CHAPTER VI

WATER QUALITY

" It is my opinion that the Earth is very noble and admirable and if it had continuedan immense globe of crystal, where in nothing had ever changed I should have esteemed it a wretched lump of no benifit to the Universe "
Galileo (1564-1642

One of the main objectives of this thesis is to evaluate the quality of the water, both surface and sub-surface in the light of the analytical results. To achieve this, various methods like Piper's diagram (1944) and estimation of water quality index (WQI) for various purpose by applying Bhargava's (1985) technique were employed. Also an attempt was made to know the mechanism of salinity in the coastal tract by using Subramanian's (1994) technique. Finally mitigatory methods have been proposed.

WATER FACIES

Geochemical analytical data indicated that the dominant ions such as Ca^{++}, Mg^{++}, Na^{+}, HCO_3^{-}, CO_3^{--}, SO_4^{--}, Cl^{-} in the water, varied in concentration from sample to sample To synthesize and interprete these data, a trilinear diagram, originally proposed by Piper (1944) has been adopted in this work. This diagram comprises three distinct fields - two triangular fields and a diamond shaped field. In the tiangular fields, plotted separately, are the percent equivalent per million (epm) values of the cations, Ca^{++} and Mg^{++} (alkaline earths) and Na^{+} (alkali) and anions, HCO_3^{-} (weak acid) and SO_4^{--} and Cl^{-} (strong acid). From the mean of pre and post monsoon samples (Table 6.1, 6.2, 6.3, 6.4, 6.5, and 6.6), the percent epm values of the aforesaid cations and anions are plotted in the Piper trilinear diagram (Fig. 6.1, 6.2 and 6.3). These plots depict the quality of the water of the valley.

BHADAR VALLEY

SURFACE WATER FACIES

Figure 6.1 shows the pre and post monsoons surface water trilinear plots. It reflects various water facies viz.

Ca dominant - Derdi (p.s) and Bhadar at Jetpur of the pre-monsoon.

Na+K dominant - Only post-monsoon water from Derdi (p.s) to Lunagiri(p.s) and from Moj nadi to Bhadar, west of Warasara.

No dominant cations - Rest of the pre and post monsoon seasons' sample.

CO_3+ HCO_3 dominant - In pre-monsoon from Karmali nadi, Sultanpur bridge, Survo nadi, Derdi (p.s) and Lunagiri (p.s) In post-monsoon water from Gondli nadi to Derdi (p.s), Jetpur (p.s) to Phophat nadi and Bhadar west of Warasara.

Cl dominant - Bhadar at Vegdi, Dhoraji, Upleta and south of Isra in pre--monsoon and Bhadar at Atkot and south of Dumiyani in the post-monsoon.

No dominant anions - Rest of pre-post monsoon seasons water.

Table : 6.1 Mean Surface Water Quality (pre-monsoon), Bhadar valley

Stations	pH	EC	T.S.S. mg/l	TDS mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardness mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	% Na	RSC
Karmali Pool	8.20	1203 60	0.00	770 30	113 60	35.00	232 50	230.00	0.00	36.07	34.13	81.00	3 50	2 321	43 97	0.38
Sultanpur Bridge	7 93	1182.36	11 95	756 71	129 58	30 00	263 75	225 00	0.00	39.08	31.08	87.00	2.25	2.525	45.70	0 82
Survo nadi	8 51	1295 64	15.00	829 21	127 80	35 00	348 75	275 00	19 20	56.11	32 91	82 50	3 25	2.158	39 94	1.38
Derdi (p.s)	9 57	4625 60	101 67	2960 38	351 45	381.67	615 00	38 33	376 00	98.20	ND	775 33	13.83	ND	ND	17.89
Galoliya nadi	8 60	2407.20	156 00	1540 61	235 48	75 00	387.50	155 00	292.80	54 11	31 08	423 00	7 00	5 765	64 55	3.59
Jetpur (p s)	10 10	4218 00	180 30	2718 72	280 45	141.33	749.34	38 33	587 20	99 20	36.56	860 67	23 17	78 597	86 25	9.03
Jetpur	8.29	3162.40	129.37	2023.93	325.41	28 33	484 17	296.67	140 80	80 16	23.56	419 33	36 00	10.955	62 55	2.94
Panchpipla (p s)	8.80	9912.00	573 60	6343.68	1533 60	165 00	1215.00	30.00	595 20	ND	ND	1776.00	46.00	ND	ND	-
S of Kerali	8 40	2383 60	145.93	1525 51	293.47	166 67	211 67	238.33	248 00	48.77	46.93	352.67	9 67	8.090	40.55	2.74
Lunagiri (p s)	9 00	2031 96	36.30	1300 46	168 63	240 00	263 75	85 00	43 20	25 05	15.85	422.00	10 50	3.457	60 34	9 77
Vegdi	8 10	1770 00	20 37	1132 80	215 37	31 67	235 00	303.33	38 40	53.44	41 44	135.33	7 00	3 376	36 89	-1.16
Bhuki	8 07	1368 80	15.23	876 03	144.37	33 33	200 83	228.33	43 20	50.10	25 19	93.00	5 00	2 549	36 41	-0.17
Dhorati	7 94	1840.80	15.30	1178 11	205 90	25 00	246 25	285 00	40 80	54 11	35 56	126 50	6 50	3 262	49 88	-0.75
S of Dumiyani	7 87	1734 60	9 95	1110 15	202 35	15 00	217 50	257 50	163 20	49.10	32.91	128.50	5 75	3 484	52.67	-1 09
Upleta	7 92	1770 00	10 90	1132 80	214.78	15 00	186 25	242 50	67 20	47 10	30 47	130.50	5.50	3.647	54 49	-1 31
S. of Isra	7 92	1770 00	13 35	1132 80	227.20	20.00	181.25	240 00	74.40	46 09	30.47	133.00	5 00	3.738	55 32	-1.16
W of Warasara	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
S of Chauta	7.83	1486 80	78 00	951 55	181.05	0 00	215 00	205 00	148.80	50 10	19.50	132.00	4.00	4.007	58 74	-0.29

ND : Not detected ; P.S · Point Source ; EC in micromho / cm

Maximum ; Minimum

Table 6.2 : Mean Surface Water Quality (post-monsoon), Bhadar valley.

Stations	pH	EC	T.S.S. mg/l	TDS mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardness mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	%Na	RSC
Atkot	8 33	1274 40	0 40	815 62	170 40	30 00	187 50	290 00	0 00	56 11	36.56	100 00	6 50	2 55	43 75	-1 74
Gondli nadi	8 42	821 28	24 40	525 62	67 45	50 00	192 50	250 00	0 00	50 10	30 47	60 00	5 50	1 65	35 46	-0 17
Sultanpur bridge	8 18	1040 76	42 00	666 09	133 13	37 50	211 25	232 50	0 00	39 08	32 91	78 50	4 25	2 23	43 06	0 06
Surv o nadi	8 11	964 96	49 00	617 57	99.40	25 00	191 25	177 50	0 00	28 06	26.21	72.00	4.25	2 28	46.59	0.42
Derdi (p s)	9 48	2301 00	165 60	1472 64	161 53	265 00	401 25	35 00	295 20	4.01	7 32	370 00	12.25	17 86	93 45	14 61
Galoliy a nadi	8 44	1486 80	64 00	951.55	173 95	35 00	233 75	207 50	31 20	39 08	26 82	140 50	6 25	4 37	6 02	0 85
Jetpur(p s)	10 71	6726.00	151 70	4304.64	317 73	935 00	480 00	65 00	477 60	12 02	ND	1024 00	31 75	-	-	38 49
Jetpur	8 42	2711 64	96 40	1735 45	344 35	20 00	441 25	370.00	0 00	77 16	43 27	230 50	36 00	4 92	55 97	0 49
Panchpipla (p s)	9 23	1932 84	24 00	1237 02	149 10	120 00	370 00	172 50	0 00	38 94	37 79	270 50	6 25	2 03	37 85	5 02
S of Kerali	8 36	1168 20	18 00	747 65	136 68	55 00	216 25	237 50	0 00	34 71	28 03	97 0	6 25	2.74	48 47	1 34
Lunagiri (p s)	10 90	9204 00	0 00	5890 56	670 95	2490 00	0 00	75 00	874 40	112 22	-	846 00	40 00	-	-	77 39
Phophal nadi	8 36	708 00	0 00	453.12	78.10	10 00	132 50	160 00	0 00	32 06	19 50	60 00	3 00	2 06	45 63	-0 70
Vegdi	8 34	1182 36	33 00	756 71	138 45	15 00	166 25	222 50	38 40	38 08	31 08	90 50	6 75	2 59	47 33	-1 22
Bhuki	8 23	1210 68	4 00	774 83	136.68	37 50	188 75	257 50	290 40	50 10	32 30	83 50	5 25	2 24	42 04	-0 82
Dhoraji	8 32	1196.52	10 80	765.77	150 88	32 50	195 00	255 00	40 80	53 11	29 86	88 50	6 00	2 44	45 23	-0 83
S. of Dumiyani	8 29	1154 04	7 20	738.58	143.78	22 50	178 75	227 50	9 60	44 09	28 64	90 00	5 75	2 69	49 25	-0 87
Moj nadi	8 42	920.40	0 00	589.06	106 78	10 00	182 50	200 00	0 00	52 10	17 06	82.00	20 50	2 52	50 53	-0 69
Upleta	8 25	1132 80	3 60	724.99	143 78	32 50	185 00	210 00	31 20	44 09	24 38	101 00	5.25	3 26	54 44	-0 09
S of Isra	8 33	3327.60	4 20	2129 66	142 00	25 00	188 50	215 00	7 20	45 09	24 99	96.50	5 25	2 97	52 00	-0 38
W of W arasara	8 13	1062 00	6 00	679 68	127 80	20 00	185 00	202 50	0 00	36 32	21 33	90 50	6.00	2 91	52 54	0 13
S of Chauta	8 14	1005 36	4 40	643 43	124 25	20 00	172 33	213 33	0 00	46.76	23 56	84 00	5.33	2.50	47 68	-0 77

ND Not detected ; PS : Point Source : EC in micromho / cm

Maximum : Minimum

Table : 6.3 Mean Sub-surface Water Quality (Pre-monsoon), Bhadar valley.

Stations	pH	EC	T.S.S. mg/l	TDS mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardnes s mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	%Na	RSC
Khirasara	7 88	774 08	8 93	494 74	67 45	18 33	173 33	171 67	38.40	35.40	20.31	48 50	1.17	1 61	28.76	0 01
Jetpur	7 60	608.88	114 00	389.68	63 90	0.00	172 50	140 00	0 00	42.08	8.53	35 00	2 00	1 29	35.95	0 03
Pedhla	8 32	1770 00	0.00	1132 80	195 25	30 00	257 50	320 00	91.20	60 12	41 44	106 00	2 50	2 58	42 15	-1 19
1 km before Pachpipla	8 26	1047 84	0 00	670 62	99 40	20 00	215 00	250 00	57 60	48 10	31 68	69 00	6 00	1 90	38 60	-0 82
Panchpipla	8 12	1184 72	14 06	758 22	111 23	15.00	205 00	248 33	67 20	35 40	39 00	71 67	2.50	1 99	26 99	-0.94
Lunagiri	8 43	1628 40	0.20	1042.18	161 53	65 00	236 25	312 50	88 80	38 08	53 03	122 50	1.75	3 03	25 46	-0 21
Vegdi	8 04	1911 60	6 10	1223 42	227 20	112 50	312 50	582 50	48 00	140 28	56 66	84 00	38 50	1 53	15.87	-2 78
Bhuki	8 02	2053 20	9 57	1314 05	246 13	13 33	200 83	460 00	28 80	112 23	43 87	104.67	3 67	2 36	25 17	-5.48
E of Bhuki	8 02	1281 48	0 00	820 15	131 35	20 00	193 75	317 50	93 60	60 12	40 83	74 00	1 25	1 80	20 58	-4 09
Dhoran	7 82	1146 96	23.00	734 05	56 80	60 00	297 50	255 00	19 20	48 10	32 91	68 00	1.00	1 85	36 89	1 77
S of Dumiyani	7 72	1366 44	10 40	874.52	177 50	15 00	146 25	235 00	91 20	44 09	30.47	134 00	2.50	3 94	31 25	-1 80
Upleta E bed	8 09	1076 16	14 40	688.74	120 70	35 00	180 00	185 00	144 00	20 04	32 91	132 00	3 00	4 22	14 64	0 42
Upleta	8 46	3894 00	11 60	2492.16	523 63	160 00	403 75	242 50	583 20	15 03	49 98	488 00	1 25	14 97	51 95	7 10
S of Isra	8 01	1486 80	4 00	951 55	191 70	30 00	290 00	190 00	96 00	36 07	24 37	216 00	2 00	6 81	26 51	1 95
Ganod	8 24	3634 40	12 50	2326 02	421 27	100 00	390 83	158.33	510 40	21 38	25 60	504 00	1 17	17 38	71 39	6 57
W of Warasara	7 96	2308.08	14.93	1477 17	327 49	26 25	230 63	387 50	85 20	55 61	57 29	174 25	11.00	4 05	40 79	-2.82
Tank water W of Warasara	8 47	2832.00	19 00	1812 48	209 45	115 00	585 00	95 00	451.20	36 07	1 21	520 00	1 00	19 12	89 01	11 52

EC in micromho / cm :

Maximum [redacted] : Minimum [redacted]

Table : 6.4 Mean Sub-surface Water Quality (Post monsoon), Bhadar valley.

