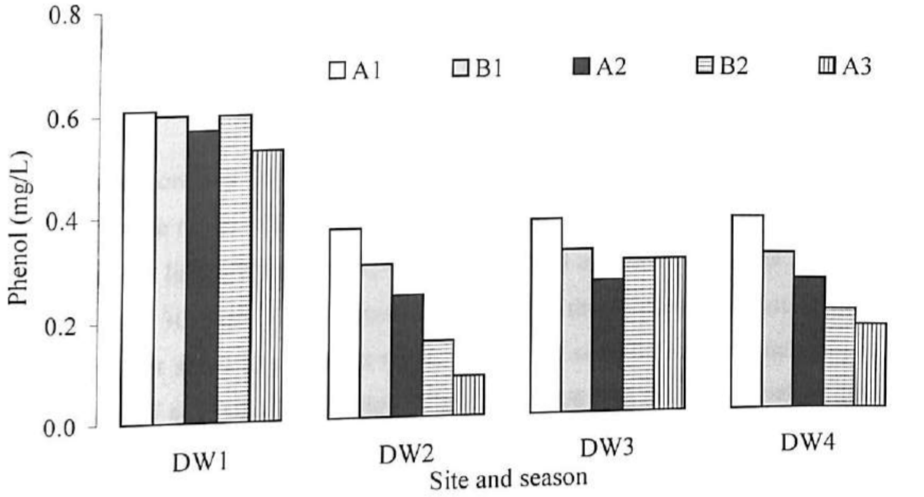

Fig. 3.29. Variation of the mean phenol content for the four drinking water sources with season.

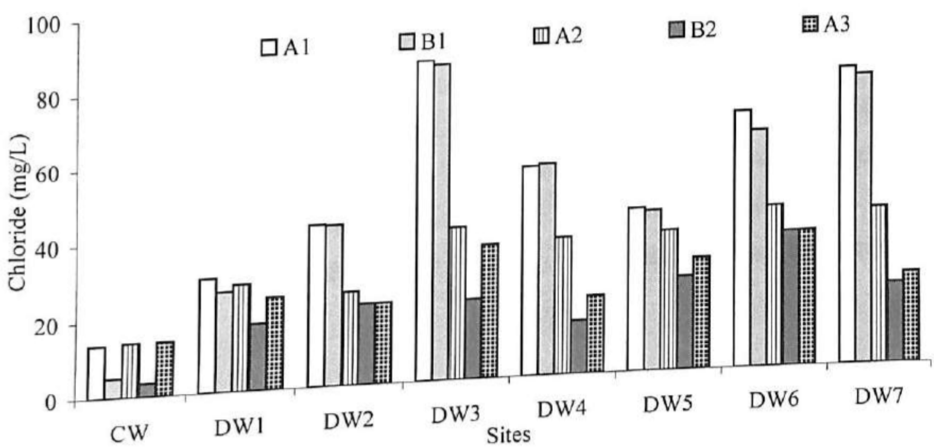

Fig. 3.30. Variation of the mean chloride content of the drinking water sources with season.

3.2.9 Sulphate (SO_4)

Sulphate has been categorized under secondary drinking water standards as it affects taste, associated with respiratory disease and laxative effects (Gawas et al., 2006).

The sulphate contents of the drinking water samples are shown in Table 3.33. The values are in the range of BDL – 48 mg/L and therefore, all the values are much below the permissible limit (WHO, 2004; 400 mg/L). DW3 and DW5 have the same amount of mean value 30 mg/L. The seasonal variation of the sulphate content of the water samples did not show any distinct trend. In the last season (A3), all the samples had least amount of sulphate. The sample DW1 and DW6 had the values below detection level. The "Control" sample had less amount of sulphate (range BDL – 18 mg/L).

The variation pattern of the mean values of the sulphate content with source and season is presented in Fig. 3.31.

3.2.10 Fluoride

The fluoride concentrations in the drinking water samples are given in Table 3.34. The values are in the range of 0.8 - 1.67 mg/L which reveals that some of the sources had fluoride in excess of the WHO guideline value for drinking water quality. The Water Technology Mission of the Government of India has also specified the permissible limit for fluoride in drinking water as 1.0 mg/L, which can be extended to 1.5 mg/L if there is no alternative source in the study area. In this study, the source, DW4, had fluoride above the permissible limit in the seasons, A1 (1.67 mg/L) and B1 (1.66 mg/L). Taking all the seasons, the mean value was 1.45 mg/L – a value touching the maximum permissible limit.

Fluoride is beneficial to certain extent when present in concentration of 0.8 – 1.0 mg/L for calcification of dental enamel especially for the children below 8 years of age (Sudarshan and Reddy, 1991). But it causes dental fluorosis beyond 3 mg/L, if such water is consumed for about 8-10 years (Nawlakhe and Bulusu, 1989). In the present investigation, the consumers should take care with respect to the fluoride content.

Table 3.33. Sulphate (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	12	18	12	11	9	9	18	12	3
DW1	15	25	13	12	BDL	25	BDL	13	9
DW2	21	46	22	38	5	46	5	26	16
DW3	38	47	46	15	3	47	3	30	20
DW4	22	22	20	40	16	40	16	24	9
DW5	40	41	48	21	2	48	2	30	19
DW6	11	20	14	26	BDL	26	BDL	14	10
DW7	32	40	38	15	2	40	2	25	16
Min	11	20	13	12	BDL				
Max	38	47	48	41	40				
Mean	26	32	29	24	10				
SD	12	12	15	11	5				

Table 3. 34. Fluoride content (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.92	1.10	0.97	1.10	1.00	0.92	1.10	1.02	0.08
DW1	0.94	1.02	1.00	0.80	1.01	0.80	1.02	0.95	0.09
DW2	1.35	0.72	1.40	1.10	1.05	0.72	1.40	1.12	0.27
DW3	0.89	0.94	1.00	0.92	0.86	0.86	1.00	0.92	0.05
DW4	1.67	1.66	1.36	1.30	1.28	1.28	1.67	1.45	0.19
DW5	0.81	1.17	1.20	1.20	1.10	0.81	1.20	1.10	0.17
DW6	0.95	1.03	1.09	0.92	1.03	0.92	1.09	1.00	0.07
DW7	1.43	1.12	1.16	1.16	1.17	1.12	1.43	1.21	0.13
Min	0.94	0.72	1.00	0.80	0.86				
Max	1.67	1.66	1.40	1.30	1.28				
Mean	1.15	1.09	1.17	1.06	1.07				
SD	0.32	0.27	0.16	0.17	0.12				

3.2.11. Nitrate (NO_3) – Nitrogen

The nitrate- nitrogen of drinking water samples with the control are given in Table 3.35 with the maximum, the minimum, the mean and the standard deviation for each site and season. The nitrate content in the study area ranges from BDL – 5.9 mg/L. The water sample, DW1, had the highest nitrate content (5.9 mg/L) in the first post-monsoon season (A1). Except DW2, all other six samples (DW 1, 3, 4, 5, 6, and 7) had nitrate – nitrogen below detection level in the third post-monsoon season (A3). The seasonal variation of the sulphate content of the water samples did not show any distinct trend. The "Control" sample had less amount of nitrate (Range BDL – 1.0 mg/L) in all the seasons. In general, all the drinking water samples possessed nitrate below permissible limit of 10 mg/L (as nitrate N, WHO).

3.2.12 Phosphate (PO_4)

The phosphate content of the drinking water samples in the study area was obtained in the range BDL – 0.7 mg/L. The values are presented in Table 3.36. Most of the samples had phosphate more than the USPHS limit (0.1 mg/L). It was observed in the present study that the sample, DW3 (0.13– 0.90 mg/L) and DW6 (0.25– 0.69 mg/L) had the maximum phosphate content in comparison to the other samples. Again in DW5, the values are in the lowest range of BDL – 0.12 mg/L.

The mean values of fluoride, nitrate and phosphate do not show any relationship with one another for the different drinking water sources. This is shown in Fig. 3.32.

3.2.13. Calcium

The amounts of calcium present in the drinking water sources of the study area are presented in Table 3.37. The observed values indicate low content of Ca in the study area. The maximum concentration of Ca was observed at DW3 (44.1 mg/L) and the minimum at DW1 (4.1 mg/L). These values indicate that, all the study samples have Ca less than the ISI permissible limit (75 mg/L). The maximum mean value was obtained at DW3 (36.3 mg/L) and the minimum at DW1 (10.21 mg/L). The health affects of Ca on humans are not conclusively established. Calcium in excess may increase the total

Table 3.35. Nitrate (NO_3) – Nitrogen (mg/L) of the drinking water from the study area

Table 3.35. Nitrate - N (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	1.1	1.0	1.1	1.0	BDL	BDL	1.1	0.8	0.5
DW1	5.9	3.0	5.1	2.0	BDL	BDL	5.9	3.2	2.4
DW2	1.3	1.1	0.7	1.0	0.6	0.6	1.3	0.9	0.3
DW3	4.6	2.3	4.5	0.7	BDL	BDL	4.6	2.4	2.1
DW4	3.1	3.1	2.5	0.0	BDL	BDL	3.1	1.7	1.6
DW5	1.7	1.5	0.9	2.1	BDL	BDL	2.1	1.3	0.8
DW6	2.4	1.7	1.5	BDL	BDL	BDL	2.4	1.1	1.1
DW7	0.4	0.6	0.3	BDL	BDL	BDL	0.6	0.3	0.2
Min	0.4	0.6	0.3	BDL	BDL				
Max	5.9	3.1	5.1	2.1	0.6				
Mean	2.8	1.9	2.2	0.8	0.3				
SD	1.9	0.9	1.8	0.9	0.2				

Table 3.36. Phosphate (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	BDL	0.10	BDL	0.08	0.02	BDL	0.10	0.04	0.05
DW1	0.01	0.80	0.02	0.03	BDL	BDL	0.80	0.17	0.35
DW2	0.11	0.11	0.18	0.25	0.10	0.10	0.25	0.15	0.06
DW3	0.36	0.73	0.44	0.90	0.13	0.13	0.90	0.51	0.31
DW4	0.03	0.16	0.02	0.43	0.10	0.02	0.43	0.15	0.17
DW5	BDL	0.12	0.01	0.03	0.05	BDL	0.12	0.04	0.05
DW6	0.51	0.69	0.41	0.30	0.25	0.25	0.69	0.43	0.18
DW7	0.02	0.53	0.35	0.25	0.20	0.02	0.53	0.27	0.19
Min	BDL	0.12	0.01	0.03	BDL				
Max	0.51	0.73	0.44	0.43	0.25				
Mean	0.17	0.45	0.20	0.30	0.14				
SD	0.20	0.31	0.19	0.29	0.09				

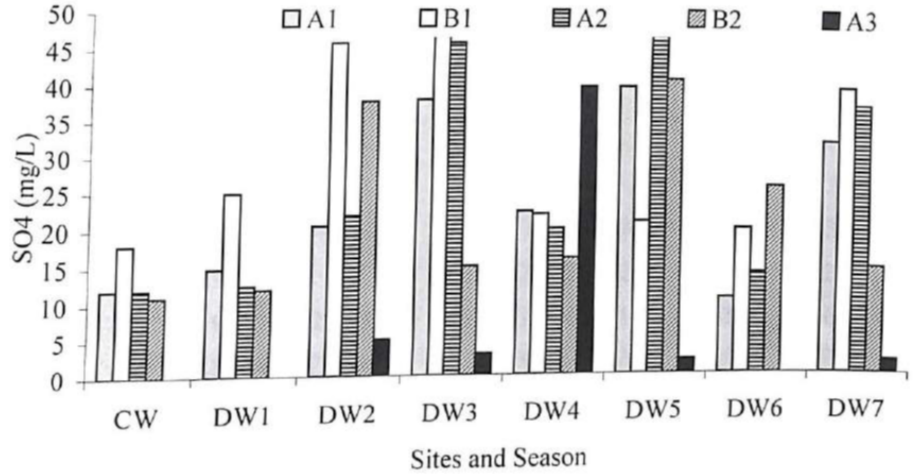

Fig. 3.31. Variation of the mean sulphate content of the drinking water sources with season.

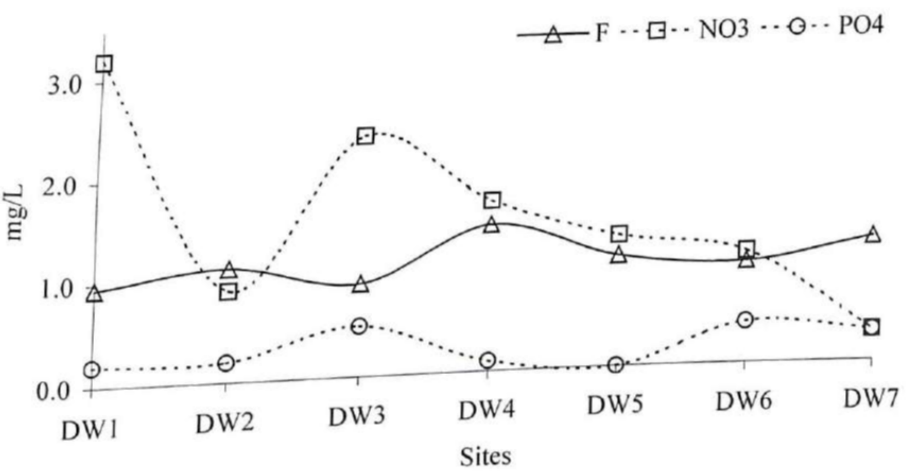

Fig. 3.32. Variation of the mean fluoride, nitrate-N and phosphate contents of the drinking water sources.

