K – Cl-HCO_3-SO_4-CO_3; and iii. Na-Mg-Ca-K – Cl-SO_4-HCO_3-CO3.