Stations	pH	EC	T.S.S. mg/l	TDS mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardness mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	%Na	RSC
Kotda Sanganı	8 06	2548 80	36 40	1631.23	372 75	10 00	145 00	710 00	0 00	112.22	104.82	100.00	13 50	1.63	24 83	-11.49
Khırasara	8.10	1416 00	52 00	951 62	163 30	35.00	215 00	427 50	0 00	85 17	52.41	62.50	1.25	1.30	24.27	-3.87
Survo Nadı (Bank)	8 47	1699 20	26 80	1087 49	220 10	30 00	190 00	270 00	0 00	34 07	45.10	131.00	5 50	3.47	51 94	-1.29
Panchpıpla	8 24	1217.86	36 00	779.43	113 60	35.00	222.50	305 00	52 80	52.11	42.66	74.00	2 25	1.92	35 59	-1 29
Lunagırı	8 12	3009 00	17 80	1925.76	417.13	50 00	292.50	537 50	67 20	101.21	69.47	229.00	3.50	4 12	45.12	-4.28
Vegdi	8.20	3540 00	21 40	2265.60	654 98	92 50	271.25	1175 00	0 00	303.61	101.73	94 50	23 75	1.20	17 78	-15.99
Jam Kandorna	8 11	1699 20	12 00	1087 49	166 85	10 00	150 00	455 00	0.00	76.15	64.60	79 00	1 50	1.61	27.62	-6 32
Bhukı	8 35	1722.80	11 60	1102 59	214 18	25 00	200 00	451 67	27 20	90 85	54 84	85.33	4 00	1.70	45 45	-4.93
Upleta	8 49	2010 72	11 60	1286 86	541 38	160.00	606 25	225 00	223 20	13 03	19.93	564 00	2.00	35 71	93 44	12.99
Ganod	8 26	4389.60	18 80	2809.34	680 42	70.00	389.17	513 33	288 00	83.50	74.35	478 00	4 00	11 89	71 29	-1 56
W of Warasara	8 30	1076 16	2900 80	688.74	95.85	40 00	262 50	175 00	0 00	30 06	24.38	111 00	19.00	3.65	60 27	2.13

EC micromho/cm

Maximum ; Minimum

Table : 6.5 Mean Surface & Sub-surface Water Quality (Pre-monsoon), Coastal area.

Stations	pH	EC	TDS mg/l	T.S.S. mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardnes s mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	%Na	RSC
Katwana *	8.00	5522 40	3534.34	12.80	1021 51	60 00	337 50	743.75	194 40	53 61	148 72	586 50	5 62	9 50	35 85	-7.34
Paswali *	8 28	3894.00	2492 16	37 20	610 60	77 50	345.50	380 00	189.60	36 08	70 71	409.50	16 00	8 81	40.01	0 64
Segras	7.68	16284 00	10421.76	66 10	2447.73	10 00	187.50	1330 00	403.20	192 39	207.21	940.00	28 00	11.77	36.72	-23 20
Bobdi nadi	7 35	60888 00	38968 32	1687 20	7029.00	10 00	250.00	14500 00	576 00	1941.88	2353 65	5766 00	185 00	20 82	46 83	-285.58
Garej	7.62	1486 80	951 55	16 00	223 65	5 00	160 00	455 00	0 00	42.08	85 33	138.00	3.00	2 81	40.05	-6 30
Garej (P)	8 72	1274 40	815 74	10 01	192 88	11.67	169 17	151 67	17.60	30.73	18.28	118.33	7.17	4 37	49 53	-13 36
Navibandar	7 83	23552.80	15073 79	179 87	5193 65	16 67	143.17	1898 33	545 60	187 04	349.03	1699 67	68 83	18 69	53 41	-35.05
JND -II *	7 58	17936 00	11479 05	132 47	3471 90	13 33	139.17	2288 33	300 80	420.84	301.83	1328 00	36.83	11 82	27.73	-43 06
Gosa *	8 04	16638 00	10648 32	48 80	2266 68	12 50	125.00	1267 50	196 80	195 39	190 14	1121 00	29 75	13 75	42 47	-22.89
Limbadi *	7 67	21240 00	13593 60	62 45	3166 60	0 00	198.75	1395 00	386 40	162 33	241 35	1680 00	42.75	19 56	47 38	-24 64
Mokal *	7 80	8496 00	5437 44	68.80	1988 00	5 00	150.00	890 00	268 80	138.28	132 85	1188 00	2.00	17 31	27.00	-15.09
Bapodar *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kerala *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jambu *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mahira *	7 93	7080 00	4531 20	43 80	1579 75	10 00	165.00	830 00	446 40	90.18	147 50	1020 00	6 00	15.39	22 65	-13 57
Nedhna *	8 26	807 12	516.56	1 20	81 65	20.00	225 00	150 00	0 00	32.06	17.07	73.00	7 00	2 59	15.22	1 36
Pharer *	7.94	8212 80	5256.19	36.00	1485 68	15 00	195 00	892 50	499 20	157.32	121 87	939 50	5 00	13 78	46 30	-14 16
Bantwa *	8.74	1982 40	1268 74	2 80	126 03	80 00	297 50	50 00	417.20	10.02	6 10	290 00	3.50	20 82	85 03	6.55

* Ground water ; EC in micromho / cm

Maximum ; Minimum

Table : 6.6 Mean Surface & Sub-surface Water Quality (Post monsoon), Coastal area.

Stations	pH	EC	T.S.S. mg/l	TDS mg/l	Cl mg/l	CO_3 mg/l	HCO_3 mg/l	Hardnes s mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SAR	%Na	RSC
Katwana *	7 66	7646 40	10 00	4893 70	1686.25	30 00	225.00	1345 00	465 60	225 45	190.74	632 00	5 00	7 52	50.80	-22 21
Paswali	8 45	1132 80	8 00	724 99	145 55	15 00	157 50	240.00	57 60	46 09	30 47	91.00	6 50	2.55	46 19	-1.72
Paswali *	8.26	2017 80	12 60	1291 39	296 43	52.50	255.00	250 00	79 20	42.09	35.35	226.50	8.25	5 85	59.33	0 93
Segras	8 15	1083.24	8 00	693 28	136.68	17.50	172.50	197 50	0 00	41 08	23 16	99.50	6 25	3.15	53.67	-0 54
Bobdi Nadi	7 67	4920 60	212 40	3149 19	4829 78	10 00	222 50	4080.00	768 00	-	-	1736.00	113.50	-	-	-
Garej	8 31	1975 32	26 00	1264 21	374.53	12 50	166.25	280.00	0.00	43 09	42.05	147 00	6 75	3 97	55.18	-2.45
Garej (P)	8 19	984 12	15 80	629 84	145.55	12.50	145.00	110 00	4 80	19 04	15 24	107 50	6 50	4 43	68 46	0.60
Navibandar	8 04	1132.80	6.60	724 99	163.30	12 50	158 75	182 50	7 20	41.09	19.50	105.50	5.75	3 51	57.10	-0 63
IND - 11 *	7 70	24942.84	60.40	15963 42	3155 95	7 50	155 00	2307 50	468 00	467 94	277 85	1300 00	38 00	11 71	55 19	-43 38
Gosa *	7 76	9416 40	52.80	6026 50	1986 23	7 50	146 25	1230 00	223 20	222 45	164 53	852 50	23 75	10 58	60 66	-21 96
Limbadi *	7 62	12036 00	8 00	7703 04	2204 53	55 00	265.00	1035 00	307 20	146 29	163 33	1034.00	35.00	13.97	68.90	-14 53
Mokal *	7 63	9912 00	8.00	6343 68	1767 90	10 00	285 50	875 00	374 40	174 35	107 24	957 00	3 00	14 06	70.42	-12 47
Bapodar *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kerala *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jambu	7 43	1416 00	12.00	9062 40	2829.35	15 00	180.00	1915 00	523 20	348 70	254 71	1067 00	2.00	10 60	54 80	-34 87
Mahira *	7 60	10620.00	16 00	6796 80	1870 85	25 00	347 50	1195 00	734 40	178 36	182 83	968.00	3.00	12.17	63 82	-17 39
Nedhna *	7 80	849 60	12.00	543 74	63 90	25 00	390 00	155 00	0 00	36 07	15 84	77 00	3.00	2 69	52.47	4.12
Pharer *	7 52	9912.00	8.00	6343 68	1764 35	5 00	242.50	1250 00	729 60	244 49	155.99	858 00	2.00	10.55	59.90	-20 86
Bantwa *	8 26	2194.80	8 00	1404 67	163 30	120.00	467.50	85 00	369 60	18 04	9 75	330.00	2 00	15 56	89.43	9.96

* Ground water; EC in mrcromho /cm

Maximum ▬ ; Minimum ▭

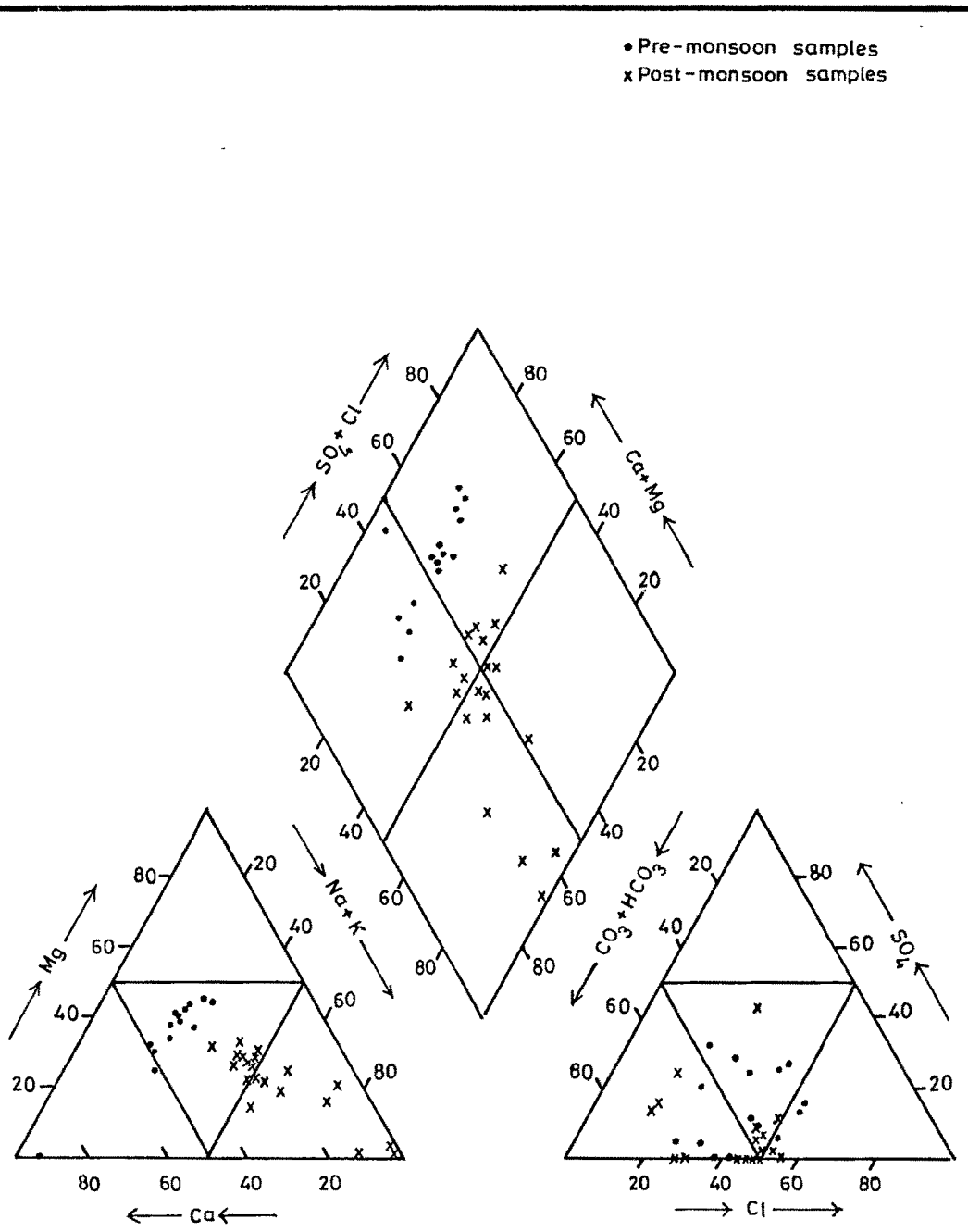

Fig.6.1: PIPER TRILINEAR DIAGRAM SHOWING CHEMICAL CHARACTERISTICS OF SURFACE WATER, BHADAR RIVER BASIN

Extrapolation of these cations and anions in the diamond plot, shows the mean pre-monsoon surface water to be of two types viz.

Ca,Mg - CO_3, HCO_3	- Water from Karmali nadi, Survo nadi, Bhadar at Sultanpur bridge, Derdi and Lunagiri (p.s).
Ca, Mg - Cl, SO_4	- Rest of the samples.

Whereas for post-monsoon water samples are of four types

Na,K - CO3, HCO3	- Derdi (p.s), Jetpur (p.s) to Lunagiri (p.s), Moj nadi and Bhadar west of Warasara.
Ca, Mg - SO_4+Cl	- Bhadar at Atkot and from Vegdi to south of Dumiyani.
Ca,Mg - CO_3, HCO_3	- Gondli nadi, Survo nadi, Phophal nadi and Bhadar at Sultanpur bridge.
Na, K - SO_4, Cl	- Galoliya nadi, Bhadar at Upleta and South of Isra.

SUB-SURFACE WATER FACIES

Figure 6.2 shows the pre and post monsoon samples of sub-surface water plotted in trilinear diagram. It exhibits mainly Na+K dominance both in the pre and post monsoon samples (beyond Dhoraji and upto west of Warasara in pre-monsoon and Survo nadi bank, Upleta, Ganod and west of Warasara in post-monsoon). However, the rest lies in the " no-dominant" field (water between Khirasara and Dhoraji in pre-monsoon and rest of the samples except that from Vegdi which is calcium dominant).

The anion plots mainly reflect Cl dominance (Bhuki, south of Dumiyani, and west of Warasara in pre-monsoon and all stations exceptive the bicarbonate and no dominant type) or CO3 + HCO3 (Khirasara, Jetpur, Lunagiri, Vegdi and Dhoraji of pre-monsoon and Khirasara, Panchpipla and west of Warasara of post-monsoon) in both the seasons or otherwise lies in the 'no dominant field (Remaining station of pre and post monsoon).

The diamond plots exhibit the following classes for pre and post monsoon seasons :

Ca, Mg - Cl, SO_4	- Pedhla, Panchpipla, Bhuki and east of Bhuki (in pre-monsoon); and all stations excepting Khirasara, Panchpipla, west of Warasara, Survo nadi bank, Upleta and Ganod (in post monsoon)
Ca, Mg - CO_3, HCO_3	- Khirasara, Jetpur, Lunagiri, Vegdi and Dhoraji (pre-monsoon); Khirasara, and Panchpipla (post -monsoon).
Na, K - SO_4, Cl	- South of Dumiyani to west of Warasara (pre--monsoon) and Survo nadi bank, Upleta and Ganod (post-monsoon).
Na, K - CO_3, HCO_3	- Only one sample (west of Warasara) in post-monsoon.