Table 3.37. Ca (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	8.01	7.62	7.76	6.96	9.75	6.96	9.75	8.02	1.04
DW1	5.40	12.65	4.10	10.40	18.50	4.10	18.50	10.21	5.81
DW2	28.52	24.04	28.05	12.02	19.20	12.02	28.52	22.37	6.89
DW3	43.94	44.1	41.00	30.03	22.40	22.40	44.1	36.29	9.66
DW4	13.94	12.02	14.74	11.68	15.80	11.68	15.80	13.64	1.76
DW5	16.52	12.02	16.03	14.21	17.60	12.02	17.60	15.28	2.19
DW6	27.84	16.03	31.23	18.85	19.20	16.03	31.23	22.63	6.53
DW7	30.50	28.05	36.07	26.74	25.60	25.60	36.07	29.39	4.15
Min	5.40	12.02	4.10	10.40	15.80				
Max	43.94	44.08	36.07	30.03	25.60				
Mean	23.80	21.30	24.50	17.70	19.80				
SD	13.07	12.01	13.58	8.19	4.65				

Table 3.38. Mg (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	7.64	6.54	6.98	5.56	7.46	5.56	7.64	6.84	0.83
DW1	3.60	8.74	2.60	8.40	12.10	2.60	12.10	7.09	3.93
DW2	18.54	16.78	19.26	10.70	15.59	10.70	19.26	16.17	3.38
DW3	20.60	19.05	21.37	26.76	18.74	18.74	26.76	21.30	3.24
DW4	9.60	7.50	8.50	6.52	8.61	6.52	9.60	8.15	1.17
DW5	12.07	5.90	12.86	7.48	9.50	5.90	12.86	9.56	2.95
DW6	18.96	8.58	24.92	12.62	14.64	8.58	24.92	15.94	6.26
DW7	19.74	14.02	25.38	13.42	16.84	13.42	25.38	17.88	4.89
Min	3.60	5.90	2.60	6.52	8.61				
Max	20.60	19.05	25.38	26.76	18.74				
Mean	14.70	11.50	16.40	12.30	13.70				
SD	6.47	5.02	8.70	6.81	4.14				

hardness of water preventing lather with soap and increases the boiling point of water (Mohan et al., 2000)

3.2.14 Magnesium

The magnesium contents of drinking water from the study area are in the range of 2.6 – 26.8 mg/L, all the values are below the highest desirable limit of 30 mg/L and the maximum permissible limit of 100 mg/L (Lohani, 2005). The values are presented in Table 3.38. The sample DW3 (mean 21.3 mg/L) had comparatively more Mg content than the other samples, whereas DW1 had the least content (mean 7.09 mg/L). The seasonal variation was not uniform. Higher concentration of Mg may be cathartic and diuretic for initial user but tolerance may be developed in short time (Kumaresan and Bagavathiraj, 1996).

A comparison of the all season mean contents of Ca, Mg and total hardness of the drinking water samples is shown in Fig. 3.33, which shows that in almost all the sites (particularly in DW3), the total hardness is much more than the total contents of Ca and Mg – indicating contributions from other sources to the hardness content.

3.2.15 Sodium (Na)

The values of sodium present in the drinking water samples are given in Table 3.39.The data also reflect the minimum, the maximum, the mean and the standard deviation for each site and for each season. In the present study, the sodium content for all the samples was in the range of 5.8 – 63 mg/L. The "Control" sample had very low value of Na (mean 5.8 mg/L).

All the samples in all the seasons had the values of Na below the permissible limit (WHO, 200 mg/L). No distinct seasonal variation could be observed. The sample DW3 (range 24.2 – 63.0 mg/L) had comparatively more Na content than the other samples in all the seasons. More content of sodium in drinking water gives an undesirable "salty" taste and this is considered harmful for the people suffering from the high blood pressure and heart diseases.

3.2.16 Potassium (K)

The potassium contents of drinking water in the study area are given in Table 3.40. The results reflect that the potassium concentration (range 2.2 – 12.8 mg/L) of the study samples was relatively lower than those of sodium. But it was reverse in the case of the "Control" sample (range 10.2 – 11.2 mg/L). The sample DW4 (mean 10.4 mg/L) had more K content and the sample DW1 (mean 3.5 mg/L) had the least value. The seasonal variation was not uniform.

The water contained much more sodium than potassium. This is more clearly seen from a comparison of the all season mean contents of sodium and potassium for all the drinking water sources as shown in Fig. 3.34.

3.2.17 Trace Metals

(a) **Aluminium (Al).** Aluminium is one of the most available elements present in soil. Al concentration in the present study was obtained in the range of 1.85 – 9.6 mg/L (Table 3.41). For all the samples in all the measurements, the values exceed the WHO guideline value (2004) of 0.2 mg/L. The control values, though within the limit, are in the higher side of the limit. The maximum value was obtained at DW3 (9.6 mg/L) in A1 batch and the minimum at DW4 (1.85 mg/L) in B2 batch.

(b) **Arsenic (As).** The arsenic content in the drinking water samples of the study area was from BDL – 0.008 μg/L (Table 3.42). The values indicate less amount of As in the drinking water of the study area and the values were below the WHO provisional guideline value of 0.01mg/L. As was obtained below detection level in the "Control" sample and in DW 4, 5 and 7.

(c) **Cadmium (Cd).** Cadmium obtained in study area was in the range of 0.2 – 0.92 mg/L (Table 3.43). All the samples have high content of Cd in all the seasons (WHO guideline value, 2004, 0.003 mg/L) The water sources may be contaminated from the leaching of soil containing the Mill effluent loaded with pigments. The pre-monsoon values were more than the post-monsoon ones. Large amount of Cd containing water taken for a long period causes serious illness in humans. The most

Table 3.39. Na (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	5.9	6.3	5.6	5.8	5.2	5.2	6.3	5.8	0.4
DW1	16.9	10.7	9.4	9.6	5.8	5.8	16.9	10.5	4.0
DW2	53.5	19.5	14.2	10.5	7.7	7.7	53.5	21.1	18.7
DW3	63.0	55.6	41.7	60.8	24.2	24.2	63.0	49.1	16.2
DW4	41.8	34.6	30.8	31.6	24.1	24.1	41.8	32.6	6.4
DW5	30.9	24.2	23.1	23.9	25.0	23.1	30.9	25.4	3.1
DW6	22.0	16.9	18.9	14.7	6.9	6.9	22.0	15.9	5.7
DW7	33.6	26.5	19.3	20.1	11.0	11.0	33.6	22.1	8.5
Min	16.9	10.7	9.4	9.6	5.8				
Max	53.5	55.6	41.7	60.8	25.0				
Mean	37.4	26.9	22.5	24.5	15.0				
SD	19.0	15.5	11.7	17.8	9.0				

Table 3.40. Potassium (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	11.2	10.2	10.4	10.5	10.3	10.2	11.2	10.5	0.4
DW1	3.9	3.7	2.2	5.0	2.8	2.2	5.0	3.5	1.1
DW2	4.1	3.8	3.9	9.7	3.7	3.7	9.7	5.0	2.6
DW3	5.2	6.6	4.8	3.8	5.0	3.8	6.6	5.1	1.0
DW4	8.6	9.3	12.8	12.6	8.9	8.6	12.8	10.4	2.1
DW5	3.8	4.2	3.6	5.1	3.7	3.6	5.1	4.1	0.6
DW6	5.3	6.4	6.1	2.4	5.9	2.4	6.4	5.2	1.6
DW7	6.8	10.2	7.1	9.5	10.4	6.8	10.4	8.8	1.7
Min	3.8	3.7	2.2	2.4	2.8				
Max	8.6	10.2	12.8	12.6	10.4				
Mean	5.4	6.3	5.8	6.9	5.8				
SD	2.6	2.8	3.6	3.7	3.1				

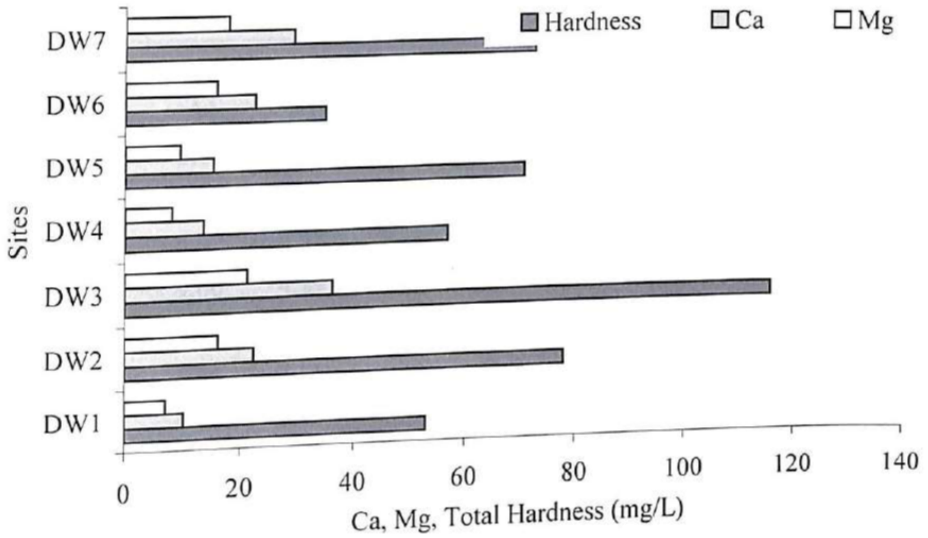

Fig. 3.33. Variation of mean values of calcium, magnesium and total hardness for the drinking water sources.

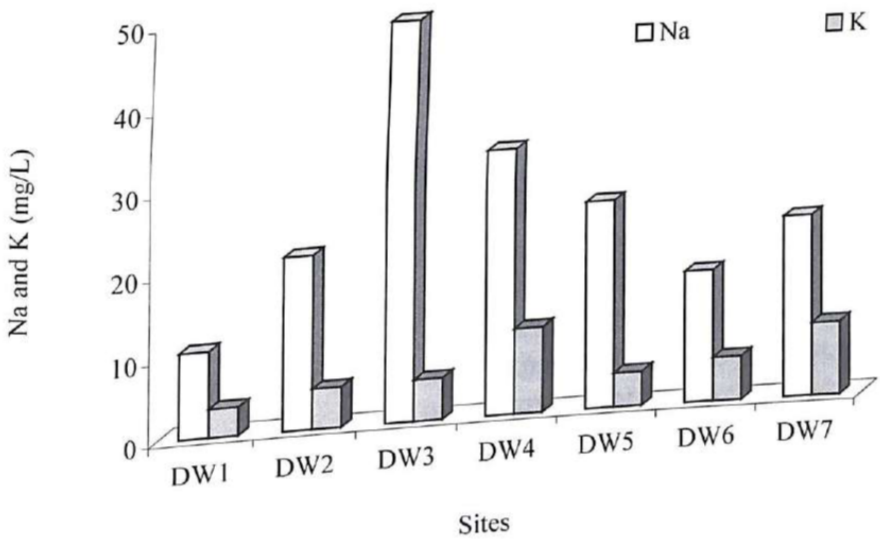

Fig. 3.34. Variation of all season mean values of sodium and potassium for the drinking water sources.

Table 3.41. Al (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.13	0.23	0.17	0.21	0.18	0.13	0.23	0.18	0.04
DW1	4.84	6.32	3.18	4.96	5.80	3.18	6.32	5.02	1.20
DW2	5.07	4.48	3.29	3.85	5.50	3.29	5.50	4.44	0.89
DW3	9.60	4.29	5.79	3.11	7.60	3.11	9.60	6.08	2.59
DW4	4.02	4.31	4.19	1.85	2.60	1.85	4.31	3.39	1.10
DW5	4.85	7.76	4.24	2.49	3.80	2.49	7.76	4.63	1.95
DW6	4.22	3.12	3.62	3.87	4.20	3.12	4.22	3.81	0.46
DW7	4.27	3.41	3.18	4.01	6.90	3.18	6.90	4.35	1.49
Min	4.02	3.12	3.18	1.85	2.60				
Max	9.60	7.76	5.79	4.96	7.60				
Mean	5.30	4.80	3.90	3.40	5.20				
SD	2.56	2.23	1.59	1.50	2.42				

Table 3.42. As (μg/mg) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DW1	0.0052	0.0048	0.0046	0.005	0.0048	0.0046	0.0052	0.00488	0.0003
DW2	0.0078	0.008	0.0075	0.007	0.007	0.007	0.008	0.00746	0.0005
DW3	0.008	0.006	0.004	0.004	0.004	0.004	0.008	0.0052	0.0018
DW4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DW5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DW6	0.006	0.0054	0.006	0.006	0.005	0.005	0.006	0.00568	0.00046
DW7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Min	BDL	BDL	BDL	BDL	BDL				
Max	0.008	0.008	0.0075	0.007	0.007				
Mean	0.0069	0.0061	0.0055	0.0055	0.0052				
SD	0.0014	0.0014	0.0016	0.0013	0.0013				

common abnormality from chronic Cd exposure involves renal toxicity characterized by prokinura. Other disturbances of renal tubular function include glycosuria disease in the urine concentrating ability and abnormalities in renal processing of uric acid, calcium and phosphorus (Tylor, 1961).

(d) **Chromium (Cr).** The chromium concentrations in the drinking water samples are given in Table 3.44. All the samples have more amount of Cr than the guideline value of 0.05 mg/L (WHO, 2004) in all the seasons. The highest value was obtained at DW2 (2.71 mg/L) in A2 batch and the lowest at DW6 (0.21 mg/L) in A1batch. In the study, all the samples had the maximum value in A2 batch. The seasonal variation was not uniform.

(e) **Copper (Cu).** The copper contents in the study area are given in Table 3.45. The highest value was obtained at DW1 (0.962 mg/L) in B1 season and the lowest at DW2 (0.001 mg/L) in A2 season. All the values including those of the Control are within the WHO guideline value (2004) of 2 mg/L.

(f) **Iron (Fe).** The concentration of Fe in the drinking water samples ranges from 0.36 to 7.36 mg/L (Table 3.46). The maximum value was obtained in the pre-monsoon season and the minimum in the post-monsoon season for all the samples. This indicates rains and storm water runoff adding to the iron input of all the sources. All the samples for all the seasons have much more Fe content than the maximum permissible limit of 0.3 mg/L (WHO, 1984.) HPS thesis). Another reason for high iron content in the drinking water may be because of the soil origin as the Assam soil is rich in iron.

(g) **Mercury (Hg).** In the study area, Hg could be measured only at DW3, in the first three batches (A1: 0.004 mg/L, B1: 0.0006 mg/L and A2: 0.0001 mg/L). In the rest of the seasons (B2 and A3), the values obtained were below detection level. The "Control" sample also did not record any mercury content.