COASTAL AREA WATER FACIES

Piper trilinear diagram (Fig. 6.3) conspicuously reflects the Na+K (alkali) dominance in both

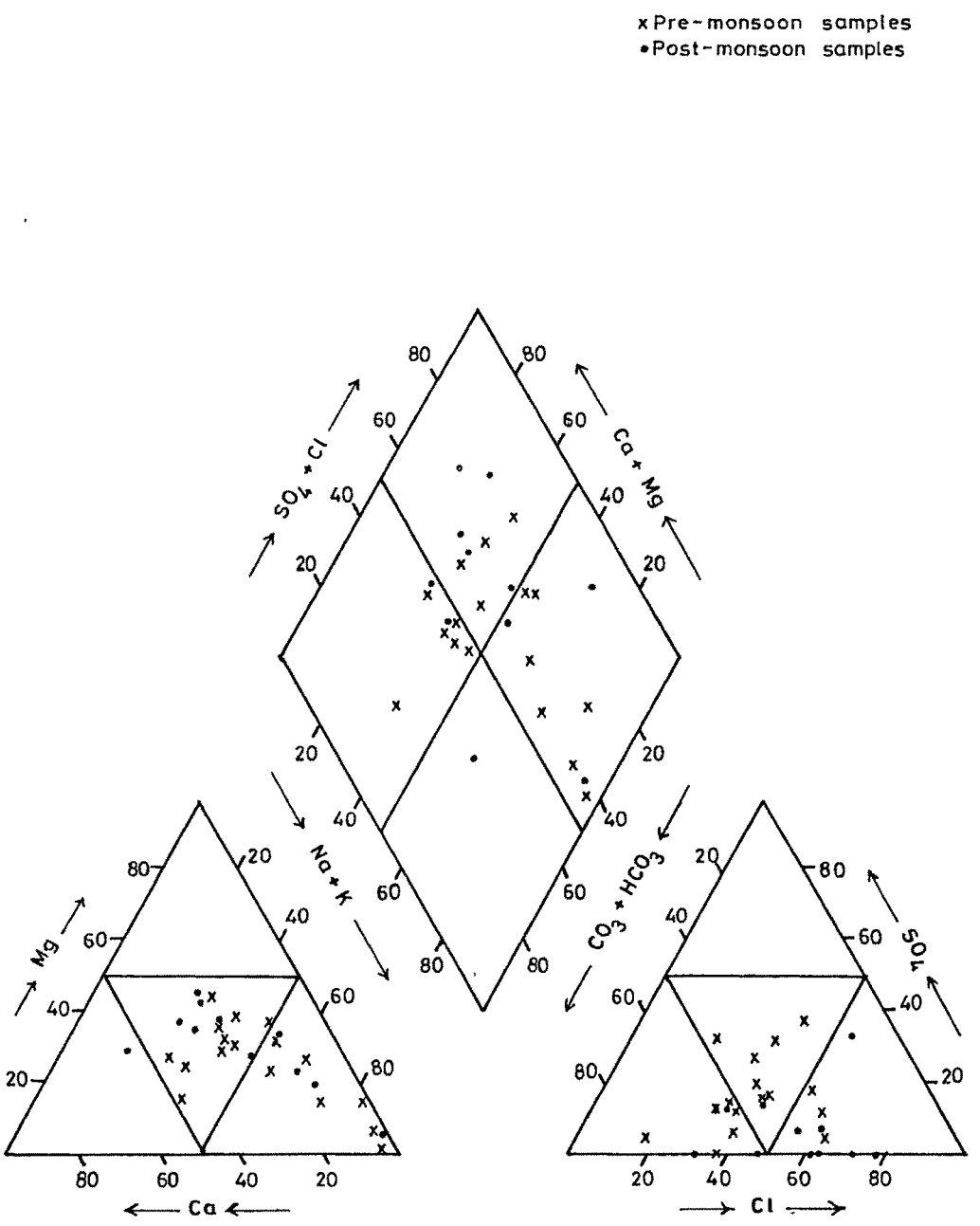

Fig.6.2 : PIPER TRILINEAR DIAGRAM SHOWING CHEMICAL CHARACTERISTICS OF SUB-SURFACE WATER

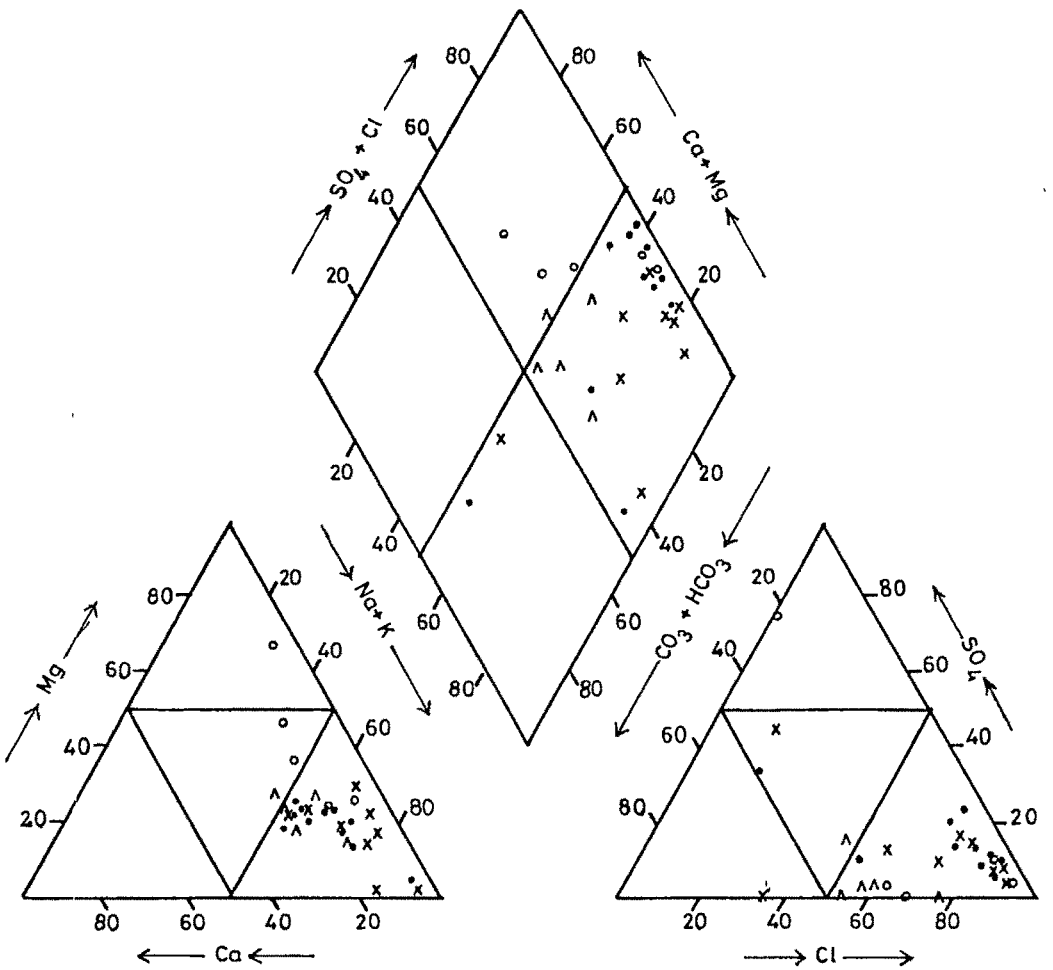

Fig.6.3: PIPER TRILINEAR DIAGRAM SHOWING CHEMICAL CHARACTERISTICS OF SURFACE AND SUB-SURFACE WATER, BHADAR RIVER BASIN. (Coastal areas, beyond Kutiyana)

pre and post monsoon samples of surface and sub-surface water. Similarly, Cl field is dominant over the rest. In the diamond plots major samples fall in the Na, K - SO_4, Cl field.

WATER QUALITY INDEX

An indexing system using the critical parameters for individual purpose has been evaluated by following the most popular aggregation technique which is the weighted multiplicative function. For this, Bhargava's (1985) formula was used for computation

$$I = \prod_{i=1}^{n} [fi(Pi)]^{1/n} \times 100$$

Where fi(Pi) is the sensitive function of the ith parameter and n is the number of water quality considered relevant for the purpose of use.

The goal of the above study was to produce an indexing system based on something specific, definable and meaningful to the planner and people and to answer the question, "How suitable is a particular water for certain use ?" Further, after plotting the standard curves, the WQI have been classified as under.

WATER CLASSES BASED ON WQI

Water class	Category	WQI
I	Excellent	≥ 90
II	Good	65-89
III	Satisfactory	35-64
IV	Poor	11-34
V.	Unacceptable	≤ 10

The sensitive function versus concentration for various parameters for different purpose are given in figures 6.4, 6.5, and 6.6. While selecting the determinands, in addition to Smith's (1990) suggestion, some more determinands were used to produce the index score and are as given in Table 6.7.

DRINKING

Having produced sub-index rating from determinand values (Fig. 6.4) aggregate final index score was produced for pre-monsoon separately and post-monsoon separately for individual station of surface and sub-surface water within the Bhadar valley proper. From the final WQI, the classes have been determined which have been tabulated in tables 6.8, 6.9 and 6.10.

WQI of both pre and post monsoon surface water reflect that natural streams such as Gondli nadi, Survo nadi, Phophal nadi and Moj nadi are satisfactory whereas the rest are either poor or unacceptable. Where as in the sub-surface water WQI reflects that Pedhla, Panchpila, east of Bhuki,

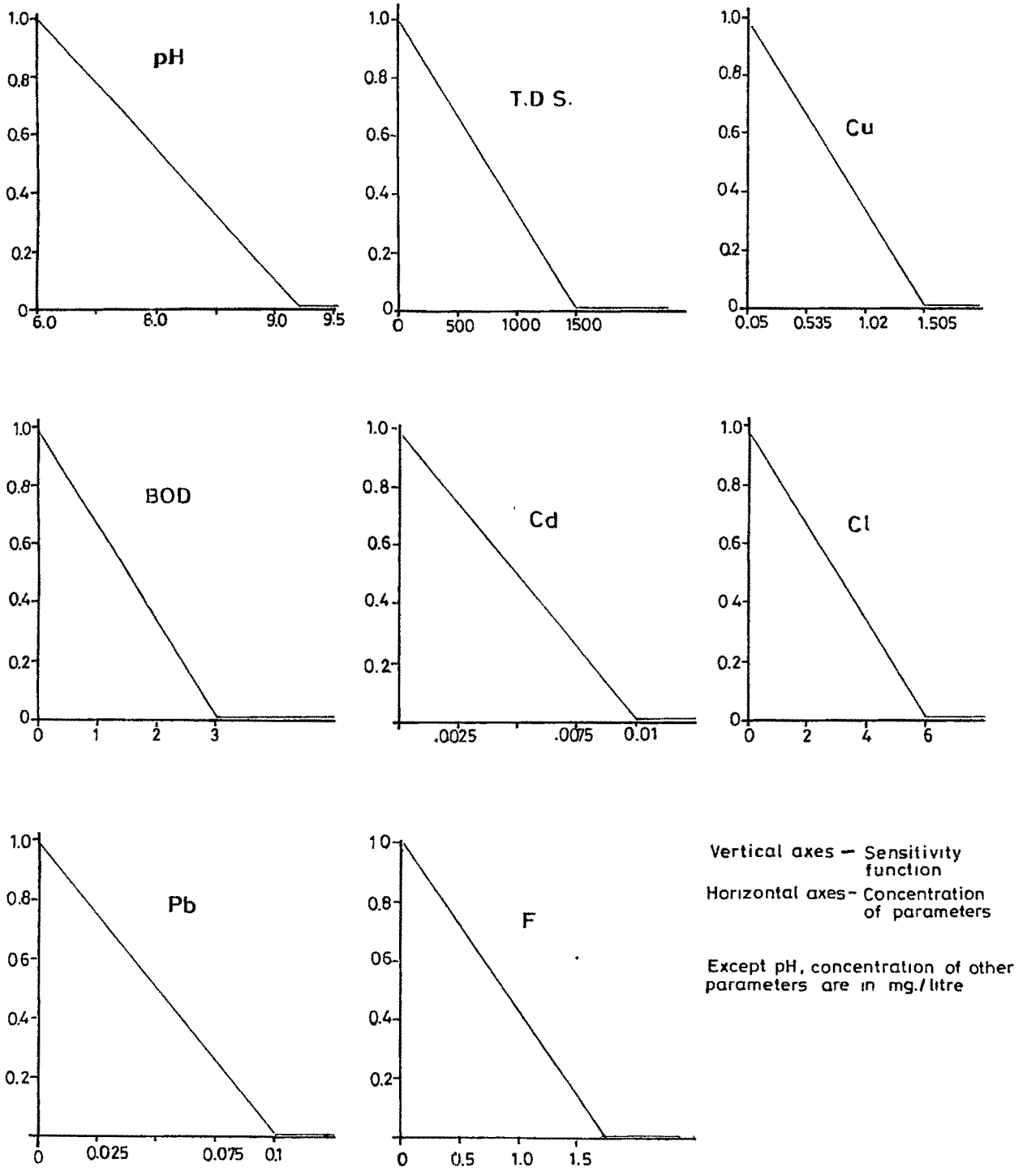

Fig.6.5 : Sensitivity function Vs. parameter value of drinking water

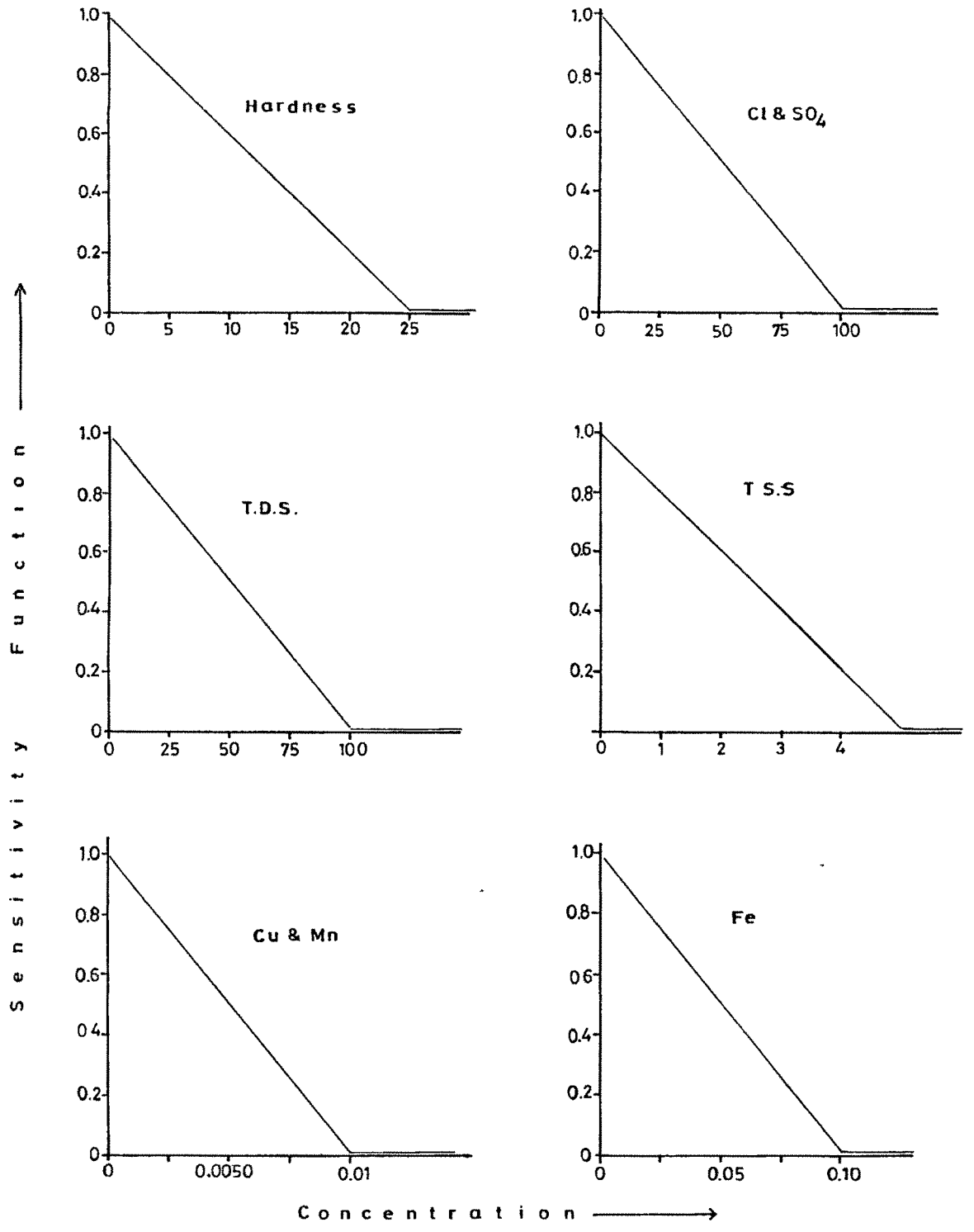

Fig.6.5: Sensitivity function Vs. parameter value of water for industrial use.

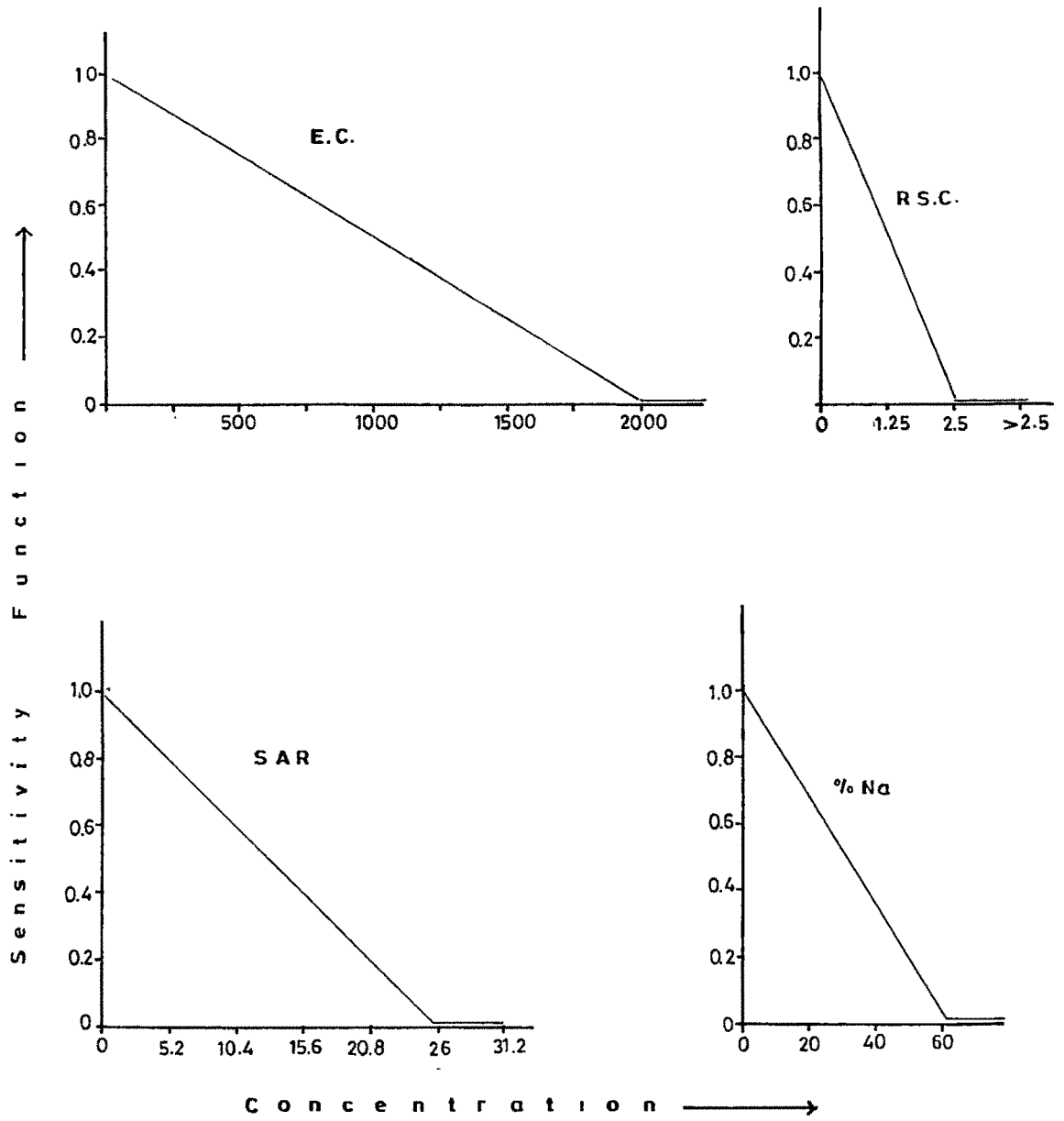

Fig.6.6: Sensitivity function Vs. parameter value of water for irrigation.

TABLE 6.7 : IMPORTANT DETERMINANDS FOR BENEFICIAL USE

Determinands	Drinking	Industrial	Irrigation
pH	*		
Total suspended solids		*	
Total dissolved salt	*	*	
Electric conductivity			*
BOD	*		
Hardness		*	
Chloride	*	*	
Sulphate		*	
Flouride	*		
Lead	*		
Cadmium	*		
Copper	*	*	
Iron		*	
Manganese		*	
Sodium Absorption Ratio			*
Residual Sodium Carbonate			*
Sodium percent			*

Survo nadi (bank) and west of 2Warasara water are satisfactory, while the rest are poor or unacceptable.

The same exercise was done for the coastal tract. The results of WQI is furnished in table 6.9. It is amply clear that none of them is fit for drinking except those at Paswali and Garej pond, which, to an extent, can be termed satisfactory. This confirms with the present day usage among the masses.

INDUSTRY

The dyeing and printing units, flourished in and around Jetpur, constitute the major industry in the Bhadar basin. These units require large quantum of fresh water at various stages in the dyeing and printing processes. Hence, the beneficial use of the surface and sub-surface water only for textile dyeing and printing have been considered while working out the WQI for industrial use.

Viet and Bhargava (1989) considered hardness, EC and depth of light penetration (DLP) as the determinands for the index score to evaluate the usability of water for industries. However, considering the U.S. Federal water pollution control (Karanth, 1990, p. 256) the standard upper limit (values in parenthesis) of the determinands for water to be used in textiles (scouring, bleaching and dyeing), are Fe(0.01 mg/l), Mn (0.01 mg/l), Cu (0.01 mg/l), Hardness (25.0 mg/l), pH (2.5, 10.5), TDS (100.0 mg/l), Colour (5 units) and TSS (5 mg/l). Of them, the author has considered six parameters. pH and colour were not taken into consideration since pH value is within the limits and secondly colour units were

Table 6.8 : WQI for Drinking (Surface water), Bhadar valley

Pre-monsoon										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Karmali pool	0.46	0.49	0 01	-	-	-	0.82	-	21	IV
Sultanpur bridge	0.59	0 50	0 01	0.01	0.00	1.00	0.78	0.16	12	IV
Survo nadi	0.32	0.46	-	-	0.01	-	0.78	-	49	III
Galoliya	0.28	0.01	0.01	0.01	0.01	0.95	0.61	0.74	08	V
Jetpur	0.42	0.01	0.01	0 01	0.01	0.94	0.47	0.10	06	V
S.of Kerali	0 47	0.01	0 01	0.01	0.01	0.99	0.52	0.44	07	V
Vegdi	0.51	0.26	0.01	0.01	0.01	1 00	0.64	0.68	12	IV
Bhuki	0.53	0.42	0.01	0.01	0.01	1.00	0.76	0.60	13	IV
Dhoraji	0.58	0.22	-	0.01	0.01	1.00	0.67	0.26	16	IV
S. of Dhumiyani	0.62	0.26	-	0.01	0.01	1.00	0.67	0.01	10	V
Upleta	0.60	0.25	0 01	0.01	0.01	1.00	0.65	0.23	11	IV
S of Isra	0.60	0.25	-	0.01	0.01	1.00	0 60	0 01	10	V
Warasara	-	-	-	-	-	-	-	-	-	?
Chauta	0.63	0.38	-	0.01	0.01	1 00	0.70	-	16	IV
Post-monsoon										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Atkot	0.41	0.46	0.01	-	-	-	0 61	-	18	IV
Gondli	0 38	0.65	-	-	-	-	0.90	-	61	III
Sultanpur Bridge	0.47	0.55	0.01	0 01	0 01	1.00	0.79	0.01	08	V
Survo nadi	0.51	0.60	-	-	-	-	0.82	-	63	III
Gololiya nadi	0.35	0.38	0.01	0 01	0.01	1 00	0.71	0.01	07	V
Jetpur	0.38	0.01	0.01	0 01	0 01	1 00	0 43	1 00	08	V
S. of Kerali	0 40	0.50	0 01	0.01	0.01	1.00	0.76	0.01	08	V
Phophal nadi	0 40	0.70	-	-	-	-	0 84	-	62	III
Vegdi	0.41	0.50	0.01	0.01	0.01	1.00	0.76	1.00	14	IV
Bhuki	0.45	0.49	0 01	0.01	0.01	1.00	0.76	1.00	14	IV
Dhoraji	0 41	0.49	-	0.01	0 01	1 00	0.74	0 01	11	IV
Dumiyani	0.42	0.51	-	0 01	0 01	1.00	0.76	1.00	21	IV
Moj nadi	0.38	0.61	-	-	-	-	0.82	-	57	III
Upleta	0.45	0.52	0.01	0.01	0 01	1.00	0.76	0 01	08	V
Isra	0 41	0.01	-	0.01	0 01	1.00	0.76	0 01	06	V
Warasara	0 51	0.55	-	-	-	-	0.79	-	60	III
Chauta	0.51	0.57	-	0.01	0 01	1.00	0 80	0 01	11	IV

Table 6.9 : WQI for drinking (sub-surface water), Bhdar valley.

Pre-monson										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Khirasara	0.60	0.66	-	0.01	0.01	0.99	0.88	0 80	22	IV
Pedhla	0.42	0.25	-	-	-	-	0.68	-	41	III
Jetpur	0.74	0.74	-	0.01	0.01	1.00	0.90	0.01	12	IV
Panchpipla	0.51	0.50	-	0.01	0.01	1.00	0.81	0 01	11	IV
1 km before Panchpipla	0.44	0.55	-	-	-	-	0.82	-	58	III
Lunagiri	0.35	0.30	-	0 01	0.01	1.00	0.73	1 00	19	IV
Vegdi	0.31	0.19	0.01	0.01	0.01	1.00	0.62	1 00	12	IV
Bhuki	0.55	0.14	-	0 01	0 01	1.00	0 59	0 46	15	IV
E of Bhuki	0.55	0 45	-	-	-	-	0 78	-	58	III
Dhoraji	0.63	0.50	-	0.01	0.01	1.00	0.90	0 96	22	IV
S. of Dumiyani	0.68	0.42	-	0 01	0 01	1.00	0.70	0 90	21	IV
Upleta(R)	0.71	0.54	0 01	-	-	-	0 79	-	23	IV
Upleta	0.35	0.01	-	0 01	0 01	1 00	0.15	1 00	09	V
Ganod	0 44	0.01	-	0.01	0.01	1.00	0.30	0.17	08	V
Warasara	0.58	0.02	-	-	-	-	0.46	-	17	IV
Isra	0.55	0.38	-	0.01	0.01	1.00	0.68	1.00	20	IV
Post-monsoon										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Kotda Sangani	0.53	0.01	-	-	-	-	0.39	-	13	IV
Khirasara	0.51	0 38	-	0.01	0 01	1.00	0.73	0.01	10	V
Survo nadi bank	0.34	0.29	-	-	-	-	0 64	-	40	III
Panchpipla	0 44	0 49	-	0 01	0.01	1.00	0.81	1.00	21	IV
Lunagiri	0.50	0.01	0.01	0 01	0.01	1.00	0.30	1 00	08	V
Vegdi	0.46	0.01	-	0.01	0.01	0.99	0.01	1.00	06	V
Jam Kandorna	0.51	0.29	0.01	-	-	-	0.72	-	18	IV
Bhuki	0.40	0 28	-	0.01	0.01	1.00	0.65	1.00	18	IV
Upleta	0.32	0.16	-	0.01	0 01	0.99	0.17	1.00	14	IV
Ganod	0.44	0.01	-	0 30	0 01	1.00	0.01	1.00	10	V
Warasara	0.41	0.56	-	-	-	-	0.83	-	57	III

Table 6.10 : WQI for drinking (Surface & sub-surface water), coastal area.