Table 3.43. Cd (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	0.002	A2	B2	A3				
CW	0.002	0.240	0.002	0.002	0.003	0.002	0.003	0.002	0.001
DW1	0.320	0.250	0.270	0.400	0.240	0.240	0.400	0.326	0.073
DW2	0.280	0.250	0.250	0.400	0.310	0.250	0.440	0.336	0.081
DW3	0.280	0.260	0.250	0.400	0.250	0.250	0.420	0.320	0.083
DW4	0.280	0.200	0.260	0.350	0.260	0.260	0.420	0.314	0.070
DW5	0.200	0.250	0.230	0.400	0.280	0.200	0.400	0.302	0.094
DW6	0.320	0.210	0.290	0.500	0.250	0.250	0.700	0.412	0.187
DW7	0.300	0.290	0.240	0.860	0.210	0.210	0.920	0.506	0.353
Min	0.200	0.200	0.230	0.350	0.210				
Max	0.320	0.260	0.290	0.860	0.310				
Mean	0.280	0.092	0.260	0.480	0.260				
SD	0.106	Min	0.092	0.233	0.094				

Table 3.44 (IV) Chromium (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	BDL	0.056	0.048	0.061	BDL	BDL	0.061	0.033	0.030
DW1	0.296	0.790	1.659	0.647	0.301	0.296	1.659	0.739	0.558
DW2	0.401	0.632	2.711	0.593	0.332	0.332	2.711	0.934	1.001
DW3	0.432	0.826	1.253	0.619	0.380	0.380	1.253	0.702	0.354
DW4	0.396	0.564	2.642	0.752	0.355	0.355	2.642	0.942	0.963
DW5	0.367	0.741	1.609	0.624	0.322	0.322	1.609	0.733	0.520
DW6	0.210	0.920	1.684	0.687	0.360	0.210	1.684	0.772	0.580
DW7	0.483	0.770	1.308	0.725	0.446	0.446	1.308	0.746	0.345
Min	0.21	0.564	1.253	0.593	0.301				
Max	0.483	0.92	2.7	0.752	0.446				
Mean	0.38	0.75	1.8	0.67	0.35				
SD	0.155	0.269	0.84	0.22	0.134				

Table 3.45.Cu (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.052	0.059	0.055	0.084	BDL	BDL	0.084	0.050	0.031
DW1	0.003	0.962	0.462	0.812	0.240	0.003	0.962	0.496	0.396
DW2	0.001	0.930	0.851	0.731	0.803	0.001	0.930	0.663	0.377
DW3	0.002	0.901	0.078	0.815	0.066	0.002	0.901	0.372	0.445
DW4	0.213	0.891	0.149	0.523	0.110	0.110	0.891	0.377	0.330
DW5	0.012	0.920	0.002	0.881	0.056	0.002	0.920	0.374	0.481
DW6	0.160	0.883	0.110	0.897	0.607	0.110	0.897	0.531	0.380
DW7	0.001	0.765	0.563	0.821	0.214	0.001	0.821	0.473	0.355
Min	0.001	0.765	0.002	0.523	0.056				
Max	0.213	0.962	0.851	0.897	0.803				
Mean	0.056	0.890	0.300	0.800	0.310				
SD	0.084	0.300	0.306	0.119	0.290				

Table 3.46. Fe (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.65	0.52	0.76	0.63	0.60	0.52	0.76	0.63	0.09
DW1	0.63	7.36	1.10	6.22	5.40	0.63	7.36	4.14	3.08
DW2	1.04	6.32	2.06	6.27	6.10	1.04	6.32	4.36	2.59
DW3	0.43	6.60	1.73	5.05	5.46	0.43	6.60	3.85	2.64
DW4	1.99	5.32	2.02	5.53	5.16	1.99	5.53	4.00	1.83
DW5	0.36	4.96	2.41	5.58	3.77	0.36	5.58	3.42	2.09
DW6	0.59	5.03	1.65	5.15	4.80	0.59	5.15	3.44	2.16
DW7	1.08	5.81	1.14	6.33	5.70	1.08	6.33	4.01	2.66
Min	0.36	4.96	1.10	5.05	3.77				
Max	1.99	7.36	2.41	6.33	6.10				
Mean	0.87	5.90	1.73	5.70	5.20				
SD	0.53	2.08	0.56	1.87	1.77				

(h) **Manganese (Mn).** Mn is one of the elements present in drinking water with iron in large amount. Mn contents in the drinking water samples are presented in Table 3.47. All the samples in B1, A2 and B2 batches had values below the WHO guideline value (2004) of 0.4 mg/L but in other two seasons, for some samples, the values exceed the guideline value. Seasonal variation was not distinct. Excessive Mn content in the drinking water imparts unpleasant taste and the metal deposit causes stain in clothes and utensils.

(i) **Nickel (Ni).** Ni concentration in the present study was obtained in the range of 0.017 – 0.480 mg/L (Table 3.48) that indicates more amount of nickel in the drinking water from the study area. WHO (2004) guideline value (2004) for Ni in drinking water is 0.02 mg/L. In A1 and A2 batches , the values were observed less for all the samples. The maximum value was obtained at A3 batch except DW1 for the all the samples. The sample DW6 had the maximum amount of Ni (0.48 mg/L) in A3 batch whereas DW7 possessed the minimum (0.04 mg/L) in A1 batch. Seasonal variation was not observed.

(j) **Lead (Pb).** Lead is one of the hazardous metals present in the drinking water sources. In the study area, Pb was obtained in the range of BDL – 0.72 mg/L (Table 3.49). Except in A3 batch, in other measurements, Pb obtained in water samples exceeds WHO guideline value (2004) of 0.01 mg/L. The sample DW2 had comparatively more Pb content than the other samples. DW2 is the only tube well source of the present study. Water of this tube well is used by the villagers for many years. Old soldering in pipes of tube well and leakage in the piping system can enhance Pb content in this source. Water seepage contaminates drinking water system to a large extent. The appreciable concentration of this metal in many of the sources should be of concern.

(k) **Zinc (Zn).** The concentration of Zn in water samples was obtained within the range of 0.08– 1.32 mg/L (Table 3.50). The maximum value was obtained at DW6 (1.32 mg/L) and the minimum at DW7 (0.08 mg/L). Seasonal variation was not observed. All the values are within the WHO (1984) permissible limit of 5 mg/L.

Table 3.47. Mn (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.08	0.05	0.05	0.08	0.01	0.01	0.08	0.05	0.03
DW1	0.10	0.08	0.08	0.06	0.13	0.06	0.13	0.09	0.03
DW2	0.43	0.08	0.08	0.06	0.42	0.06	0.43	0.21	0.19
DW3	0.70	0.08	0.08	0.07	0.96	0.07	0.96	0.38	0.42
DW4	0.39	0.08	0.08	0.07	0.06	0.06	0.39	0.14	0.14
DW5	0.10	0.07	0.07	0.06	0.36	0.06	0.36	0.13	0.13
DW6	0.05	0.08	0.08	0.07	0.07	0.05	0.08	0.07	0.01
DW7	0.19	0.09	0.09	0.07	0.30	0.07	0.30	0.15	0.10
Min	0.39	0.07	0.07	0.06	0.07				
Max	0.70	0.09	0.09	0.07	0.96				
Mean	0.28	0.08	0.08	0.07	0.33				
SD	0.23	0.01	0.01	0.01	0.31				

Table 3.48 Ni (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	BDL	0.1	BDL	0.2	0.2	BDL	0.2	0.1	0.1
DW1	0.1	0.2	0.1	0.2	BDL	BDL	0.2	0.1	0.1
DW2	0.1	0.2	BDL	0.2	0.2	BDL	0.2	0.1	0.1
DW3	0.1	BDL	0.1	0.1	0.3	BDL	0.3	0.1	0.1
DW4	0.1	0.3	0.1	0.2	0.3	0.1	0.3	0.2	0.1
DW5	0.1	0.2	0.1	BDL	0.3	BDL	0.3	0.1	0.1
DW6	0.1	0.2	0.1	0.2	0.5	0.1	0.5	0.2	0.2
DW7	BDL	0.2	BDL	0.1	0.1	BDL	0.1	0.1	0.1
Min	BDL	BDL	BDL	BDL	BDL				
Max	0.1	0.3	0.1	0.2	0.5				
Mean	0.1	0.2	0.1	0.2	0.2				
SD	0.0	0.1	0.0	0.1	0.2				

Table 3.49. Pb (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	BDL	BDL	0.02	0.01	BDL	BDL	0.02	0.006	0.009
DW1	0.12	0.23	0.19	0.09	BDL	BDL	0.23	0.126	0.090
DW2	0.72	0.56	0.49	0.46	0.42	0.42	0.72	0.530	0.118
DW3	0.36	0.43	0.42	0.29	0.23	0.23	0.43	0.346	0.086
DW4	0.11	0.21	0.13	0.18	BDL	BDL	0.21	0.126	0.081
DW5	0.18	0.24	0.21	0.11	0.07	0.07	0.24	0.162	0.070
DW6	0.32	0.34	0.25	0.09	BDL	BDL	0.34	0.200	0.149
DW7	0.14	0.16	0.2	0.1	0.13	0.1	0.2	0.146	0.037
Min	0.11	0.16	0.13	0.09	BDL				
Max	0.72	0.56	0.49	0.46	0.42				
Mean	0.28	0.32	0.27	0.19	0.21				
SD	0.225	0.172	0.151	0.144	0.152				

Table 3.50. Zn (mg/L) in the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.06	0.49	0.07	0.29	0.15	0.06	0.49	0.21	0.18
DW1	0.61	0.31	0.50	0.33	0.12	0.12	0.61	0.37	0.19
DW2	0.53	0.51	0.43	0.91	0.61	0.43	0.91	0.60	0.19
DW3	0.39	0.48	0.34	0.39	0.11	0.11	0.48	0.34	0.14
DW4	0.37	0.40	0.39	0.67	0.30	0.30	0.67	0.43	0.14
DW5	0.42	0.40	0.38	0.40	0.21	0.21	0.42	0.36	0.09
DW6	0.50	0.84	1.32	0.38	0.21	0.21	1.32	0.65	0.44
DW7	0.42	0.72	0.38	0.50	0.08	0.08	0.72	0.42	0.23
Min	0.37	0.31	0.38	0.33	0.08				
Max	0.61	0.84	1.32	0.91	0.60				
Mean	0.46	0.50	0.56	0.50	0.23				
SD	0.16	0.18	0.36	0.21	0.17				

It is seen from the results that the water samples collected from the drinking water sources in the study area contained appreciable amount of the metals Al, Fe, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn. A comparative evaluation of their all season mean values is presented in Fig. 3.35 (Cr, Cu, Zn), Fig. 3.36 (Al, Fe), and Fig. 3.37 (Cd, Mn, Ni, Pb). In particular, Cr-content was very high (Fig. 3.35) and all the mean values were above the permissible limit for drinking water. Similarly worrying is the presence of considerable amounts of the toxic metals Cd, Ni and Pb in all the drinking water sources (Fig. 3.37). The mean values of these three metals exceeded the permissible limits in most cases. Cd and Pb showed large presence in some of the samples making the water unfit for human consumption.

The mean Al-content exceeded the mean Fe-content in all the samples excepting the sample DW4 (Fig. 3.35). In any case, the iron-content was very high in all the sources making the water unsuitable for drinking and use for laundering, etc.

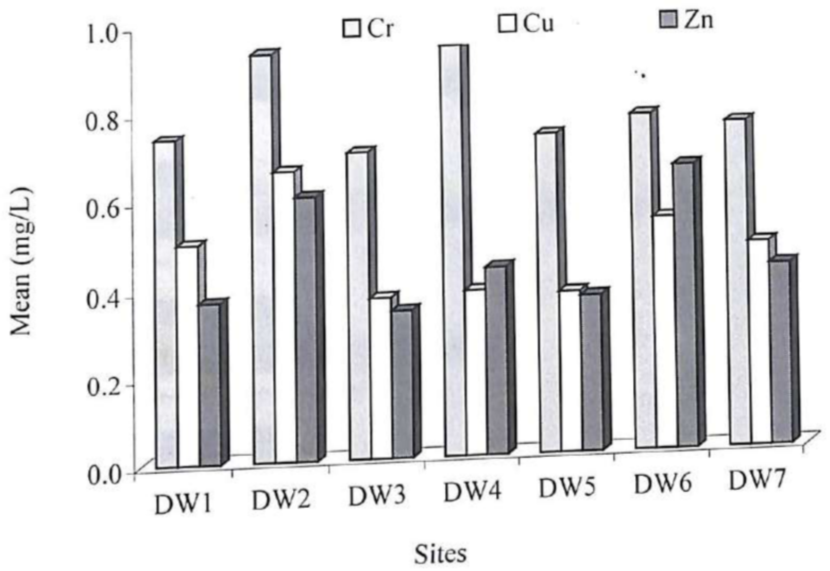

Fig. 3.35. Variation of all season mean values of chromium, copper and zinc for the drinking water sources.

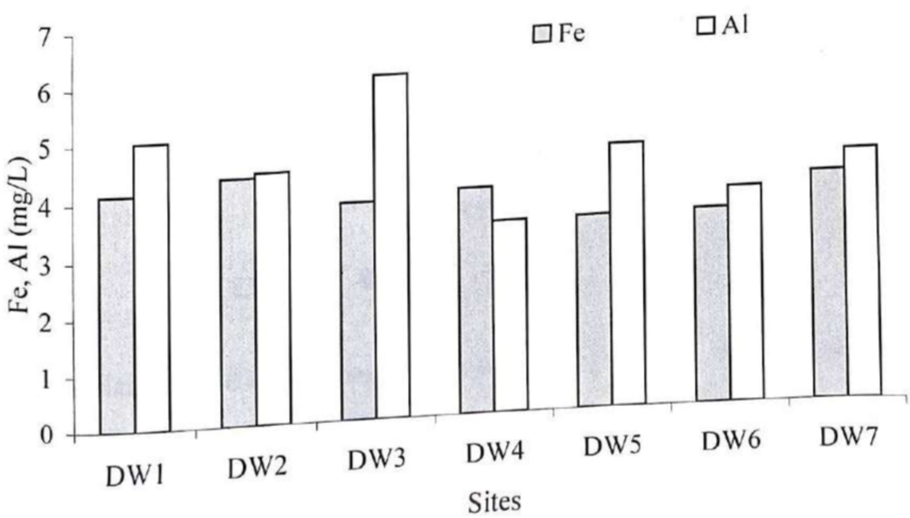

Fig. 3.36. Variation of all season mean values of aluminium and iron for the drinking water sources.

The site, SW1 had the least variation of values (Std Dev 0.29) among all the seasons whereas the site, SW4 had the maximum variation (Std Dev 1.71). For all the seasons, the maximum mean value was obtained at A2 season and the minimum at B2 season.

The ranges of values for pH are shown in Fig. 3.38 which indicates that the surface water pH did not vary by the same extent at the different sites, the variation was the least at the site, SW1, but was very large at SW4, SW5 and SW8. The surface water sources thus had different buffering capacities to inflow of mostly acidic effluent.

3.3.2. Electrical Conductivity (EC)

Most of the water samples in the study area had high electrical conductivity in the range of 0.12 – 3.01 mS/cm (Table 3.52). The sites did not show uniform variation with respect to distance and season. The maximum value was obtained at SW4 (3.01 mS/cm) in B1 season and the minimum at SW5 (0.12 mS/cm) in B2 season. Among all the eight sites, SW4 had the highest mean value (1.50 mS/cm) whereas SW 7 had the minimum (0.72 mS/cm). The high values of EC indicate that more ionic matter was present in the surface water. SW4 had the maximum variation of values (Std Dev 1.23) as this site was very near to the Mill, the least variation was obtained for SW2 (Std Dev 0.2).

The electrical conductivities of the surface did not show any regular trend of variation with the seasons for any of the sites. This is shown in Fig. 3.39.