Pre-monsoon										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Katwana *	0.58	0.01	-	-	-	-	0.01	-	04	V
Paswali *	0.43	0.01	0 01	-	-	-	0.01	1 00	05	V
Segras	0.70	0.01	-	0.01	0.01	1.00	0.01	0.01	03	V
Bobdi nadi	0 84	0.01	-	-	-	-	0.01	-	04	V
Garej	0.74	0.37	-	0.01	0.01	1 00	0.62	0.04	13	IV
Garej Pond	0.23	0.46	-	-	-	-	0.68	-	42	III
Navibandar	0 63	0.01	-	0 01	0.01	1.00	0 01	0.01	03	V
JND - 11 *	0 75	0.01	-	-	-	-	0.01	-	04	V
Gosa *	0.73	0.01	-	0.01	1.00	1.00	0.01	1.00	07	V
Limbadi *	0.71	0.01	-	-	-	-	0 01	-	04	V
Mokal *	0.64	0.01	-	-	-	-	0 01	-	04	V
Mahira *	0 56	0 01	-	0.01	1 00	1 00	0.01	1.00	07	V
Nedhna *	0.44	0.66	-	0.01	1.00	1.00	0.86	1.00	22	IV
Pharer *	0.58	0.01	0.01	-	-	-	0 01	-	03	V
Bantwa *	0.22	0.01	-	-	-	-	0 79	-	12	IV
Post-monsoon										
Stations	**pH**	**TDS**	**BOD**	**Cd**	**Pb**	**Cu**	**Cl**	**F**	**WQI**	**Class**
Katwana *	0 71	0.01	-	-	-	-	0.01	-	04	V
Paswali	0.35	0.52	-	-	-	-	0.76	-	52	III
Paswali *	0.44	0.14	0 01	-	-	-	0.51	1.00	20	IV
Segras	0.49	0.54	-	0.01	0 01	0 99	0 76	0.01	11	IV
Bobdi nadi	0.66	0 01	-	0 01	0 01	0.99	0 01	1.00	07	V
Garej	0.42	0 16	-	0.01	0.01	1.00	0 38	1.00	16	IV
Garej Pond	0 46	0.58	0.01	-	-	-	0 76	-	21	IV
Navibandar	0.53	0.52	-	0.01	0.01	1.00	0 73	0.01	11	IV
JND - 11 *	0.68	0.01	-	-	-	-	0.01	-	04	V
Gosa *	0.66	0.01	-	0 01	0 01	1.00	0 01	1.00	07	V
Limbadi *	0.74	0.01	-	-	-	-	0.01	-	04	V
Mokal *	0.74	0 01	-	-	-	-	0.01	-	04	V
Jambu *	0.80	0.01	-	-	-	-	0 01	-	04	V
Mahira *	0.74	0.01	-	0 01	0 01	1.00	0 01	1.00	07	V
Nedhna *	0.64	0.64	-	0.01	0 01	1 00	0 90	1.00	23	IV
Pharer *	0.78	0 01	-	-	-	-	0.01	-	04	V
Bantwa *	0.44	0.06	-	-	-	-	0.73	-	27	IV

* Sub-surface water

not measured. Further, Cl- amd SO4 are also taken into account as they too are important (Kotaiah and Kumara Swamy, 1994, P. 110) Figure 6.5 depicts the plots of sensitive function versus permitted upper limit concentration of different variables. The WQI and the water class is furnished in tables 6.11, 6.12 and 6.13. WQI clearly indicates that the water quality is a "unacceptable " catagory for both surface and sub-surface samples.

IRRIGATION

Viet and Bhargava (1989) considered EC and chloride as the determinands to specify the WQI for irrigation. However, considering the importance of percent sodium, sodium absorption ratio (SAR) and residual sodium carbonate (RSC) as suggested by Wilcox (1955) and Richard (1954), the latter three were also taken into account to obtain the index score. The sensitive function versus concentration of variables plot is as furnished in figure 6.6. Effluent waste water from textile units are also used for irrigation. Therefore, WQI of point source were also calculated and are given in table 6.14, 6.15, and 6.16.

Except the point source, the surface water of Bhadar valley in pre-monsoon belong to satisfactory to poor water class for irrigational use. In the post-monsoon by and large all water belong to satisfactory category excepting those of Gondli nadi and Bhadar at Jetpur which are good; whereas south of Isra, it is of poor quality. The improvement in the surface water quality in the post-monsoon season is on account of precipitation.

For sub-surface water, except at Upleta and Ganod, the water quality is to good to satisfactory for irrigation, irrespective of the seasons.

In the coastal block, WQI for irrigation of the surface and sub-surface water are satisfactory in Garej, Nedhna, Jambu, sluice gate Navibandar, Segras and Paswali. The rest are poor or unacceptable.

In addition to above Index scoring the author has made an attempt to evaluate the quality of water for agricultural purpose separately for Bhadar valley and coastal region, western us sdinity diagram based on U.S. Salinity diagram , R.S.C. and Wilcox plot.

Bhadar valley

U.S. Salinity diagram

The parameters considered in the U.S. salinity diagram are furnished in table 6.14,15,16. The diagram 6.7 exhibits the mean EC and SAR values of pre and post monsoon surface samples of Bhadar valley. Majority of the pre-monsoon water belong to C3-S1 type (good water), however, a few deviates and falls into the field of C4-S1, C4-S2, C4-S3, C4-S5 and C5-S1 types. According to this plot, Galoliya nadi, Bhadar at Jetpur and south of Kerali are moderate whereas, the point source are unsuitable for the same purpose. Likewise, all post-monsoon water samples are good except that of the point source at Derdi which is unsuitable and that of Jetpur which is of moderate category.

Table 6.11 : WQI for Industrial use (Surface water) , Bhadar valley.

Pre-monsoon										
Stations	**TDS**	**Hardness**	**Cu**	**Mn**	**Cl**	**SO_4**	**TSS**	**Fe**	**WQI**	**Class**
Karmali pool	0.01	0.01	-	-	0.01	1.00	1 00	-	6	V
Sultanpur bridge	0.01	0.1	0.01	1.00	0.01	1.00	0.01	1 00	6	V
Survo nadi	0.01	0.01	-	-	0.01	0.80	0.01	-	2	V
Galoliya nadi	0.01	0 01	0.01	0.80	0 01	0.01	0.01	0 60	3	V
Jetpur	0.01	0.01	0 01	1.00	0.01	0.01	0.01	1 00	3	V
S.of Kerali	0.01	0 01	0.01	1.00	0 01	0 01	0.10	0.50	5	V
Vegdi	0.01	0.01	0.01	1.00	0.01	0.62	0.01	1.00	5	V
Bhuki	0.01	0.01	0 01	1.00	0.01	0.58	0.01	1 00	5	V
Dhoraji	0.01	0.01	0.01	1 00	0 01	0 60	0.01	0.84	5	V
S of Dhumiyani	0.01	0.01	0 01	1 00	0.01	0 01	0.01	1.00	3	V
Upleta	0 01	0.01	0 01	1.00	0.01	0.33	0.01	1.00	5	V
S of Isra	0 01	0.01	0 01	1 00	0 01	0 26	0.10	1.00	5	V
Chauta	0.01	0 01	0.01	1 00	0.01	0.01	0.01	1.00	4	V
Post-monsoon										
Stations	**TDS**	**Hardness**	**Cl**	**SO_4**	**TSS**	**Fe**	**Mn**	**Cu**	**WQI**	**Class**
Atkot	0.0.1	0.0.1	0.0.1	1.00	0.99	-	-	-	06	V
Gondli nadi	0.01	0.01	0.33	1 00	0 01	-	-	-	05	V
Sultanpur bridge	0 01	0.01	0 01	1.00	0.01	0 32	1.00	0.01	05	V
Survo nadi	0 01	0 01	0.01	1.00	001	-	-	-	02	V
Gololiya nadi	0.01	0.01	0.01	0 69	0.01	1 00	1.00	0.01	05	V
Jetpur	0.01	0 01 .	0 01	1 00	0.01	0 01	1 00	0 01	03	V
S of Kerali	0.01	0.01	0.01	1.00	001	1.00	0.01	0 01	03	V
Phophal nadi	0.01	0.01	0.24	1 00	1.00	-	-	-	12	IV
Vegdi	0.01	0.01	0.01	0 62	0.01	1.00	0.20	0 01	04	V
Bhuki	0.01	0 01	0 01	0.01	0.20	1 00	0.60	0.01	04	V
Dhoraji	0.01	0.01	0 01	0 60	0.01	1.00	0 60	0.01	05	V
Dumiyani	0.01	0.01	0.01	0.90	0.01	1.00	1.00	0 01	05	V
Moj nadi	0.01	0 01	0 01	1.00	1.00	-	-	-	06	V
Upleta	001	001	001	0 69	0 28	1.00	1.00	0.01	08	V
Isra	0.01	0 01	0 01	0 92	0.18	1 00	1 00	0 01	08	V
Warasara	0 01	0.01	0.01	1.00	0.01	-	-	-	02	V
Chauta	001	001	001	1 00	0.12	1.00	0.40	0.01	07	V

Table 6.12 : WQI for Industrial use (Sub-surface water), Bhadar valley.

Pre-monsoon										
Stations	**TDS**	**Hardness**	**Cl**	**SO_4**	**TSS**	**Fe**	**Mn**	**Cu**	**WQI**	**Class**
Khirasara	0 01	0 01	0.33	0.62	0 01	0.81	1.00	0.01	8	V
Jetpur	0.01	0.01	0 37	1.00	0.01	1.00	1.00	0.01	9	V
Pedhla	0.01	0.01	0.01	0.10	1.00	-	-	-	4	V
1 km before Panchpipla	0.01	0.01	0.02	0 44	1.00	-	-	-	6	V
Panchpipla	0.01	0.01	0.01	0 33	0 01	1.00	1 00	0 01	5	V
Lunagiri	0.01	0.01	0 01	0.12	0 96	1.00	1.00	0.01	8	V
Vegdi	0.01	0.01	0.01	0 52	0.01	0.61	1.00	0 01	5	V
Bhuki	0.01	0.01	0 01	0.71	0 01	1.00	1.00	0 01	5	V
E. of Bhuki	0.01	0.01	0 01	0.08	1 00	-	-	-	4	V
Dhoraji	0.01	0.01	0.44	0.81	0.01	0 69	1 00	0.01	8	V
S. of Dumiyani	0.01	0.01	0 01	0.10	0 01	0.68	1.00	0.01	4	V
Upleta(R) bed	0.01	0.01	0 01	0.01	0 01	-	-	-	1	V
Upleta	0 01	0.01	0 01	0.01	0.01	0 61	1.00	0 01	3	V
Isra	0.01	0.01	0.01	0 05	0 20	0.48	1.00	0.01	5	V
Ganod	0.01	0.01	0.01	0 01	0 01	0.97	1.00	0 01	3	V
W. of Warasara	0.01	0.01	0 01	0 16	0 01	-	-	-	2	V
Post-monsoon										
Stations	**TDS**	**Hardness**	**Cl**	**SO_4**	**TSS**	**Fe**	**Mn**	**Cu**	**WQI**	**Class**
Kotda Sanghani	0.01	0.01	0.01	1.00	0 01	-	-	-	2	V
Khirasara	0.01	0 01	0.01	1 00	0.01	1.00	1.00	0.01	6	V
Survo nadi bank	0.01	0.01	0 01	1 00	0.01	-	-	-	2	V
Panchpipla	0.01	0.01	0 01	0 48	0.01	0 01	0 01	0.01	2	V
Lunagiri	0.01	0.01	0.01	0 33	0.01	1.00	0.01	0.01	3	V
Vegdi	0.01	0.01	0.01	1.00	0.01	1.00	0 70	0.01	5	V
Jam Kardoma	0 01	0.01	0 01	1 00	0.01	-	-	-	2	V
Bhuki	0.01	0.01	0 01	0 73	0.01	1.00	0.40	0 01	5	V
Upleta	0.01	0.01	0 01	0 01	0.01	1.00	1.00	0.01	3	V
Ganod	0.01	0.01	0 01	0 01	0.01	1.00	1.00	0 01	3	V
W of Warasara	0.01	0 01	0 05	1 00	0.01	-	-	-	3	V

Table 6.13 : WQI for Industrial use (Surface & sub-surface water), coastal area.

Pre-monsoon										
Stations	TDS	Hardness	Cl	SO4	TSS	Fe	Mn	Cu	WQI	Class
Katwana *	0.0.1	0.0.1	0.0.1	0.01	0.01	-	-	-	01	V
Paswali *	0.01	0.01	0 01	0.01	0.01	0 63	1.00	0.01	03	V
Segras	0 01	0.01	0.01	0.01	0.01	0.52	1.00	0.01	03	V
Bobdi nadi	0.01	0.01	0.01	0.01	0.01	-	-	-	01	V
Garej	0.01	0.01	0 01	1.00	0.01	0.79	1.00	0 01	05	V
Garej Pond	0.01	0.01	0 01	0.82	0.01	-	-	-	02	V
Navibandar	0.01	0.01	0.01	0.01	0 01	0.67	1.00	0.01	03	V
JND - 11 *	0.01	0.01	0.01	0.01	0.01	-	-	-	01	V
Gosa *	0.01	0.01	0.01	0.01	0 01	0 90	1.00	0 01	03	V
Limbadi *	0.01	0.01	0 01	001	0 01	-	-	-	01	V
Mokal *	0.01	0.01	0.01	0.01	0.01	-	-	-	01	V
Mahira *	0.01	0.01	0.01	0 01	0 01	0.80	1.00	0.01	03	V
Nedhna *	0.01	0 01	0.20	1.00	0 76	0.52	1.00	0 01	13	V
Pharer *	001	001	001	0.01	0 01	-	-	-	01	V
Bantwa *	0.01	0 01	0 01	0.01	0.44	-	-	-	02	V
Post-monsoon										
Stations	TDS	Hardness	Cl	SO4	TSS	Fe	Mn	Cu	WQI	Class
Katwana *	0.01	0.01	0.01	0.01	0.01	-	-	-	1	V
Paswali	0 01	0.01	0.01	0 44	0.01	-	-	-	2	V
Paswali *	0 01	0.01	0.01	0 22	0 01	1.00	1.00	0.01	5	V
Segras	0 01	0.01	0.01	1.00	0.01	1.00	1.00	0 01	6	V
Bobdi nadi	0.01	0.01	0.01	0.01	0.01	1.00	0.50	0.01	3	V
Garej	0.01	0.01	0 01	1.00	0.01	1 00	1.00	0 01	6	V
Garej Pond	0 01	0.01	0 01	0 94	0 01	-	-	-	2	V
Navibandar	0 01	0.01	0 01	0.92	0.01	1 00	1 00	0 01	6	V
JND - 11 *	0 01	0.01	0.01	0.01	0.01	-	-	-	1	V
Gosa *	0 01	0.01	0 01	0 01	0.01	1.00	1.00	0 01	3	V
Limbadi *	0 01	0.01	0 01	0.01	0.01	-	-	-	1	V
Mokal *	001	0.01	0.01	0 01	0.01	-	-	-	1	V
Jambu *	001	0.01	0.01	0.01	0.01	-	-	-	1	V
Mahira *	001	0.01	0 01	0.01	0.01	1.00	0.10	0.01	2	V
Nedhna *	001	0.01	0.37	1.00	001	1 00	1.00	0 01	9	V
Pharer *	0.01	0.01	0.01	0 01	0 01	-	-	-	1	V
Bantwa *	0.01	0 01	0 01	0 01	0 01	-	-	-	1	V

* Sub-surface water

Table 6.14 : WQI for Irrigation (Surface water), Bhadar valley.