3.3.3 Total Alkalinity

The alkalinity values for all the water samples and for all the seasons were obtained in the range of 61 mg/L at SW6 to 1250 mg/L at SW3 and SW4 (Table 3.53). The high value of alkalinity was mainly due to the presence of carbonates and bicarbonates in the surface water. No seasonal or distance variation was observed for any site. The high values of alkalinity are indicative of eutrophic growth in the water body. The least of the mean values (179 mg/L) was obtained for all the samples for A2 batch whereas the batches, A1 and B1, had got the maximum (781 mg/L) of the mean values. The site, SW3 had the maximum variation while the site, SW1 had the minimum variation in all the seasons. The variation pattern for the sites is shown in Fig. 3.40.

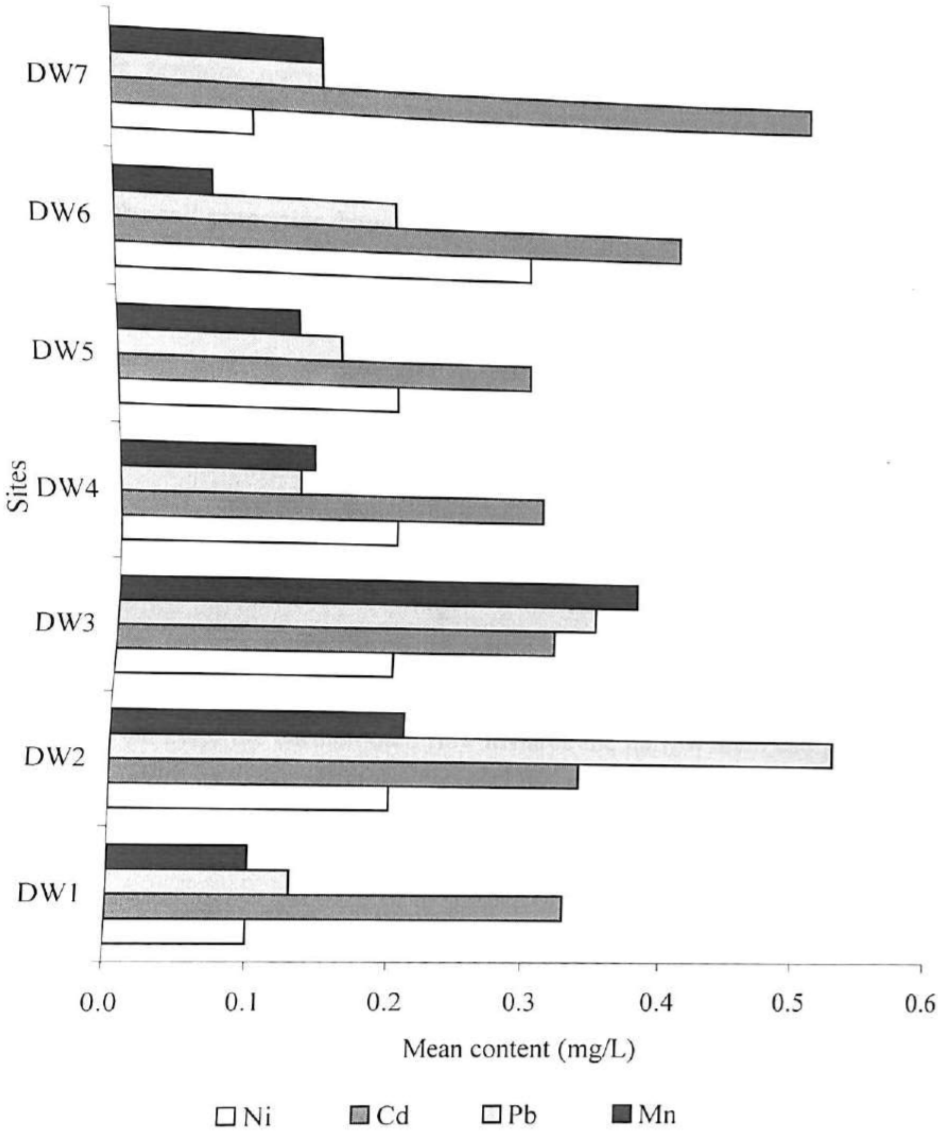

Fig. 3.37. Variation of all season mean values of nickel, cadmium, lead and manganese contents for the drinking water sources.

3.3 Surface Water quality

The wastewater contains nutrients which enhance the growth of the crop plants. Industrial wastewaters are being used for irrigation in some areas due to water scarcity (Girisha et al., 2006). Continuous use of water containing a large amount of soluble salts may alter the soil properties depending upon the quality and quantity of salt present and affect the crop growth (Aishwath and Pal, 2000). Therefore, the knowledge of the quality of water and its nutrient content is essential for judging the suitability of the same for irrigation and its contribution to plant nutrient supply. The nature and concentration of various ions particularly the proportions of the divalent and monovalent cations are important for the water quality (Ghose et al., 1983).

The only source of surface water available in the study area comes from the mill campus through a kaccha nallah (earthen drain). During the summer, rain water contributes to the surface water. Since the whole area is sloping downwards to the western side, rain water from the northeastern and the southern sides of the area (Side A) between the Mill and the earthen dam flow towards the narrow drain and get mixed up with water in the vast agricultural land beyond. Surface water samples for this study were collected from 8 different places in 4 sampling seasons as shown below:

S/N	Name	Season
1	A1	2002 post -monsoon
2	B1	2003 pre -monsoon
3	A2	2003 post -monsoon
4	B2	2004 pre -monsoon

The results are discussed below parameter-wise.

3.3.1 pH

In the present study, the pH value of surface water ranges from 3.4 – 8.0 (Table 3.51) for all the seasons. The values for some samples were quite low which could not be considered as good for aquatic plants and fish. No distinct seasonal variation was observed. The pH values had no uniformity with respect to distance away from the Mill.

The site, SW1 had the least variation of values (Std Dev 0.29) among all the seasons whereas the site, SW4 had the maximum variation (Std Dev 1.71). For all the seasons, the maximum mean value was obtained at A2 season and the minimum at B2 season.

The ranges of values for pH are shown in Fig. 3.38 which indicates that the surface water pH did not vary by the same extent at the different sites, the variation was the least at the site, SW1, but was very large at SW4, SW5 and SW8. The surface water sources thus had different buffering capacities to inflow of mostly acidic effluent.

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Table 3.51 pH of surface water samples in the study area.

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	6.80	6.25	6.45	6.87	6.25	6.87	6.59	0.29
SW2	5.50	5.90	6.21	3.95	3.95	6.21	5.39	1.00
SW3	4.50	5.10	5.92	4.23	4.23	5.92	4.94	0.75
SW4	6.60	6.70	7.13	3.43	3.43	7.13	5.97	1.71
SW5	4.80	4.50	7.93	6.90	4.50	7.93	6.03	1.66
SW6	5.00	6.50	6.65	6.34	5.00	6.65	6.12	0.76
SW7	5.80	7.20	8.01	6.60	5.80	8.01	6.90	0.93
SW8	5.30	6.60	6.34	3.83	3.83	6.60	5.52	1.26
Min	4.50	4.50	5.92	3.43				
Max	6.80	7.20	8.01	6.90				
Mean	5.54	6.09	6.83	5.27				
SD	0.82	0.89	0.79	1.53				

Table 3.52 Electrical Conductivity (mS/cm) values in the study area.

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.90	1.81	0.95	0.16	0.16	1.81	0.96	0.67
SW2	1.20	1.15	1.05	0.76	0.76	1.20	1.04	0.20
SW3	1.83	0.98	1.39	0.60	0.60	1.83	1.20	0.53
SW4	0.47	3.01	0.52	2.00	0.47	3.01	1.50	1.23
SW5	0.54	0.69	2.02	0.12	0.12	2.02	0.84	0.82
SW6	0.85	0.83	1.37	0.29	0.29	1.37	0.84	0.44
SW7	0.96	1.12	0.56	0.24	0.24	1.12	0.72	0.40
SW8	0.94	0.86	0.96	1.38	0.86	1.38	1.04	0.23
Min	0.47	0.69	0.52	0.12				
Max	1.83	3.01	2.02	2.00				
Mean	0.96	1.31	1.10	0.69				
SD	0.42	0.77	0.49	0.67				

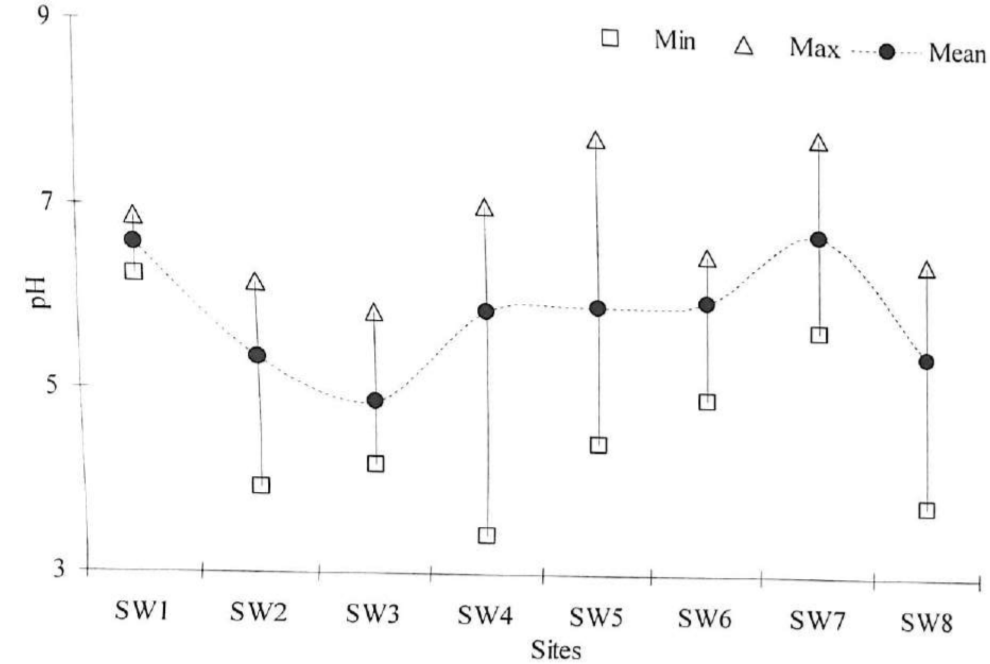


Fig. 3.38. pH ranges of the water in the eight surface water sites

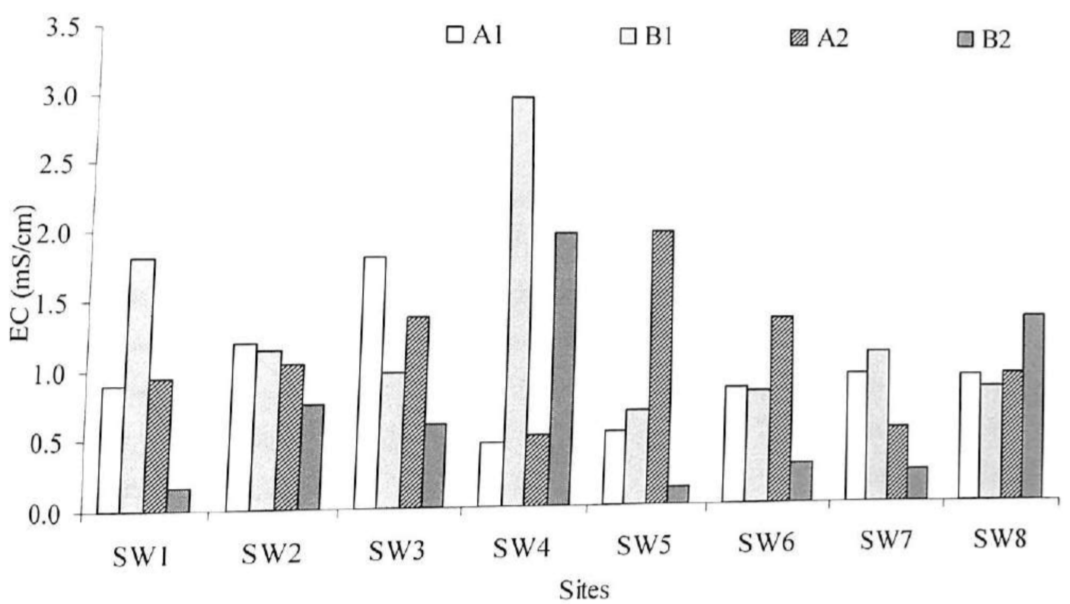


Fig. 3.39. Seasonal variation of electrical conductivities of the surface water samples for the different sites.

3.3.4 Total Hardness

Total hardness for surface water was obtained within the range 20 – 430 mg/L (Table 3.54). The surface water nearer to the Mill had more hardness in all the seasons. The maximum value was obtained at SW1 (A2) and the minimum at SW4 at B1 season. In most of the cases, the values are more during the post-monsoon season than in the pre-monsoon. Rain was scarce during the post-monsoon period and the water volume was much reduced during this period, causing an increase in Ca and Mg contents in the surface water. The highest mean value was obtained at A2 season (165.06 mg/L) but the lowest at the next pre-monsoon season (B2, 58.25 mg/L). The lower value of the total hardness in the surface water when compared with the ground water can be attributed to dilution of the ionic constituents (Kannan, 1991)

3.3.5.Total Solids (TS)

The surface water always contains different types of solids. Besides dissolved materials different organic substances and inorganic matter are also present in the surface water, which sometimes are not beneficial to the living being present in the surface water. The TS available in the surface water in the study area was within the range 530 – 8340 mg/L (Table 3.55). The site, SW1 had the maximum TS load (mean value 3503 mg/L) whereas the site, SW6 had the minimum (729 mg/L).

3.3.6.Total dissolved Solids (TDS)

The TDS of water is probably the most used criterion of its quality. In the study area, TDS was obtained within the range of 365 – 3380 mg/L (Table 3.56). The site, SW6 had comparatively low value (mean 534 mg/L) than the others. This is because of the minimum contact of the surface water sample at this site with the effluent water from the Mill. In A1 season, the deviation of the data was found the least (Std Dev 251), but the values in the B2 season had large deviations (Std Dev 1062). The seasonal variation was not distinct. Several of the constituents of dissolved solids have properties that necessitate special attention. These are alkalinity, hardness, fluoride, metals, organics and nutrients (Peavy et al. 1987).