Pre-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Karmali nadi	0.84	0 40	0 27	0 91	54	III
Sultanpur bridge	0.70	0.42	0 26	0 90	51	III
Survo nadi	0.46	0 36	0.34	0.91	47	III
Derdi (p.s)	0.01	0.01	-	-	01	V
Galoliya nadi	0.01	0.01	0.01	0.78	09	V
Jetpur (p.s)	0.01	0.01	0.01	0.01	01	V
Jetpur	0.01	0.01	0 01	0.58	03	V
Panchpipla (p s)	-	0.01	-	-	01	V
S of Keralı .	0.01	0.01	0 34	0.70	07	V
Lunagırı (p s)	0.01	0.01	0.01	0.86	03	V
Vegdı	1.00	0.12	0 40	0.87	45	III
Bhuki	1.00	0.32	0 41	0.90	59	III
Dhoraji	1.00	0.08	0 18	0.87	33	IV
Dumıyanı	1.00	0.13	0.14	0 86	35	III
Upleta	1 00	0 12	0.12	0.86	33	IV
Isra	1.00	0 12	0.10	0.86	32	IV
Chauta	1 00	0 26	0 02	0.83	26	IV
Post-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Atkot	1.00	0 37	0 30	0.90	56	III
Gondali nadi	1 00	0 59	0 43	0 93	70	II
Sultanpur bridge	1 00	0.48	0 30	0 91	60	III
Survo nadı	0 84	0.52	0 21	0.91	54	III
Derdı (p.s)	0 01	0 01	0 01	0 32	2	V
Galoliya nadi	0 64	0 28	0.90	0 83	60	III
Jetpur (p s)	0 01	0.01	-	-	1	V
Jetpur	0 80	0 01	0 08	0.82	15	IV
Panchpıpla (p.s)	0 01	0 05	0.38	0.91	11	IV
S of Keralı	0 49	0.43	0.22	0.90	45	III
Lunagiri (p s)	1 00	0 01	-	-	1	V
Phopal nadi	1.00	0 66	0.27	0.91	63	III
Vegdı	1 00	0 42	0 24	0.90	55	III
Bhuki	1.00	0 40	0 32	0.91	58	III
Dhoraji	1 00	0 40	0 27	0.90	56	III
S. of Dumıyanı	1.00	0 43	0 20	0 90	53	III
Moj nadi	1 00	0 54	0 18	0.90	54	III
Upleta	1.00	0 44	0 12	0.88	46	III
S of Isra	1 00	0 01	0 16	0 88	19	IV
W of Warasara	1 00	0 46	0.16	0.89	51	III
S of Chauta	1.00	0 50	0.24	0.90	57	III

Table 6.15 : WQI for irrigation (Sub-surface water), Bhadar valley

Pre-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Khirasara	1 00	0 62	0 53	0.94	74	II
Jetpur	0.99	0.90	0.43	0.96	78	II
Pedhla	1.00	0.12	0.32	0.90	43	III
1 km before Panchpipla	1.00	0 48	0 37	0.90	63	III
Panchpipla	1.00	0.42	0 56	0.91	68	II
Lunagiri	1.00	0.20	0.59	0.88	57	III
Vegdi	1.00	0.06	0 75	0.94	45	III
Bhuki	1.00	0 01	0 59	0.90	27	IV
E of Bhuki	1.00	0.36	0.68	0 92	69	II
Dhoraji	1 00	0 44	0 40	0 92	63	III
S. of Dumiyani	1.00	0 33	0 49	0.75	59	III
Upleta(river bed)	0.84	0.47	0 75	0.83	70	II
Upleta	0.01	0.01	0 17	0 41	05	V
S. of Isra	0.24	0.26	0.58	0 54	37	III
Ganod	0.01	0.01	0.01	0 34	02	V
W. of Warasara	1.00	0.01	0 33	0 83	23	IV
Post-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Kotda Sanghani	1.00	0 01	0 59	0.94	27	IV
Khirasara	1.00	0.31	0.60	0 95	65	II
Survo nadi (bank)	1 00	0.16	0 16	0.86	38	III
Panchpipla	1.00	0 37	0 43	0.91	62	III
Lunagiri	1.00	0 01	0 27	0 83	22	IV
Vegdi	1 00	0 01	0 70	0 95	28	IV
Jam Kandorna	1.00	0 16	0 54	0 94	53	III
Bhuki	1 00	0 15	0 27	0 94	44	III
Upleta	0 01	0 01	0 01	0 01	1	V
Ganod	1.00	0 01	0 01	0.53	8	V
W of Warasara	0.02	0 47	0 01	0 86	17	IV

Table 6.16 : WQI for irrigation (surface & sub-surface water), Coastal area

Pre-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Katwana *	1.00	0 01	0.43	0.63	23	IV
Paswali *	0.74	0.01	0.34	0.65	20	IV
Segras	1.00	0 01	0.40	0.53	21	IV
Bobdi nadi	1 00	0.01	0.24	0.20	15	IV
Garej	1.00	0.26	0.34	0 90	53	III
Garej pond	1.00	0.37	0.19	0.83	49	III
Navibandar	1.00	0.01	0 14	0.28	14	IV
JND 11 *	1.00	0 01	0.56	0.53	23	IV
Gosa *	1.00	0.01	0.32	0.48	20	IV
Limbadi *	1.00	0.01	0 24	0.24	15	IV
Mokal *	1.00	0.01	0 56	0.34	21	IV
Mahira *	1.00	0.01	0 63	0.41	22	IV
Nedhna *	0.46	0.60	0 75	0.90	66	II
Pharer *	1 00	0.01	0.24	0.48	18	IV
Bantwa *	0.01	0.02	0.01	0.20	02	V
Post-monsoon						
Stations	**RSC**	**EC**	**%Na**	**SAR**	**WQI**	**Class**
Katwana *	1.00	0.01	0.17	0.71	19	IV
Paswali	1.00	0 43	0 24	0.90	55	III
Paswali *	0 64	0 01	0.03	0.78	11	IV
Segras	1 00	0 47	0 14	0 88	49	III
Bobdi nadi	-	0.01	-	-	01	V
Garej	1.00	0.02	0.10	0.84	20	IV
Garej pond	0.76	0.53	0 01	0 82	24	IV
Navibandar	1 00	0 43	0 07	0 86	40	III
JND 11 *	1 00	0.01	0.10	0.55	15	IV
Gosa *	1.00	0.01	0 01	0 60	09	V
Limbadi *	1.00	0 01	0 01	0.46	08	V
Mokal *	1.00	0 01	0 01	0 46	08	V
Jambu *	1 00	0.30	0 1	0 60	37	III
Mahira *	1.00	0 01	0 01	0.53	08	V
Nedhna *	0.01	0 58	0 16	0 90	17	IV
Pharer *	1 00	0.01	0 02	0 60	10	V
Bantwa *	0 01	0 01	0 01	0 40	02	V

* Sub-surface water

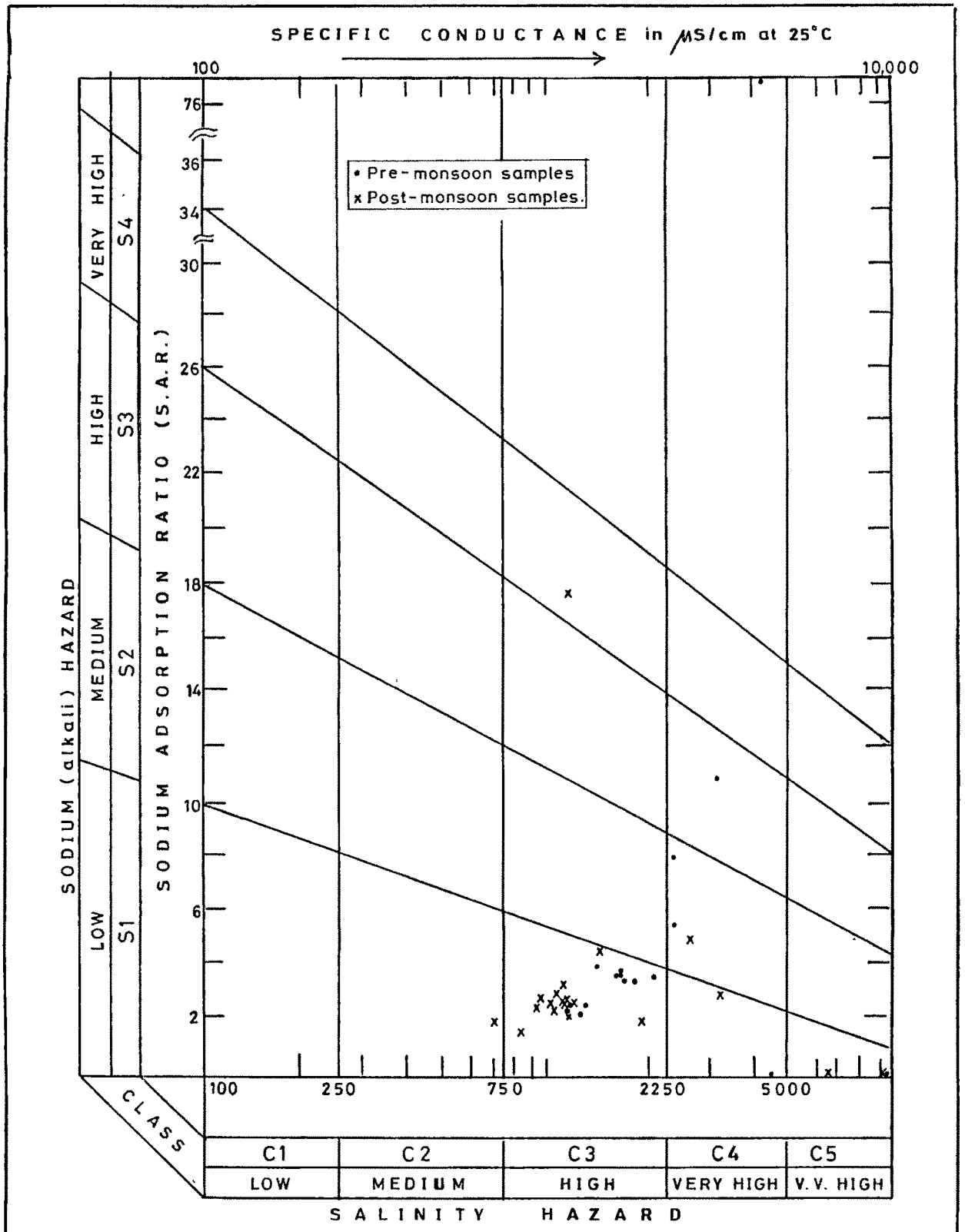

Fig6.7 : SURFACE WATER QUALITY FOR IRRIGATION
(U.S. Salinity Laboratory)

EC and SAR values plot of ground water (Fig. 6.8) indicates that the quality of the water is as follows :

For pre-monsoon,

Khirasara to Upleta river bed	- Good
Upleta and Ganod	- Unsuitable and
South of Isra and- West of Warasara	- Moderate.

However, in the post-monsoon, except three water is good for irrigation in all other stations. The three stations are,

Lunagiri	- Moderate
Upleta and Ganod	- Unsuitable

Water Quality based on (RSC)

Suitability of water for irrigation also depends on the RSC and on its basis, water has been classified (Richard, 1954) as under :

Safe	<1.25 epm
Marginal	1.2 - 2.50 epm
Unsuitable	>2.50 epm

RSC is computed from the formula, RSC = $(HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$ where the concentrations are expressed in epm.

On the basis of RSC, pre--monsoon surface water reflects the following quality:

Karmali nadi to Sultanpur Bridge and beyond Lunagiri	- safe
Derdi to Lunagiri	- Unsuitable
Survo nadi	- Marginal

However, for the surface water of the post-monsoon the water classes are :

Derdi, Jetpur, panchpipla and Lunagiri point sources	- Unsuitable
South of Kerali	- Moderate,
The rest of the locations	- Safe.

In the sub--surface water of the pre-monsoon, those from Upleta and Ganod are unsuitable, whereas Dhoraji, and south of Isra are marginal and the rest are safe. On the other hand, for the post-monsoon ground water of Upleta is usuitable, while west of Warasara is moderate and the rest all are safe.

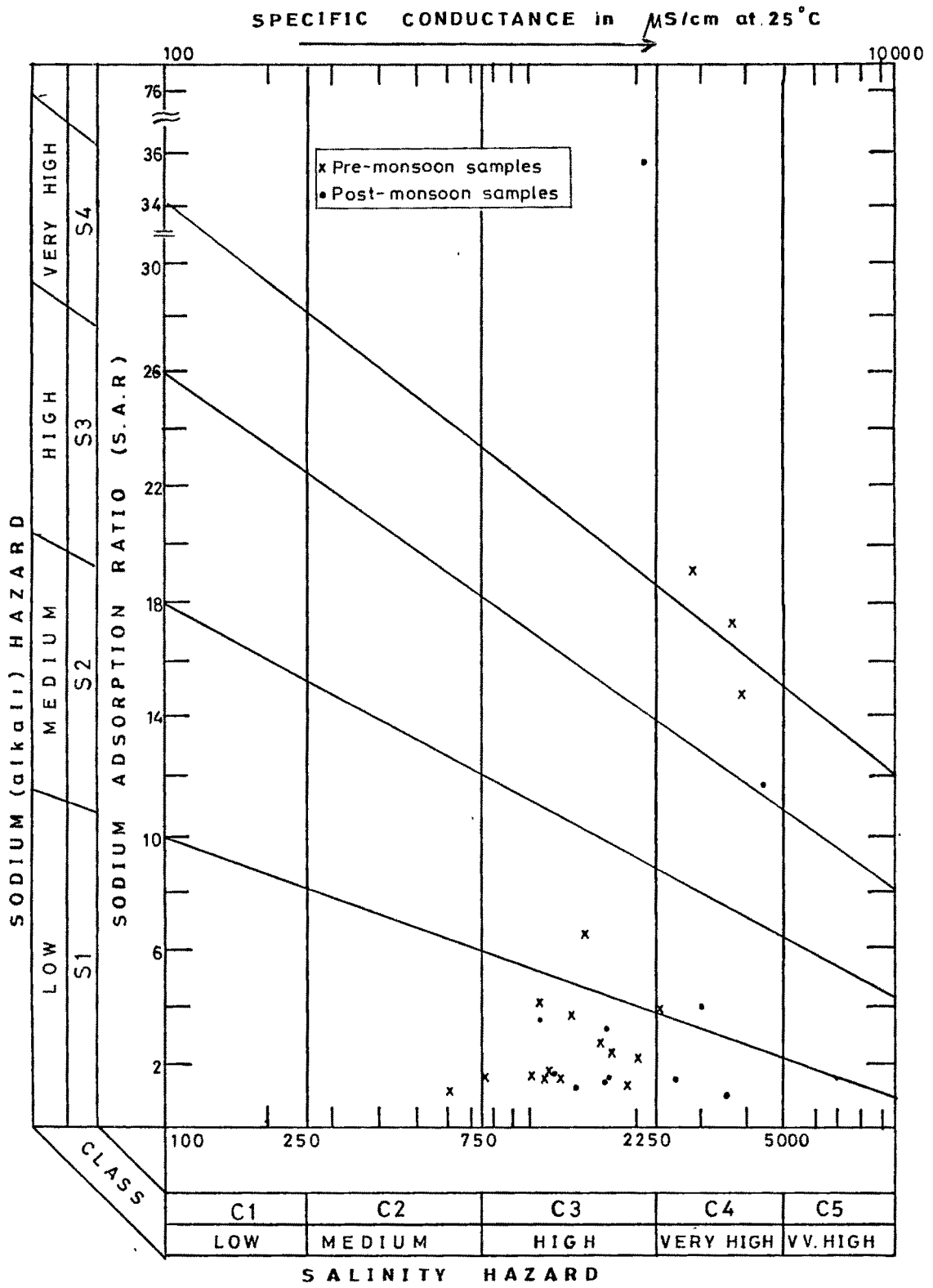

Fig.6.8; SUB-SURFACE WATER QUALITY FOR IRRIGATION
(U.S. Salinity Laboratory)

Wilcox plot

Figure 6.9 depicts the EC versus percent sodium plot (Wilcox, 1955) for the pre and post monsoon surface water. The results of the plot are as under:

Karmali nadi , Survo nadi, Bhadar at Sultanpur bridge, Vegdi, Bhuki and Dhoraji	- Good to permissible
Lunagiri (p.s) and from Bhadar south of Dumiyani to south of Chauta	- Permissible to doubtful
Galoliya nadi, and the Bhadar south of Kerali	- Doubtful to unsuitable
Bhadar at Jetpur, Derdi, Jetpur and Panchpipla point sources	- Unsuitable

Post-monsoon results are:

Derdi (p.s) and Bhadar at Jetpur	- Doubtful to unsuitable
Jetpur (p.s) Lunagiri(p.s) and Bhadar south of Isra	- Unsuitable
The rest	- Good to permissible

The mean EC and percent sodium values of the sub-surface water for the pre and post monsoon seasons are plotted in figure 6.9. The conclusions arrived at for the pre-monsoonal water at different places are as follows:

Upleta and Ganod	- Unsuitable
Bhuki and west of Warasara	- Doubtful to unsuitable
The rest	- Good to permissible

For the post-monsoon water samples the results are:

Vegdi and Ganod	- Unsuitable
Kotda Sanghani, Lunagiri and Upleta	- Doubtful to unsuitable
West of Warasara	- Permissible to doubtful
The rest	- Good to permissible

Coastal Region

U.S. Salinity diagram

For the surface and sub-surface water, EC and SAR values for the pre and post monsoon seasons are plotted in U.S. Salinity diagram (Fig. 6.10). According to the diagram, the pre-monsoon surface water from Garej and Garej pond are good, while the rest are unsuitable for irrigation. Whereas for sub-surface water for the same season, except Nedhna (good), Katwana and Paswali (moderate) the rest all are unsuitable. Likewise in the post-monsoon, all the surface samples are good for irrigation, whereas, for the sub-surface water except Nedhna (good), Katwana, Paswali and Jambu (moderate) the remaining all are unsuitable.

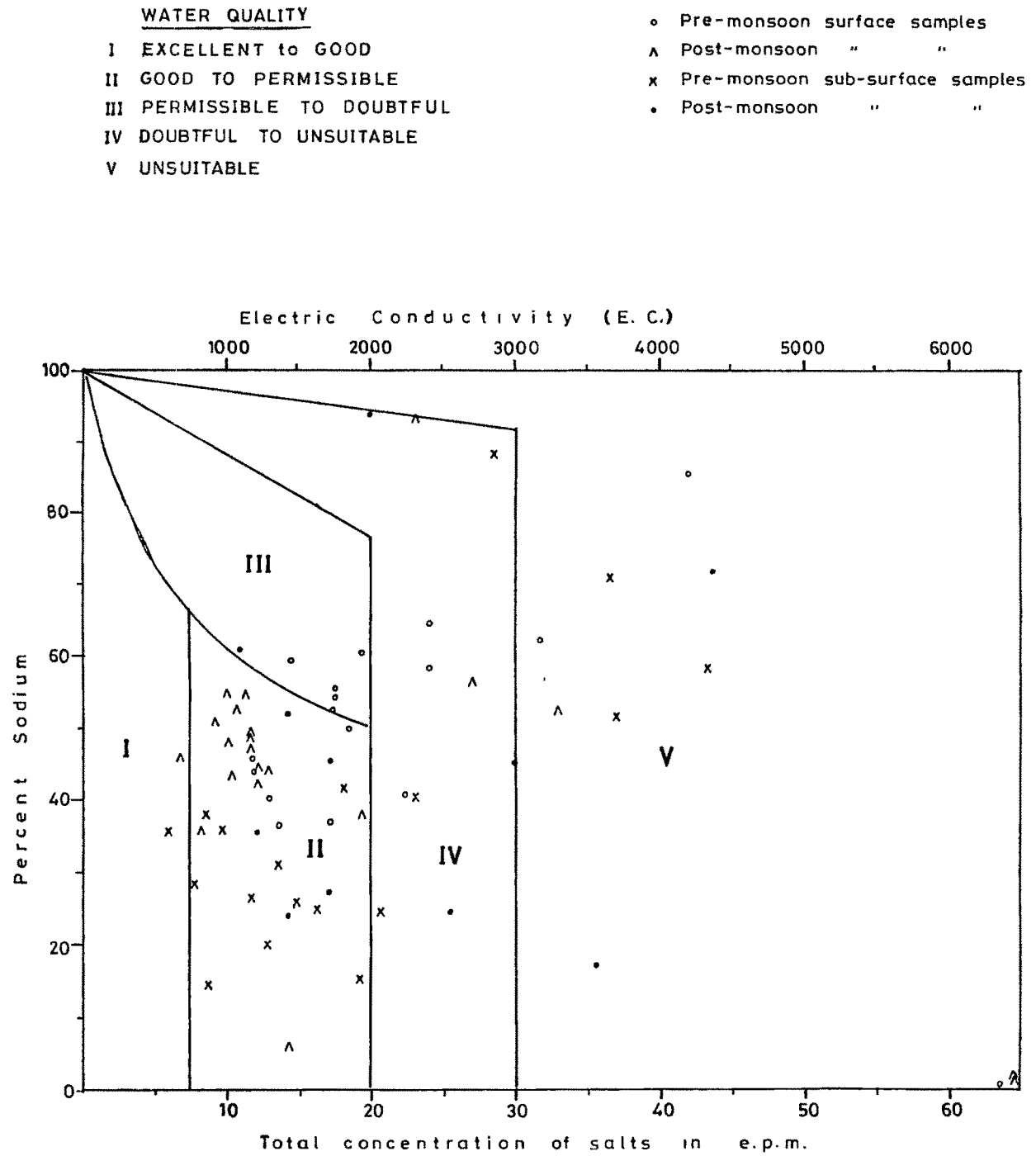

Fig.6.9: SURFACE AND SUB-SURFACE WATER QUALITY (upto Kutiyana) FOR IRRIGATION. (After Wilcox, 1955)

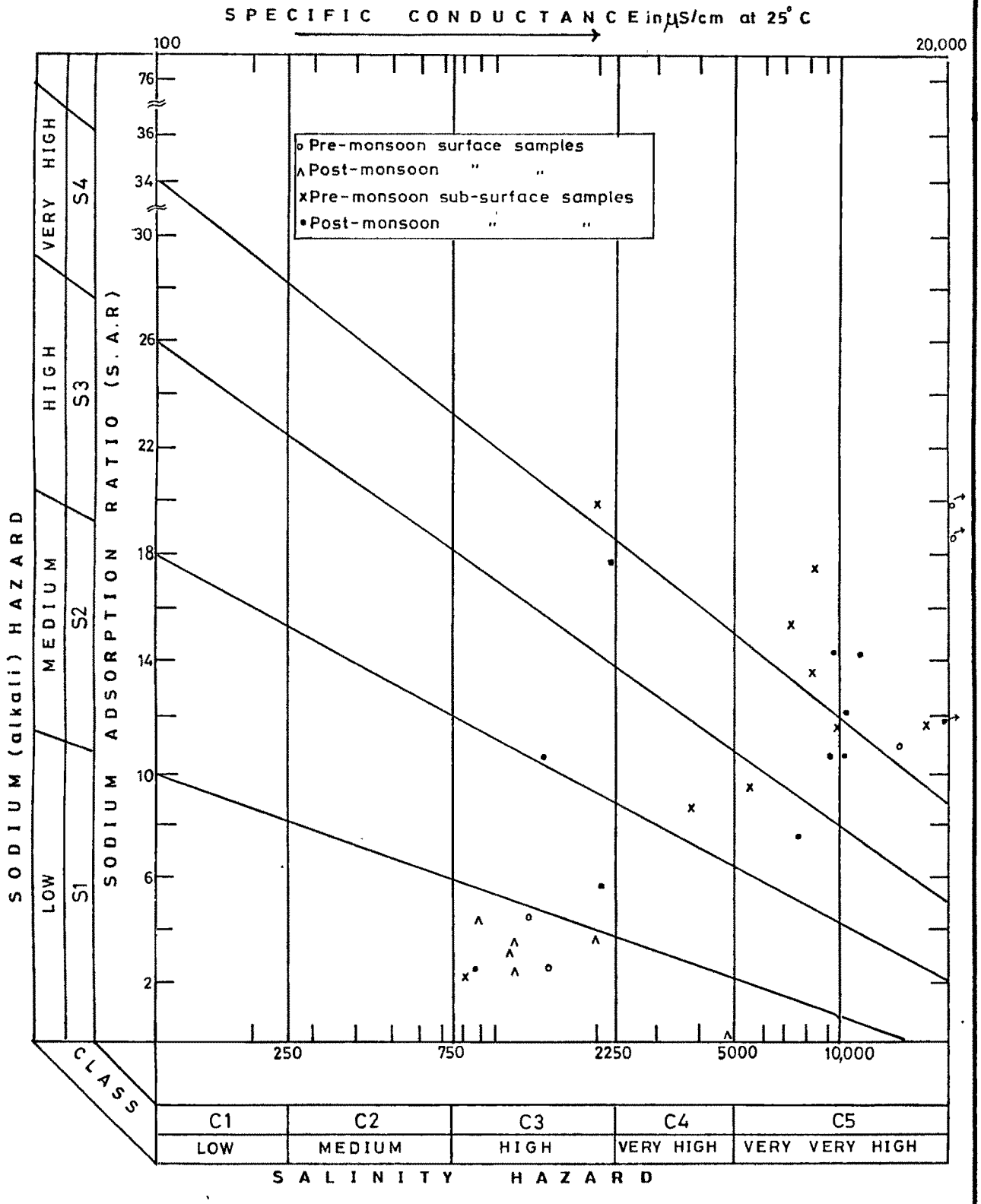

Fig.6.10: U.S. SALINITY DIAGRAM DEPICTING SURFACE AND SUB-SURFACE WATER QUALITY OF COASTAL AREAS, (beyond Kutiyana), BHADAR RIVER BASIN

RSC

RSC values suggest that excepting Nedhna ground water (marginal) and Bantwa sub-surface water (unsuitable), the remaining surface and sub-surface water are safe for irrigation in the pre-monsoon. However, in the post-monsoon the above mentioned Nedhna and Bantwa sub-surface water are of unsuitable class, while the rest surface and ground water samples are safe.

Wilcox Plot

Figure 6.11 depicts the mean EC versus mean percent sodium plot for the surface and sub-surface water of the coastal region in pre and post monsoon seasons. The plots depicts that, except surface water of Garej and Garej pond, ground water of Nedhna (good to permissible) and sub-surface water of Bantwa (doubtful to unsuitable), rest all surface and sub-surface water are unsuitable for irrigation in the pre-monsoon season.

For the post-monsoon the water samples the deduction is as follows:

Jambu and Nedhna (G.W) and Paswali, Segras and Navibandar (S.W)	- Good to permissible
Garej and Garej pond (S.W)	- Permissible to doubtful
Paswali and Bantwa (G.W)	- Doubtful to unsuitable
The rest G.W. and S.W. samples	- Unsuitable for irrigation.

Further, to understand the mechanism controlling the water chemistry in the coastal area, the ratio of Na+K/Na+K+Ca and that of Cl/Cl+HCO_3 versus TDS were plotted in the Subramanian's (1994) plot (Fig. 6.12) for the surface and sub-surface water of pre and post monsoon seasons. The plots reveal that irrespective of the seasons, the surface and sub-surface water belong to rock dominance and evaporation dominance categories depicting the lithology and evaporation as the only two factors, controlling the chemistry of water in the coastal area.

IMPACT ON HEALTH

The analytical data reflect high concentration of various parameters. WQI reveals the water to be poor and unacceptable for potability from all the locations except a few. Villagers, therefore, residing on the bank of the river have no alternative but to use these water. Consumption of such water, on a long run has led to various ailments.