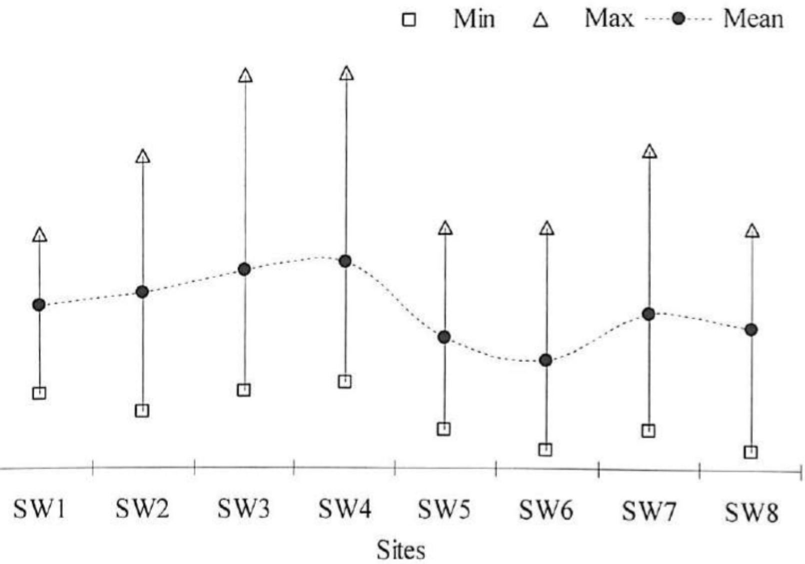
The TDS content of all the surface water samples was considerable and was the major contributor to the total solids (TS) as is seen in Fig. 3.41.

Table 3.53 Total Alkalinity (mg/L) in the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	750	750	366	244	244	750	528	262
SW2	750	1000	183	305	183	1000	560	382
SW3	750	1250	244	244	244	1250	622	482
SW4	1250	750	274	305	274	1250	645	458
SW5	750	500	122	274	122	750	412	274
SW6	750	250	61	305	61	750	342	292
SW7	500	1000	122	305	122	1000	482	378
SW8	750	750	61	215	61	750	444	359
Min	500	250	61	215				
Max	1250	1250	366	305				
Mean	781	781	179	275				
SD	209	312	109	36				

Table 3.54. Total Hardness (mg/L) in the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	130.65	123.75	430.00	30.00	30.00	430.00	178.60	173.77
SW2	86.76	84.30	190.00	40.00	40.00	190.00	100.27	63.56
SW3	147.90	140.59	260.00	50.00	50.00	260.00	149.62	86.01
SW4	31.94	18.46	123.50	106.00	18.46	123.50	69.98	52.48
SW5	220.76	53.82	96.00	30.00	30.00	220.76	100.15	84.91
SW6	106.25	72.30	84.00	30.00	30.00	106.25	73.14	32.02
SW7	49.11	75.43	66.00	20.00	20.00	75.43	52.64	24.33
SW8	70.73	60.98	71.00	160.00	60.98	160.00	90.68	46.45
Min	31.94	18.46	66.00	20.00				
Max	220.76	140.59	430.00	160.00				
Mean	105.51	78.70	165.06	58.25				
SD	60.79	38.74	126.24	49.12				



ranges of values of total alkalinity for the different surface water sites

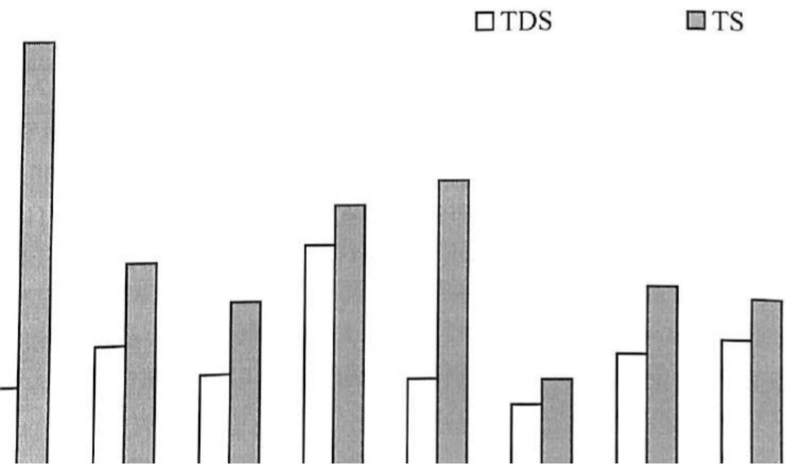


Table 3.55 Total Solids (TS) values of the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	1750	1820	2100	8340	1750	8340	3503	3229
SW2	2000	1965	1619	1300	1300	2000	1721	329
SW3	1600	1510	960	1480	960	1600	1388	290
SW4	530	815	3215	4120	530	4120	2170	1772
SW5	1170	1720	803	5780	803	5780	2368	2306
SW6	560	1010	785	560	560	1010	729	215
SW7	670	1360	1749	2200	670	2200	1495	648
SW8	1050	1050	943	2540	943	2540	1396	764
Min	530	815	785	560				
Max	2000	1965	3215	8340				
Mean	1166	1406	1522	3290				
SD	568	419	843	2641				

Table 3.56.Total Dissolve Solids (TDS) content of the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	710	725	1156	540	540	1156	783	263
SW2	1060	985	1035	1160	985	1160	1060	74
SW3	410	1163	785	880	410	1163	810	311
SW4	810	736	2438	3380	736	3380	1841	1292
SW5	520	1670	514	260	260	1670	741	631
SW6	385	840	592	320	320	840	534	235
SW7	365	880	1446	1040	365	1446	933	447
SW8	420	1000	633	2160	420	2160	1053	776
Min	365	725	514	260				
Max	1060	1670	2438	3380				
Mean	585	1000	1075	1218				
SD	251	307	636	1062				

3.3.7 Chloride (Cl^-)

High concentration of chloride in surface water arises from entry of sewage and many of the soluble chlorides present in soil (Banerji, 1994). Chlorides usually occur as NaCl, $CaCl_2$, $MgCl_2$ and other metallic salts in widely varying concentrations in all natural waters. They enter water by solvent action of water on salts present in the soil, from polluting material like sewage and trade wastes (Grana Rani et al., 2006), etc. The chloride concentration in the surface water in this work was within the range of 17.8 – 326.6 mg/L (Table 3.57). In the first two seasons, all the samples had got more Cl^- content in comparison to the other two seasons. This indicates that the Cl^- content in the surface water largely came from the Mill effluent. The site, SW3 had more Cl^- content in comparison to the other sites (mean value 174.1 mg/L) whereas the site SW7 had the least (mean 103.8 mg/L). Chloride is the most troublesome anion for irrigation in the sense that it is toxic to the plants (Dhanya et al., 2005).

3.3.8 Fluoride (F^-)

The fluoride is one of the anions present in surface water. The surface water in the present study was enriched with fluoride, the content being in the range of 0.81 – 6.90 mg/L (Table 3.58). The sample SW5 had very high content of F^- in the A1 season. This was likely to be due to entry of wastewater from the Mill carrying fluorides. If the fluoride had originated from the rock i.e., its source was largely mineral, the values would have been uniformly high in all the samples in all the seasons. The site SW5 (3.63 mg/L) had the maximum mean content of fluoride whereas SW7 (0.83 mg/L) had the least. The values did not show any type of distinct variation with distance from the Mill. Large amount of fluoride in surface water may lead to its increase in the nearby drinking water sources and it may also affect fish in hatching of their eggs (Barik and Patel, 2004) and aquatic birds.

Table 3.57. Chloride (Cl^-) values of the surface water samples of the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	276.9	310.2	42.6	24.9	24.9	310.2	163.6	150.8
SW2	312.4	302.4	35.5	24.9	24.9	312.4	168.8	160.2
SW3	326.6	314.8	30.1	24.9	24.9	326.6	174.1	169.4
SW4	113.6	230.9	53.2	42.6	42.6	230.9	110.1	86.4
SW5	156.2	319.5	24.9	17.8	17.8	319.5	129.6	141.7
SW6	191.7	284.0	24.8	28.4	24.8	284.0	132.2	127.7
SW7	198.8	156.2	35.5	24.9	24.9	198.8	103.8	86.9
SW8	234.3	269.8	28.4	39.1	28.4	269.8	142.9	127.0
Min	113.6	156.2	24.8	17.8				
Max	326.6	319.5	53.2	42.6				
Mean	226.3	273.5	34.4	28.4				
SD	75.3	55.7	9.7	8.3				

Table 3.58 Fluoride (F^-) of the water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.814	1.100	2.136	1.200	0.814	2.136	1.313	0.573
SW2	1.607	1.230	1.908	1.900	1.230	1.908	1.661	0.320
SW3	1.037	0.985	3.240	3.200	0.985	3.240	2.116	1.276
SW4	1.529	0.200	1.090	1.100	0.200	1.529	0.980	0.559
SW5	6.908	3.598	1.220	2.800	1.220	6.908	3.632	2.397
SW6	1.432	0.812	2.830	2.800	0.812	2.830	1.969	1.010
SW7	0.925	0.222	1.090	1.100	0.222	1.100	0.834	0.416
SW8	3.192	2.277	2.800	2.100	2.100	3.192	2.592	0.498
Min	0.814	0.200	1.090	1.100				
Max	6.908	3.598	3.240	3.200				
Mean	2.181	1.303	2.039	2.025				
SD	2.051	1.133	0.857	0.845				

3.3.9 Sulphate (SO_4^{--})

The sulphate content in the surface water for the four seasons was in the range of 18 – 203 mg/L (Table 3.59). The site, SW6, had the minimum mean value (63.3 mg/L) whereas SW2 got the maximum (185.9 mg/L). Less deviation was observed for the site SW2 (Std Dev 18.8) and more in SW5 (Std. Dev 80.2) among the seasons. The maximum mean value was obtained in B1 season (143.1 mg/L) and the minimum in B2 season (74.1 mg/L).

3.3.10 phosphate (PO_4^{---})

Phosphate is one of the most available anions present in surface water. In the present study, PO_4 was present within the range BDL – 1.6 mg/L (Table 3.60) for all the seasons. The sample SW4 had the maximum range of phosphate in all the seasons (0.413 - 1.6 mg/L). More PO_4 content in surface water leads to luxuriant growth of unnecessary weeds, etc., preventing entry of sunlight for self-purification and gradually leads to developing of conditions of eutrophication. The water sources did not exhibit any specific trend with respect to distance and season

3.3.11 Nitrate (NO_3^-)

One important source of nitrate in the surface water is biological oxidation of nitrogenous substances introduced by sewage and industrial waste (Purandara et al., 2003). Nitrate is one of the major anions present in the surface water of the study area in the range of BDL – 9.0 mg/L (Table 3.61). The site, SW1, had large amounts of nitrate with the mean content (4.0 mg/L, Std Dev 3.7) being the highest among all the sources while the source, SW5, had the lowest nitrate content as observed from the minimum mean value (1.1 mg/L).

Of the anions measured in this work, it was observed that chloride and sulphate were the major contributors to the anion content. The mean chloride exceeded the mean sulphate in most of the sites excepting at the sites SW2 and SW4 (Fig. 3.42). Fluoride, phosphate and nitrate did not show such trends, and their relative variation with respect to one another was different for each site (Fig. 3.43).

Table 3.59. Sulphate (SO_4^{--}) content in the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	112.5	127.0	120.0	50.0	50.0	127.0	102.4	35.4
SW2	195.5	203.0	185.0	160.0	160.0	203.0	185.9	18.8
SW3	135.0	127.5	90.0	18.0	18.0	135.0	92.6	53.5
SW4	115.0	120.5	160.0	132.0	115.0	160.0	131.9	20.0
SW5	117.5	200.0	52.0	18.0	18.0	200.0	96.9	80.2
SW6	45.0	125.0	28.0	55.0	28.0	125.0	63.3	42.6
SW7	90.0	129.5	90.0	60.0	60.0	129.5	92.4	28.5
SW8	85.0	112.5	64.0	100.0	64.0	112.5	90.4	20.9
Min	45.0	112.5	28.0	18.0				
Max	195.5	203.0	185.0	160.0				
Mean	111.9	143.1	98.6	74.1				
SD	43.5	36.4	53.7	51.9				

Table 3.60. Phosphate (PO_4^{---}) of the surface water in the study area (mg/L).

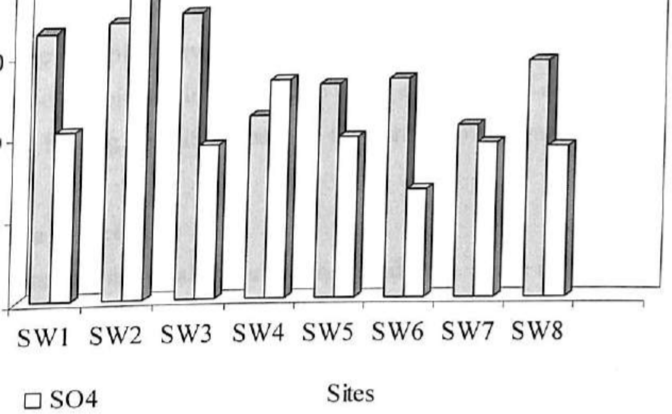
Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.251	0.220	0.310	0.700	0.220	0.700	0.370	0.223
SW2	0.157	0.180	1.100	0.800	0.157	1.100	0.559	0.468
SW3	BDL	0.030	0.810	1.200	BDL	1.200	0.510	0.593
SW4	0.413	0.440	1.600	1.030	0.413	1.600	0.871	0.563
SW5	BDL	BDL	BDL	1.050	BDL	1.050	0.263	0.525
SW6	BDL	BDL	0.060	1.350	BDL	1.350	0.353	0.666
SW7	BDL	0.193	0.920	1.050	BDL	1.050	0.541	0.522
SW8	0.036	BDL	1.020	0.250	BDL	1.020	0.327	0.475
Min	BDL	BDL	BDL	0.250				
Max	0.413	0.440	1.600	1.350				
Mean	0.107	0.133	0.728	0.929				
SD	0.155	0.156	0.558	0.342				

Table 3.61.Nitrate (NO_3^-) content in surface water samples (mg/L).

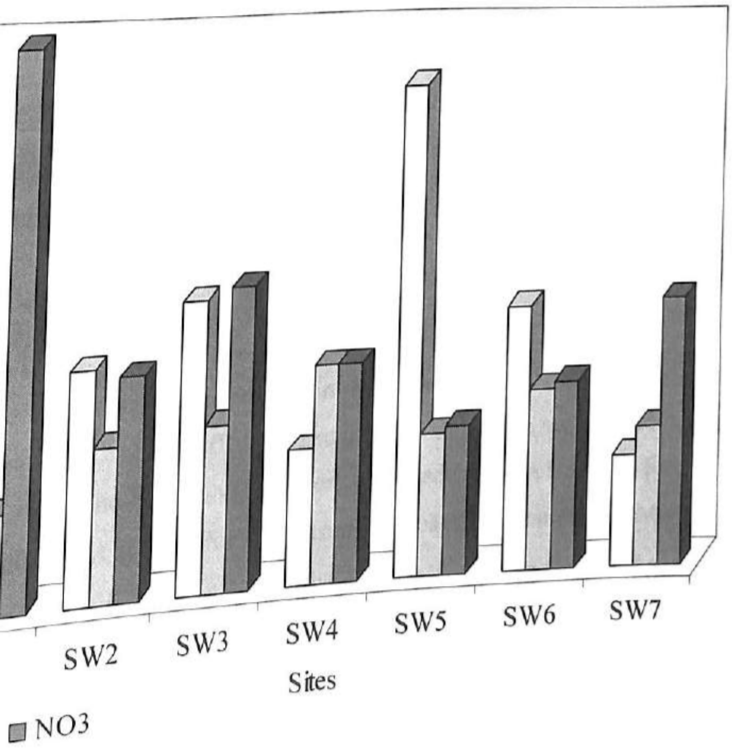
Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	3.6	3.2	9.0	BDL	BDL	9.0	4.0	3.7
SW2	1.0	1.2	4.3	BDL	BDL	4.3	1.6	1.9
SW3	1.4	1.2	3.2	2.9	1.2	3.2	2.2	1.0
SW4	1.2	1.3	1.8	2.0	1.2	2.0	1.6	0.4
SW5	0.3	1.0	2.0	1.2	0.3	2.0	1.1	0.7
SW6	1.4	3.5	0.8	0.0	0.0	3.5	1.4	1.5
SW7	1.5	6.5	0.1	0.0	0.0	6.5	2.0	3.1
SW8	1.5	3.5	0.1	7.0	0.1	7.0	3.0	3.0
Min	0.3	1.0	0.1	BDL				
Max	3.6	6.5	9.0	7.0				
Mean	1.5	2.7	2.7	1.6				
SD	0.9	1.9	3.0	2.4				

Table 3.62. Phenol content in the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.62	0.38	0.59	0.22	0.22	0.62	0.45	0.19
SW2	1.40	0.96	1.50	0.36	0.36	1.50	1.06	0.52
SW3	0.81	0.70	0.75	0.10	0.10	0.81	0.59	0.33
SW4	0.61	0.31	0.62	0.10	0.10	0.62	0.41	0.25
SW5	0.48	0.35	1.80	0.14	0.14	1.80	0.69	0.75
SW6	0.58	0.33	0.86	0.21	0.21	0.86	0.50	0.29
SW7	0.56	0.61	0.81	0.21	0.21	0.81	0.55	0.25
SW8	0.69	0.29	0.80	BDL				
Min	0.48	0.29	0.59	BDL				
Max	1.40	0.96	1.80	0.36				
Mean	0.72	0.49	0.97	0.17				
SD	0.29	0.24	0.44	0.11				



of mean chloride and sulphate contents of the surface water for the



of mean fluoride, phosphate and nitrate contents of the surface

sites.

3.3.12 Phenol

Phenolic compounds generally enter surface water through the route of industrial effluents (ATSDR, 1989). In the study area, the phenol was from BDL – 1.8 mg/L (Table 3.62). All the samples have very high content of phenol except SW8 in the batch, B2. The presence of phenol in the surface water of the area is a clear indication of the industrial effluent having definite impact on the surface water quality.

3.3.13 Oil and grease (O&G)

Oil and grease are essential materials required in an industry. Some of these compounds constitute the raw material for the industrial units while many industries also use them as greasing materials for machinery items. The oil and grease contents of the surface water in the study area were in the range of BDL – 3.89 mg/L (Table 3.63). The maximum amount was recorded at SW3 in A1 (3.89 mg/L) but the source, SW4 had the highest mean value (2.31 mg/L) in comparison to the other samples. In the batch, B2, all the samples contained less oil and grease (range BDL - 0.12 mg/L).

The relative proportion of phenol and oil & grease is shown in Fig. 3.44 with respect to their mean values for the different sites. At the sites, SW3 and SW4, oil and grease was much more than the phenol content.

3.3.14. Calcium (Ca)

Calcium is one of the important cations present in the surface water. It may come from different mineral sources in soil or effluent discharge. The values ranges from 4.1–196.4 mg/L (Table 3.64). The highest values were obtained in the A1 season for SW5 whereas the lowest value was at SW5 for B2 season. Almost in all the cases, the values decreased from A1 season to B2 season. Thus, the surface water was receiving effluent discharge with decreasing Ca load from the Mill during B2 season compared to the season, A1.

Table 3.63. Oil and grease (O&G) content in the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	1.56	0.16	2.31	0.12	0.12	2.31	1.04	1.08
SW2	1.58	0.74	1.95	0.03	0.03	1.95	1.07	0.86
SW3	3.89	0.82	2.78	0.05	0.05	3.89	1.88	1.76
SW4	3.37	2.74	3.06	0.06	0.06	3.37	2.31	1.52
SW5	2.78	0.12	0.48	0.02	0.02	2.78	0.85	1.30
SW6	0.11	0.15	2.05	0.01	0.01	2.05	0.58	0.98
SW7	0.60	0.17	0.41	BDL	BDL	0.60	0.29	0.26
SW8	0.10	0.15	0.57	0.01	0.01	0.57	0.21	0.25
Min	0.10	0.12	0.41	BDL				
Max	3.89	2.74	3.06	0.12				
Mean	1.75	0.63	1.70	0.04				
SD	1.47	0.90	1.07	0.04				

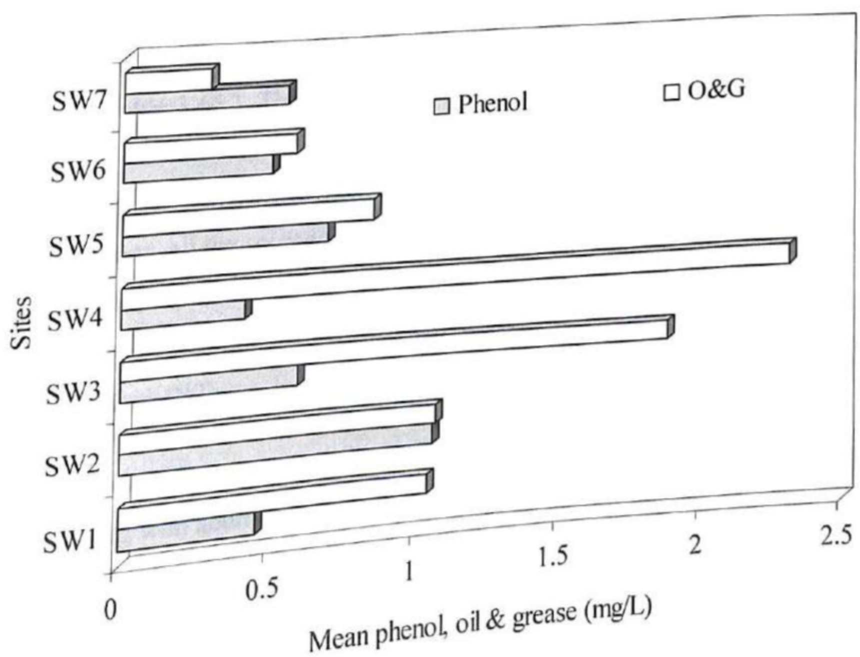


Fig. 3.44. Relative proportion of phenol and oil & grease in the surface water samples.

3.3.15 Magnesium (Mg)

It is an established fact that calcium and magnesium do not behave in an identical pattern in the soil system and Mg deteriorates soil structure particularly when saline water is sodium dominated (Aishwath, 2005). Magnesium is one of the common metals present in the surface water along with Ca. The contents in the present case were in the range of 2.2 – 64.8 mg/L (Table 3.65). The mean values of Mg in the study area show that the highest Mg content was obtained in A2 (31.1 mg/L) and the minimum in A1 season (10.1 mg/L). None of the samples showed any trend in all the seasons.

Since calcium and magnesium are the major contributing cations to the total hardness of water, the comparative variation pattern of hardness along with that of Ca and Mg for all the sites is presented in Fig. 3.45. Ca appears to be the major contributor in each case with almost twice as much contribution than that of Mg.

3.3.16 Sodium (Na)

In the present study, the amount of sodium in the surface water was in the range 10.7 – 288.5 mg/L (Table 3.66). Thus, the surface water was very rich in sodium in some of the sources (SW1, SW2 and SW3) in a few seasons (A1 and B1). The source, SW3, had the maximum mean value (178.7 mg/L) whereas SW4 had the least (92.0 mg/L). In the first three seasons, all the sources had got sufficient amount of Na content but in the last season (B2), all the samples had very low sodium content. The values reflect that because of some reasons the surface water received less sodium from effluent of the Mill in this season (B2).

3.3.17 Potassium (K)

Potassium along with sodium are very common to textile chemicals. In the study area, K was obtained in the range of 2.0 – 24.4 mg/L (Table 3.67). The source, SW5, had the highest K content in B1 season (24.4 mg/L) but lowest at A1 (2.0 mg/L). The values thus show large deviation for SW5 (Std Dev 10.6). Seasonal variation was not seen. A distinct trend for all the samples was not observed.

All the surface water samples had much less potassium compared to sodium (Fig. 3.46). The excessive Na-content must have resulted from effluent input from the textile mill.

Table 3.64. Calcium (Ca) in the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	36.03	27.15	87.60	8.16	8.16	87.60	39.74	33.96
SW2	72.14	70.90	51.17	16.32	16.32	72.14	52.63	26.04
SW3	116.23	112.40	35.11	12.02	12.02	116.23	68.94	53.26
SW4	20.58	16.03	106.50	36.07	16.03	106.50	44.80	42.02
SW5	196.40	44.08	26.18	4.08	4.08	196.40	67.69	87.36
SW6	72.14	60.12	20.60	12.02	12.02	72.14	41.22	29.39
SW7	32.06	68.13	39.40	12.02	12.02	68.13	37.90	23.24
SW8	56.11	56.11	42.23	28.05	28.05	56.11	45.63	13.42
Min	20.58	16.03	20.60	4.08				
Max	196.40	112.40	106.50	36.07				
Mean	75.21	56.87	51.10	16.09				
SD	57.49	29.60	30.29	10.68				

Table 3.65. Magnesium (Mg) content in surface water in the study area (mg/L).

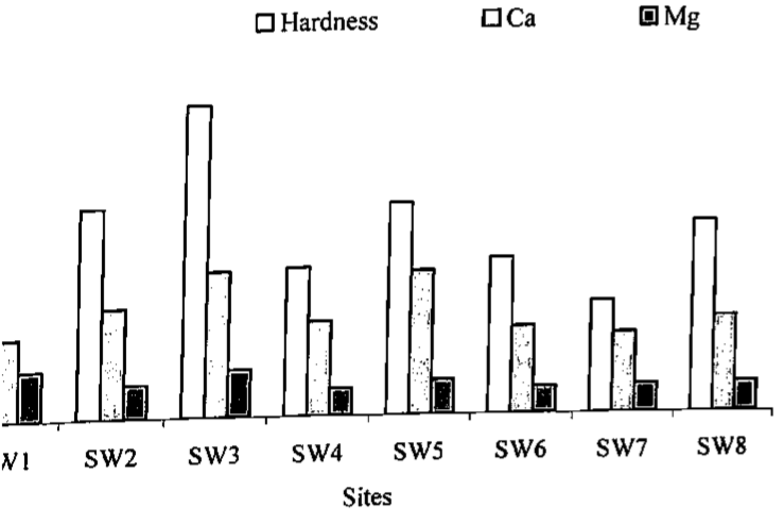
Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	12.6	10.9	64.8	8.2	8.2	64.8	24.1	27.2
SW2	9.6	9.3	30.4	15.8	9.3	30.4	16.3	9.9
SW3	20.7	21.3	35.6	13.4	13.4	35.6	22.8	9.3
SW4	2.2	7.6	11.6	30.9	2.2	30.9	13.1	12.5
SW5	14.8	12.8	28.3	11.3	11.3	28.3	16.8	7.8
SW6	10.4	10.6	20.0	10.5	10.4	20.0	12.9	4.8
SW7	6.5	4.5	35.8	7.4	4.5	35.8	13.6	14.9
SW8	3.8	5.6	22.6	25.8	3.8	25.8	14.5	11.4
Min	2.2	4.5	11.6	7.4				
Max	20.7	21.3	64.8	30.9				
Mean	10.1	10.3	31.1	15.4				
SD	6.1	5.2	15.9	8.5				

Table 3.66. Sodium (Na) content in surface water in the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	202.4	212.2	225.6	31.3	31.3	225.6	167.9	91.5
SW2	232.0	196.4	88.5	74.9	74.9	232.0	148.0	78.1
SW3	288.5	282.4	79.3	64.7	64.7	288.5	178.7	123.4
SW4	79.7	112.6	165.1	10.7	10.7	165.1	92.0	64.6
SW5	91.6	284.3	49.1	19.5	19.5	284.3	111.1	119.2
SW6	120.8	246.9	55.4	51.4	51.4	246.9	118.6	91.2
SW7	162.5	229.2	60.6	43.7	43.7	229.2	124.0	87.6
SW8	156.0	198.7	52.9	57.6	52.9	198.7	116.3	72.6
Min	79.7	112.6	49.1	10.7				
Max	288.5	284.3	225.6	74.9				
Mean	166.7	220.3	97.1	44.2				
SD	71.5	55.3	64.2	22.3				

Table 3.67. Potassium (K) of the surface water samples (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	4.0	4.9	16.3	3.7	3.7	16.3	7.2	6.1
SW2	7.8	8.2	5.3	6.2	5.3	8.2	6.9	1.4
SW3	21.6	18.3	6.9	5.7	5.7	21.6	13.1	8.0
SW4	9.0	6.3	14.2	12.8	6.3	14.2	10.6	3.6
SW5	2.0	24.4	5.3	2.9	2.0	24.4	8.7	10.6
SW6	12.0	16.4	3.2	4.3	3.2	16.4	9.0	6.3
SW7	15.3	16.0	3.3	3.8	3.3	16.0	9.6	7.0
SW8	12.0	11.8	4.6	13.8	4.6	13.8	10.6	4.1
Min	2.0	4.9	3.2	2.9				
Max	21.6	24.4	16.3	13.8				
Mean	10.5	13.3	7.4	6.7				
SD	6.3	6.7	5.0	4.3				



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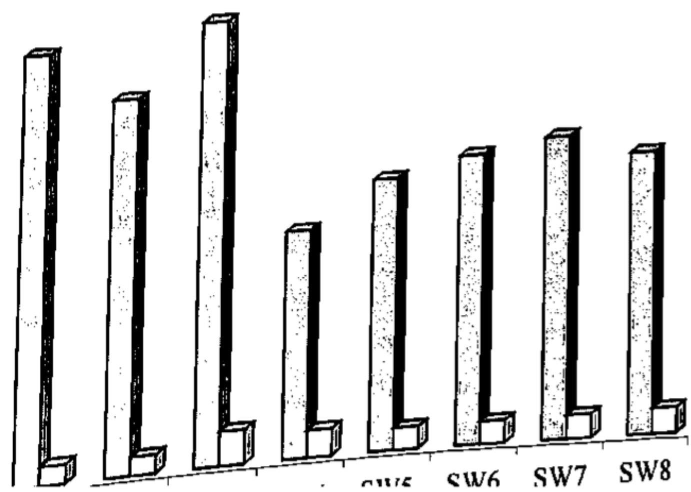


3.3.18. Trace metal ions : Al, As, Cd, Cr, Cu, Fe,Hg, Mn, Ni, Pb, Zn

The Sewage water is used for irrigating agricultural fields (Sauerback, 1987) which increases crop production and results in accumulation of heavy metals (Sommers et al., 1976).