In this regard, a preliminary survey was carried out in the year 1995 in the villages of Jetpur, Dhoraji and Upleta talukas. It revealed that the people in direct contact with the surface water of Bhadar have rashes on their skin causing irritation and uneasiness. The intake of these water have created a number of health hazards like throat pain, burning in the epigastric region, head-ache, body-ache, giddiness and chronic neurological problems. Such conclusions have also been arrived at by Prasad et al. (1986) for Varanasi and Prakash et al. (1992) for Guwahati regions. More severe is the problem in the village Isra, where many people have the cases of appendicitis. In addition to this,

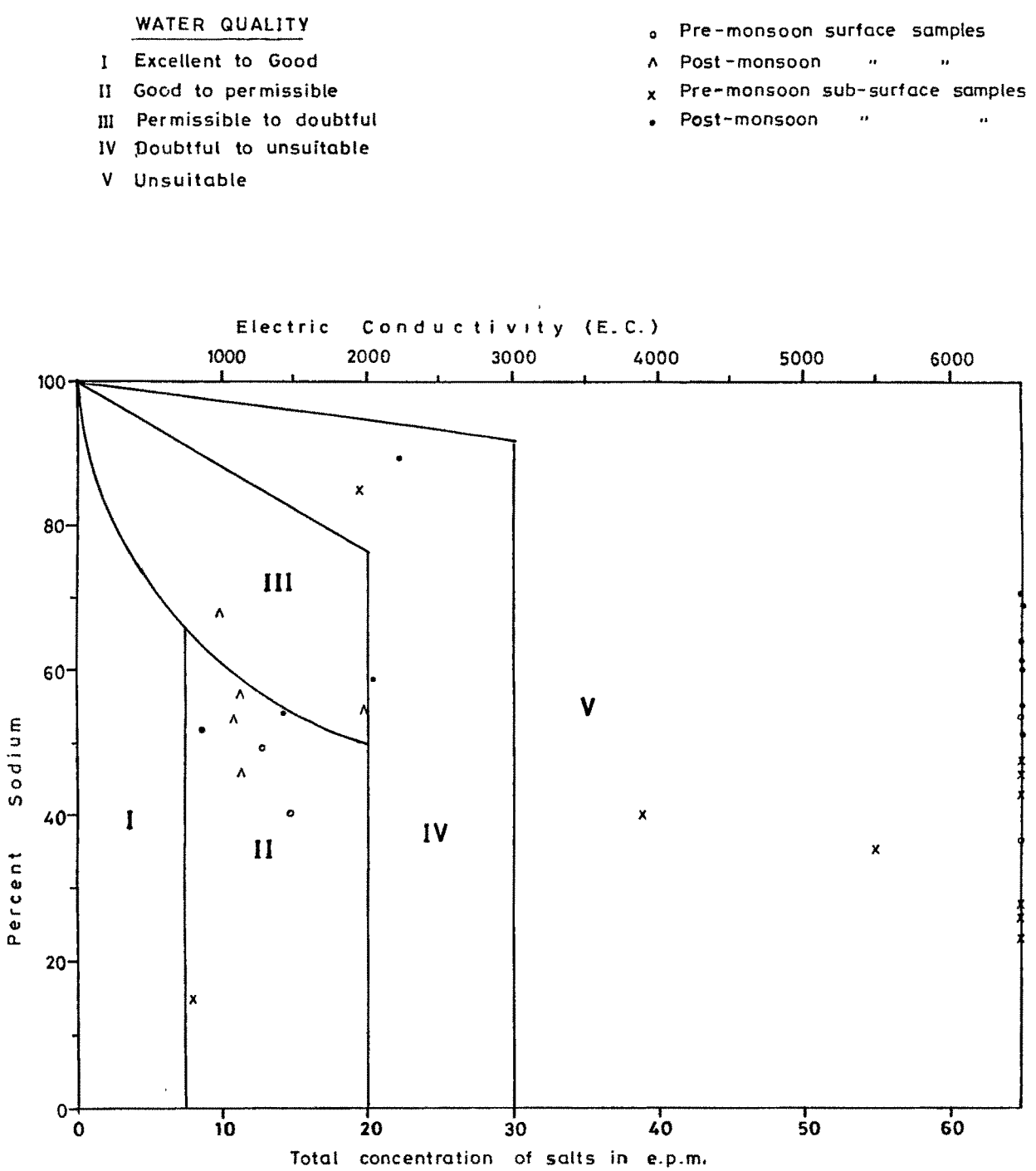

Fig.6.11: SURFACE AND SUB-SURFACE WATER QUALITY (beyond Kutiyana, Coastal areas) FOR IRRIGATION. (After Wilcox, 1955)

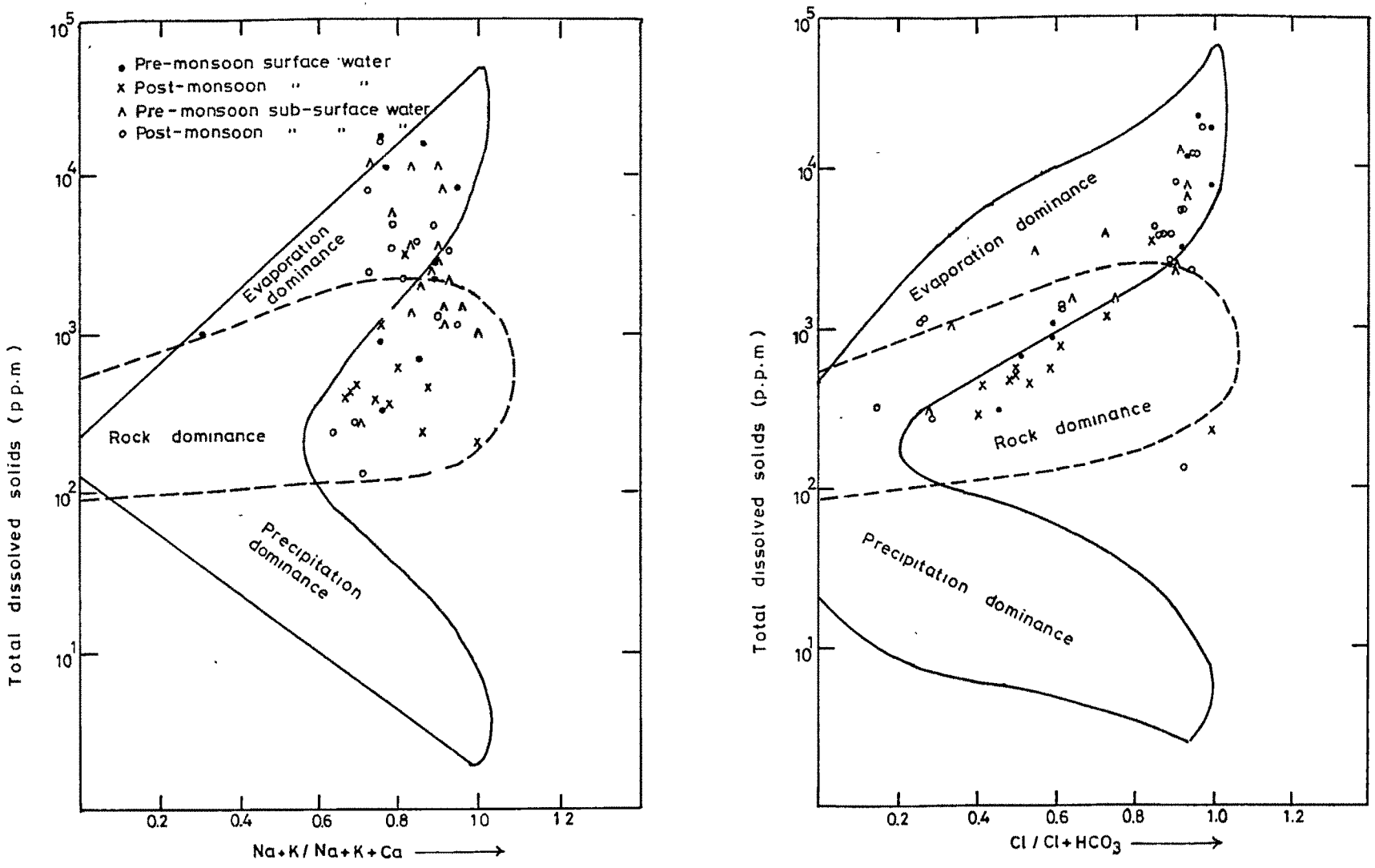

Fig.6.12: Mechanisms controlling water chemistry of coastal areas, Bhadar basin.

doctors of this region have reported number of cases of kidney problem and cancer. It is also confirmed that the throat cancer is very common in the village Dhoraji. The prevalance of the afore-said diseases in the valley could be on account of dye industrial effluents contamination and many other unknown reasons. Hence, a detailed socio-medicine and clinical study is warranted, to understand the real inter-relationship of water quality and diseases.

MITIGATION

The impact of the effluent waste disposal system in the dyeing and printing units at Jetpur has deteriorated the surface (Fig. 6.13) and sub-surface water quality in the Bhadar valley. On account of this, a division bench of Gujarat High Court in its order (1 st August, 1995), directed the closure of all units till no further treatment facilities are made available by August 21, 1995. Upon this, there was a sudden low profile in the activities of these units. But, still today (April, 1997) more than 1500 units are effectively functioning.

It is desireable to have a sustainable development rather than complete closure of industrial units which collectively have an annual turnover of Rs. 150 crore and are employing more than 40,000 people. In the light of the existing scenario in the Bhadar valley, therefore, some mitigatory measures are proposed to reduce the menace caused by the now infamous Jetpur dyeing and printing units.

* The existing effluent treatment plant (ETP) should be again made functional.
* More ETP's should be errected and all waste water from the units should be channelized preferably by closed canals upto the ETP's.
* Monitoting of the canals should be made mandatory.
* Washing units should be earmarked within certain prescribed area and their waste should also be send to the ETP's.
* It is adviseable that after the treatment the water may be recycled.

The above mentioned recomendations are mainly related to the waste water disposal plan. The already contaminated aquifers have to be rectified. For this, discharge followed by recharge of the aquifers are essential, which may be conducted during the pre-monsoon and monsoon times through recharge wells. This flushing method, if repeated, may reduce the effect of the contaminants within the aquifers. The water required for this flusing may be drawn from the Bhadar dam. However, the feasibility of the flushing methods have to be examined in details by considering other requirements of water.

As far as saline water intrusion is concerned it is indeed very difficult to rectify the problem. However, Babushkin (1963) suggested a method of exploitation by coupled wells for prevention of sucking of saline water. Santing (1963) proposed a method by which lateral migration of the interface towards the fresh-water well can be prevented by duplicated symmetrical pumping well system i.e if a well turn saline due to upcomming of the interface, a second pump is installed to tap the

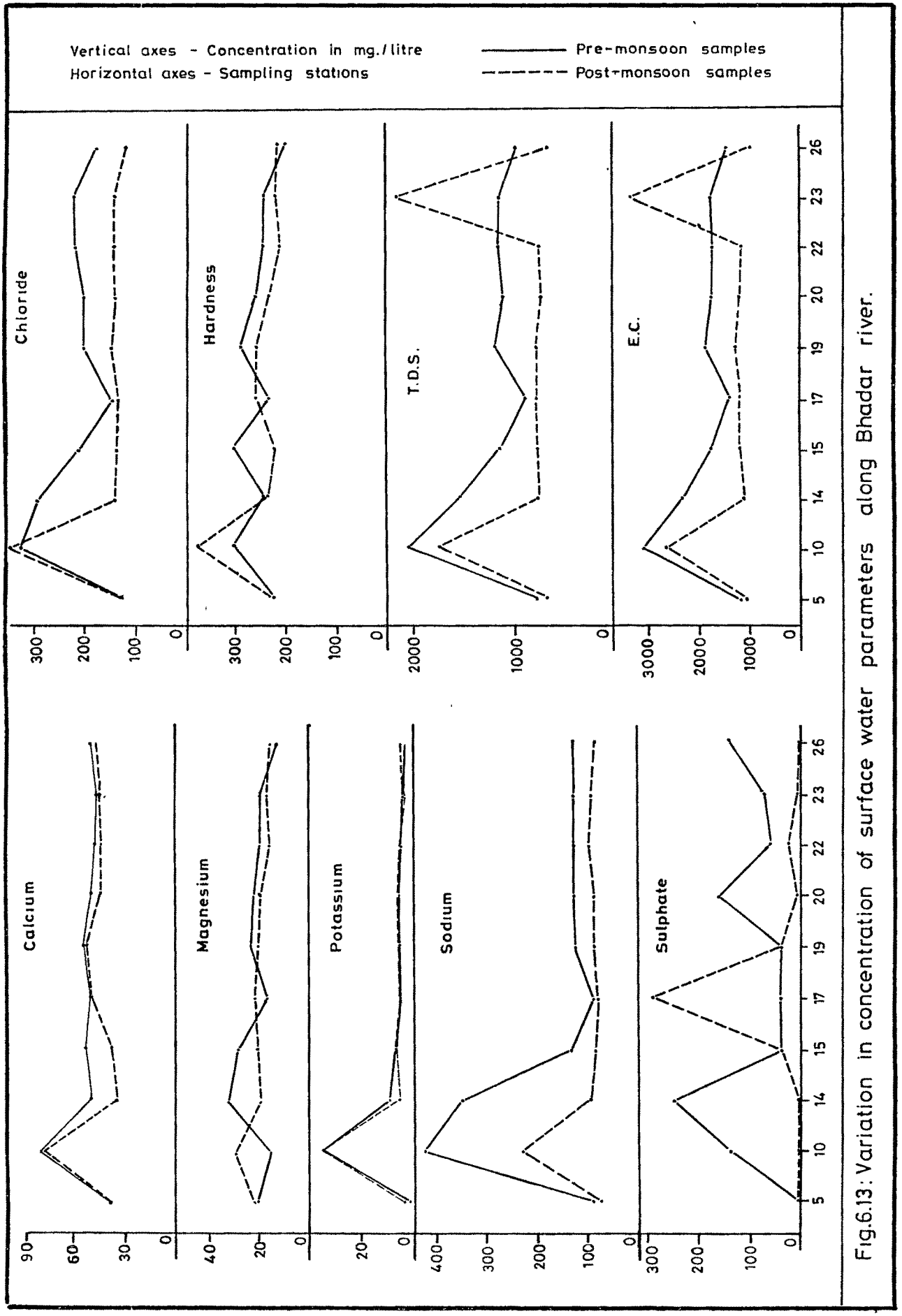

Fig.6.13: Variation in concentration of surface water parameters along Bhadar river.

bottom section of the well. Thus, while the upper pump draws water from the upper fresh-water zone, the lower one pumps the up-conned saline water. Todd (1959) suggested measures to control sea-water intrusion which are as follows:

* Reducing the pumpage, cyclic pumping and re-arrangement of the pumping pattern or redistribution of extraction points in order to restore a seaward hydraulic gradient.
* Artificially recharging the intruded aquifer to maintain proper water levels and hydraulic gradients by eliminating over draft conditions.
* Developing a pumping trough in the region adjoining the coast in order to limit intrusion.
* Creating a fresh water ridge by injection of wells or other artificial recharge methods.
* Constructing artificial sub-surface barriers like dykes or injecting materals such as cement, grout or bentonite mud through boreholes.

However, in the light of the existing socio-economic scenario, the coastal zone problem of salinity in Bhadar basin may be reduced by taking appropriate measures which are:

* No excess of ground water draft
* Erection of tidal regulatory gates in all the inlets and
* Practice of rain harvesting methods.