(i) Aluminium (Al)

Al obtained in the study area was from 4.7– 71.4 mg/L (Table 3.68). A large amount of aluminium in the surface water samples leaves no doubt about the effluents bringing in a lot of Al-salts to the surrounding areas. The maximum value was obtained at SW1 (mean 38.4 mg/L) and the minimum at SW6 (mean 17.0 mg/L). No distinct seasonal trend was observed for any site. The values were more in the batches A1 and B1 compared to the other seasons.

(ii) Arsenic (As)

The values of arsenic for all the sources in the study area are presented in Table 3.69. Interestingly, the samples nearer to the Mill, SW1 and SW2, had As below detection level while SW4 and SW8 had got As in all the seasons. Again SW5, 6 and 7 had As in the first two seasons (A1 and B1) and but the values were below detection level in the last two seasons (A2 and B2). The values have a decreasing trend from A1 to A2 seasons with slight exception at SW4 and SW8.

(iii) Cadmium (Cd)

Cadmium was obtained in the study area within the range of 0.01– 0.32 mg/L (Table 3.70) for all the seasons. The maximum mean value was obtained for SW4 (0.17 mg/L) and the minimum mean value was at SW5 (0.02 mg/L). The pre monsoon values were generally more than the post monsoon values. Cd comes to surface water only from industrial waste and therefore, the content in the surface water must have come from the Mill effluent. It is to be noted that the Cd content in all the sites for all the seasons was high.

Table 3.68. Aluminium (Al) of the water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	62.6	71.4	10.1	9.4	9.4	71.4	38.4	33.2
SW2	20.7	53.4	11.5	49.6	11.5	53.4	33.8	20.8
SW3	17.2	41.9	13.5	38.6	13.5	41.9	27.8	14.5
SW4	16.2	43.0	58.0	14.7	14.7	58.0	33.0	21.2
SW5	24.7	26.7	11.4	18.6	11.4	26.7	20.4	6.9
SW6	23.5	36.7	4.7	5.2	4.7	36.7	17.5	15.5
SW7	17.3	24.5	14.2	23.3	14.2	24.5	19.8	4.9
SW8	5.4	28.5	13.3	20.8	5.4	28.5	17.0	9.9
Min	5.4	24.5	4.7	5.2				
Max	62.6	71.4	58.0	49.6				
Mean	23.4	42.5	17.1	22.5				
SD	16.9	15.7	16.8	14.9				

Table 3.69 As (μg/L) content in surface water samples of the study area.

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	BDL	BDL	BDL	BDL	--	--	--	--
SW2	BDL	BDL	BDL	BDL	--	--	--	--
SW3	BDL	BDL	BDL	BDL	--	--	--	--
SW4	0.006	0.007	0.006	0.006	0.006	0.007	0.006	--
SW5	0.002	0.001	BDL	BDL	BDL	0.002	0.001	--
SW6	0.001	0.001	BDL	BDL	BDL	0.001	0.001	--
SW7	0.002	0.001	BDL	BDL	BDL	0.002	0.001	--
SW8	0.001	0.002	0.001	0.001	0.001	0.002	0.001	--
Min	BDL	BDL	BDL	BDL				
Max	0.006	0.007	0.006	0.006				
Mean	0.002	0.002	0.004	0.003				
SD	0.002	0.002	0.003	0.003				

Table 3.70. Cadmium (Cd) of the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.010	0.123	0.010	0.144	0.010	0.144	0.072	0.072
SW2	0.017	0.090	0.013	0.010	0.010	0.090	0.033	0.038
SW3	0.020	0.232	0.010	0.176	0.010	0.232	0.110	0.112
SW4	0.080	0.320	0.010	0.250	0.010	0.320	0.165	0.144
SW5	0.010	0.033	0.018	0.026	0.010	0.033	0.022	0.010
SW6	0.015	0.084	0.016	0.081	0.015	0.084	0.049	0.039
SW7	0.016	0.086	0.011	0.094	0.011	0.094	0.052	0.044
SW8	0.011	0.122	0.012	0.205	0.011	0.205	0.088	0.094
Min	0.010	0.033	0.010	0.010				
Max	0.020	0.320	0.018	0.250				
Mean	0.020	0.140	0.010	0.120				
SD	0.023	0.090	0.003	0.080				

Table 3.71. Chromium(Cr) of the water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.06	1.13	0.10	1.07	0.06	1.13	0.59	0.59
SW2	0.05	1.10	0.06	0.86	0.05	1.10	0.51	0.54
SW3	0.05	0.62	0.06	0.68	0.05	0.68	0.35	0.35
SW4	0.55	1.83	0.68	1.98	0.55	1.98	1.26	0.75
SW5	0.02	0.85	0.09	0.65	0.02	0.85	0.40	0.41
SW6	0.04	0.69	0.04	0.74	0.04	0.74	0.38	0.39
SW7	0.02	0.75	0.59	0.73	0.02	0.75	0.52	0.34
SW8	0.03	0.81	0.06	0.73	0.03	0.81	0.41	0.42
Min	0.02	0.60	0.04	0.68				
Max	0.55	1.80	0.68	1.98				
Mean	0.10	0.97	0.20	0.90				
SD	0.20	0.40	0.26	0.40				

(iv) Chromium

Surface water of the study area contained considerable amount of total Cr (both Cr(III) and Cr(VI) taken together). The values were from 0.02– 1.98 mg/L (Table 3.71). The minimum value (0.02 mg/L was obtained for SW5 in A1 season and the maximum (1.98 mg/L) for SW4 in B2 season. Taking the mean of the Cr-contents for all the sites, the highest (0.97 mg/L) was obtained in B1 and the lowest (0.1mg/L) in A1. With respect to seasonal variation, the values were found to be more in the pre-monsoon season than in the post-monsoon season for all the sites. Cr(VI) is toxic towards both aquatic life and plant and therefore, adverse effects, if any, of the same needs to be carefully investigated.

(v) Copper (Cu)

Copper contents of the surface water of the study area were obtained in the range of 0.05 – 2.13 mg/L (Table 3.72). The site SW4 had the maximum amount of Cu (mean 1.09 mg/L) and the site SW3 had the lowest (mean 0.24 mg/L). The values obtained were more in the pre-monsoon seasons (B1 and B2) than in the post-monsoon seasons (A1 and A2). Excess Cu in the surface water is toxic to aquatic plants and animals (Singh and Gupta, 2004) depending on pH, alkalinity and the presence of organic compounds.

(vi) Iron (Fe)

Sufficient amount of iron was found in the present study. The values for the present study are given in Table 3.73. The textile mill uses soft water for its different activities during the process of cloth manufacture. In the effluent unit, ferrous alum is added as a coagulating agent. This may be responsible for enhancing the iron content of the surface water within the study area. In this study iron was obtained in the range of 0.5 – 13.5 mg/L (Table 3.73). The site SW4 had the highest mean value (7.85 mg/L) whereas SW3 had the least (1.88 mg/L). The seasonal variation was not distinct. The maximum mean value was obtained in B2 season (13.50 mg/L) and the minimum at A2 season (3.60 mg/L).

Table 3.72 Copper (Cu) of the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.564	0.612	0.625	0.523	0.523	0.625	0.581	0.047
SW2	0.377	0.665	0.403	0.619	0.377	0.665	0.516	0.147
SW3	0.262	0.240	0.312	0.163	0.163	0.312	0.244	0.062
SW4	0.262	2.132	0.204	1.753	0.204	2.132	1.088	0.999
SW5	0.260	1.110	0.079	0.614	0.079	1.110	0.516	0.454
SW6	0.174	1.250	0.036	1.013	0.036	1.250	0.618	0.603
SW7	0.050	1.171	0.021	0.836	0.021	1.171	0.520	0.575
SW8	0.062	0.830	0.137	0.747	0.062	0.830	0.444	0.400
Min	0.050	0.240	0.021	0.160				
Max	0.564	2.130	0.625	1.750				
Mean	0.250	1.000	0.230	0.780				
SD	0.170	0.570	0.210	0.460				

Table 3.73. Iron (Fe) of the water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	1.90	10.40	2.60	6.70	1.90	10.40	5.40	3.95
SW2	2.04	6.34	2.50	3.80	2.04	6.34	3.67	1.93
SW3	2.40	2.60	1.10	1.40	1.10	2.60	1.88	0.74
SW4	2.90	12.50	2.50	13.50	2.50	13.50	7.85	5.96
SW5	2.40	8.70	2.28	6.80	2.28	8.70	5.05	3.22
SW6	8.80	10.50	0.52	0.60	0.52	10.50	5.11	5.29
SW7	6.30	7.34	7.02	1.70	1.70	7.34	5.59	2.63
SW8	4.30	5.65	3.60	1.20	1.20	5.65	3.69	1.86
Min	1.90	2.60	0.50	0.60				
Max	6.30	12.50	3.60	13.50				
Mean	3.90	8.00	2.80	4.50				
SD	2.50	3.20	1.96	4.39				

(vii) Mercury (Hg)

The site, SW6, had Hg below detection level in all the seasons. The site, SW4, had Hg in all the seasons within the range of 0.002 – 0.005 mg/L. The site, SW3 had Hg (0.001 mg/L) only in the first season (A1) and below detection level at the other three seasons. In the last season, most of the sites had Hg in the surface water at below detection level.

(viii) Manganese (Mn)

Manganese is an important micronutrient for aquatic organisms. In the study area, Mn-content was from 0.05– 9.07 mg/L (Table 3.74). For all the sites, it was generally found that there was more Mn in the surface water samples during A1 and B1 seasons compared to A2 and B2. The highest value was obtained at SW3 (7.45 mg/L) in the first winter (A1) and the lowest at SW7 and SW8 in the second winter (A2). The site SW3 had the highest (3.48 mg/L) and SW1 the lowest (0.26 mg/L) mean values. In the last two seasons i.e. in the second winter season (A2) and the second summer season (B2), all the sites had low Mn content.

(xi) Nickel (Ni)

Nickel enters surface water from different sources e.g. from rocks and soil, industrial waste or from biological recycling. It exists either in ionic form or in complexes with humic acid. Leaching from Ni containing pipes, Ni compounds have been known to cause nickel dermatitis on skin contact with humans and also have been responsible for causing respiratory tract irritation and asthma in industrial workers through inhalation (Fishbein L 1991). Amount of Ni present in the surface water was in the range of BDL – 3.9 mg/L (Table 3.75). The maximum mean value was obtained at SW4 (1.62 mg/L) and the minimum at SW7 (0.03 mg/L). The seasonal variation of the mean values indicates that the values had an increasing trend from A1 (0.2 mg/L) to A2 (0.6 mg/L) which then decreased to 0.25 mg/L in B2 season. In the last pre monsoon season (B2), the sites SW1, SW5, SW6 and SW8 had nickel at below detection level.

Table 3.75. Manganese (Mn) of the water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.33	0.54	0.08	0.07	0.54	0.07	0.26	0.22
SW2	1.94	2.12	0.07	0.06	2.12	0.06	1.05	1.14
SW3	7.45	6.33	0.08	0.06	7.45	0.06	3.48	3.96
SW4	5.35	5.23	0.07	0.07	5.35	0.07	2.68	3.02
SW5	1.20	2.31	0.06	0.07	2.31	0.06	0.91	1.08
SW6	6.84	4.30	0.07	0.06	6.84	0.06	2.82	3.34
SW7	4.30	1.20	0.05	0.06	4.30	0.06	1.40	2.01
SW8	3.20	9.07	0.05	0.06	9.07	0.05	3.10	4.25
Min	7.45	9.07	0.08	0.07				
Max	0.33	0.54	0.05	0.05				
Mean	3.80	3.90	0.06	0.06				
SD	2.60	2.90	0.01	0.01				

Table 3.76. Nickel (Ni) of the surface water from the study area (mg/L).

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.63	0.60	0.01	BDL	BDL	0.63	0.31	0.35
SW2	0.09	0.52	0.06	0.45	0.06	0.52	0.28	0.24
SW3	0.28	0.21	0.24	0.12	0.12	0.28	0.21	0.07
SW4	0.02	2.16	3.90	0.40	0.02	3.90	1.62	1.78
SW5	0.07	0.11	0.02	BDL	BDL	0.11	0.05	0.05
SW6	0.21	0.19	0.06	BDL	BDL	0.21	0.12	0.10
SW7	0.02	0.06	0.01	0.04	0.01	0.06	0.03	0.02
SW8	0.26	0.34	0.00	BDL	BDL	0.34	0.15	0.18
Min	0.02	0.06	0.00	BDL				
Max	0.63	2.16	3.90	0.45				
Mean	0.20	0.52	0.60	0.25				
SD	0.20	0.70	1.36	0.19				

(x) Lead (Pb)

Lead was present in the surface water within the range of BDL – 0.23 mg/L (Table 3.76). The maximum mean value was obtained at SW1 (0.2 mg/L) and the minimum at SW8 (0.01 mg/L). In B1 (0.23 mg/L) and A2 (0.23 mg/L) seasons the values were comparatively more than the other two seasons (A1 0.14 mg/L, B2 0.19 mg/L). The seasonal standard deviation from one season to another was almost uniform (0.07). The site SW8 had lead content at below detection level in the first winter season (A1) but in subsequent three seasons, the Pb content increased in that particular site.

(xi) Zinc (Zn)

Zinc is an essential element for growth of living beings. The surface water in the study area contained Zn from 0.1 – 4.21 mg/L (Table 3.77) for all the four seasons. The site SW4 had comparatively more Zn content than the other stations (mean 2.61 mg/L). Interestingly, in all the seasons and all the sites, the highest value was obtained at SW4 (4.21 mg/L) and the lowest at SW7 (0.01 mg/L) during the first winter season (A1). The maximum mean value was obtained at A2 season (1.7 mg/L) and the minimum at B2 season (0.56 mg/L). No distinct seasonal variation was observed.

Comparison of the contents

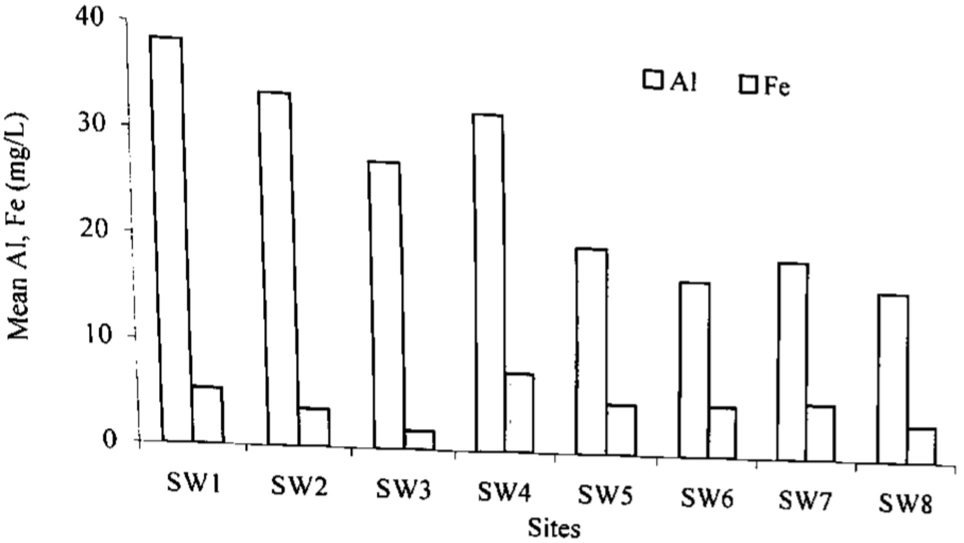
All the surface water samples had very high Al-content followed by Fe-content. This is shown for the mean values of the two constituents in Fig. 3.47. Mn and Zn contents were also high, but not as high as Al and Fe. The two metals, Mn and Zn, did not show a consistent pattern of presence relative to one another as is shown for their mean values in Fig. 3.47. The heavy metals, Cd, Cr, Cu, Pb and Ni were present in the surface water sources to different extents and the relative proportion of their contents do not follow a fixed pattern (Fig. 3.48). The site, SW4, had very high values of Cu, Ni and Cr in comparison to all other sites.

Table 3.77.Lead (Pb) of the water from the study area (mg/L)

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	0.14	0.23	0.23	0.19	0.14	0.23	0.20	0.04
SW2	0.07	0.12	0.07	0.03	0.03	0.12	0.07	0.04
SW3	0.20	0.23	0.19	0.11	0.11	0.23	0.18	0.05
SW4	0.02	0.11	0.09	0.11	0.02	0.11	0.08	0.04
SW5	0.01	0.09	0.17	0.09	0.01	0.17	0.09	0.07
SW6	0.06	0.09	0.16	0.10	0.06	0.16	0.10	0.04
SW7	0.13	0.15	0.14	0.10	0.10	0.15	0.13	0.02
SW8	BDL	0.02	0.02	0.01	BDL	0.02	0.01	0.01
Min	BDL	0.02	0.02	0.01				
Max	0.14	0.23	0.23	0.19				
Mean	0.08	0.13	0.13	0.09				
SD	0.07	0.07	0.07	0.05				

Table 3.78. Zinc (Zn) of the surface water from the study area (mg/L)

Site	Sampling Season				Min	Max	Mean	SD
	A1	B1	A2	B2				
SW1	4.07	3.36	2.29	0.97	4.07	0.97	2.67	1.35
SW2	1.39	1.40	3.34	0.97	3.34	0.97	1.78	1.06
SW3	0.38	0.34	1.65	0.41	1.65	0.34	0.70	0.64
SW4	4.21	2.05	3.10	1.06	4.21	1.06	2.61	1.36
SW5	0.23	1.10	0.54	0.36	1.10	0.23	0.56	0.38
SW6	0.32	0.36	0.67	0.16	0.67	0.16	0.38	0.21
SW7	0.10	0.12	0.20	0.39	0.39	0.10	0.20	0.13
SW8	0.15	0.20	0.45	0.18	0.45	0.15	0.25	0.14
Min	0.10	0.12	0.45	0.16				
Max	4.21	3.36	3.34	1.06				
Mean	1.35	1.10	1.70	0.56				
SD	1.80	1.10	1.25	0.37				



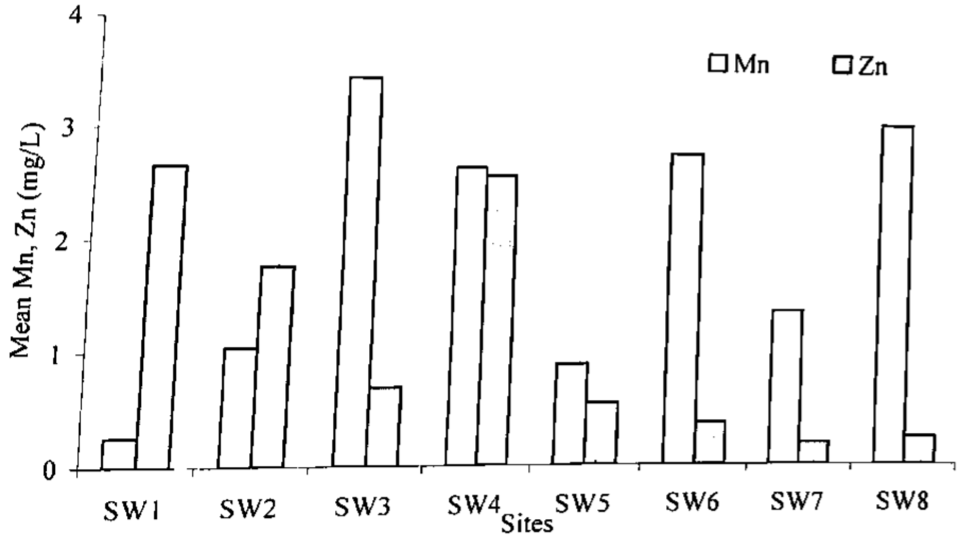


Fig. 3.47. Variation of the mean values of Al and Fe (top), and Mn and Zn (bottom) in the surface water of the sampling sites.

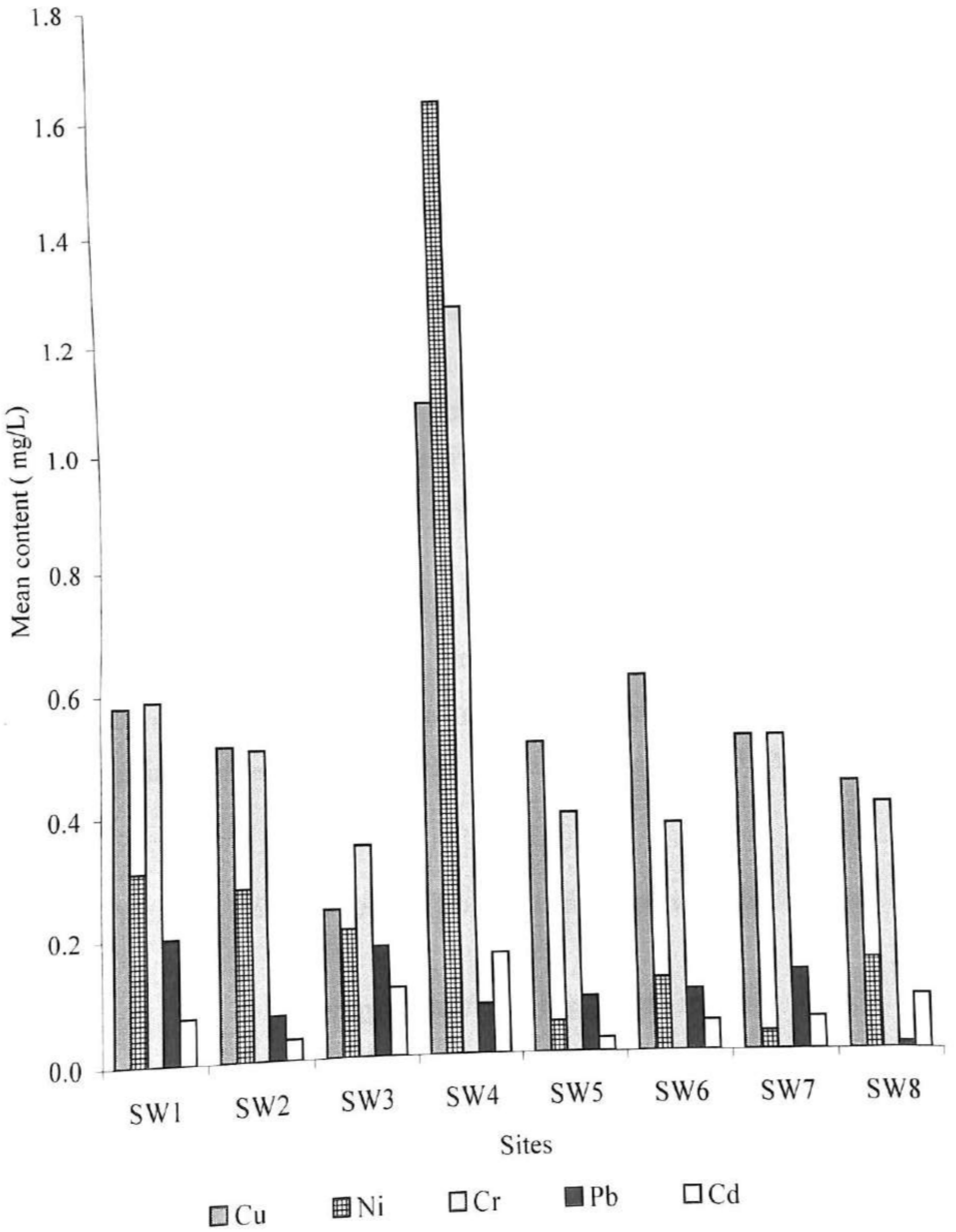


Fig. 3.48. Variation of the mean values of Cd, Cr, Cu, Ni and Pb in the surface water of the sampling sites.

3.4 Rice grain and husk

The paddy crop is normally planted in flooded soils, the uptake of metals through roots depends on the presence of metal concentration in water as well as in the soil. This uptake mechanism of heavy metals includes both adsorption (from soil) and absorption (from water) and takes place through roots. The existence of genetic differences in heavy metal uptake and accumulation as well as tolerance have been found in diverse crop plants, including rice (Aniol and Gustafson, 1990; Yang et al., 2000; Zhang et al., 2000; Arao and Ae, 2003; Liu et al., 2003), indicating the possibility of developing the reasonable cultivars suitable for planting in the contaminated soil. Studies have shown that uptake and accumulation of metals by different plant species depend on several factors, and various researchers have identified several reasons (Bingham et al., 1975; Dowdy et al., 1978).

3.4.1 Rice Grains

Uptake of metals Al, As, Cu, Cr, Cd, Hg, Fe, Mn, Ni, Pb and Zn by rice plants grown in the study area during the harvesting season of third post-monsoon season was measured separately for grains and husks. The results are depicted in Table 3.78 for grains with a Control sample.

The literature (Weigert, 1991) values and the ranges for few metals in rice grain are given below:

	Minimum (mg/kg)	Maximum (mg/kg)
Cu	2.4 (Mean)	
Fe	20.0	31.0
Pb	0.01	1.0
Mn	11.0 (Mean)	
Zn	8.0	20.0

In the present study, it was observed that all the five samples were rich with aluminium (range 30.2 – 110.5 mg/kg). The distant sample (R5, 30.2 mg/kg) had the least Al-content

Table 3.78. Metals present in the rice grains (mg/kg)

Metals	Content (mg/kg) in Rice grain samples					
	R1	R2	R3	R4	R5	CR
Al	110.50	92.60	43.70	34.75	30.23	17.30
Cd	1.38	1.66	1.00	0.67	0.77	0.25
Cr	2.40	1.40	1.50	2.15	1.19	0.33
Cu	10.20	5.10	5.20	4.70	4.30	2.80
Fe	59.00	44.70	36.00	37.80	40.00	28.00
Mn	60.00	46.80	38.10	54.80	45.50	23.00
Ni	3.10	0.93	2.70	1.70	1.50	0.86
Pb	8.82	8.13	2.50	1.60	2.47	1.40
Zn	61.60	46.00	59.76	28.20	18.77	13.30

while the "Control" had 17.3 mg/kg of Al. In acidic environment, phosphate ions exert significant influence on the toxic effects of Al in different cereals (Zsoldos et al., 2004). With respect to Cd, the sample R2 (1.66 mg/kg) had the highest content whereas R4 (0.6 mg/kg) had the least. The maximum permissible Cd concentration in rice is 0.5 mg/kg (DOH/ROC 1988). The "control"(CR) had the value 0.25 mg/kg of Cd, which is below the permissible limit. A high level of cadmium concentration in rice grain is harmful to human health (Chen 1992, Chen *et al.* 1994).
Although Cd is not an essential or beneficial element for plants, they generally exhibit measurable Cd concentrations, particularly in roots, but also in leaves, most probably as a result of inadvertent uptake and translocation (Assunção et al., 2003).

Cr was found highest in R1 (2.4 mg/kg) and lowest at R5 (1.19 mg/kg) whereas the "Control" sample had the value 0.33 mg/kg. Readily soluble Cr^{6+} in soils is toxic to plants and animals. There is no evidence yet of an essential role of Cr in plant metabolism (Pendias and Pendias, 1989). Chromium is widely distributed in wholegrain breads and cereals, apple peel, potatoes, green pepper, eggs, chicken, cornflakes, broccoli, spinach, grape juice, green beans, banana and sugar (Body building website,2007) .

The presence of Cu in grains of the rice samples (Range 4.3 – 10.2 mg/kg) was more than the mean literature value of 2.4 mg/kg. The "Control" sample had slightly more value (2.8 mg/kg).

Substantial amount of Fe was present in all the grain samples (range: 36 – 59 mg/kg). The sample R1 (59 mg/kg) had the highest value. The "Control" (28 mg/kg) sample had Fe within the range (20 – 31 mg/kg) given in the literature. Fe toxicity can affect the rice crop throughout its growth cycle.

All the samples have high amount of Mn, which was within the range of 38.1 – 60.0 mg/kg. The "Control" sample have the value of 23.0 mg/kg, which was more than the literature value. Manganese (usually present as Mn^{2+} in the soil solution) is an essential nutrient that can be toxic to crops when occurring in excess (Marschner, 1995).

The concentration of Ni was within the range of 0.93 (R2) – 3.1 (R1) mg/kg. Ni content of the "Control" sample was 0.86 mg/kg.

The rice grain samples were rich with lead. The sample R1 (8.82 mg/kg) had the highest value whereas R4 had the lowest (1.6 mg/kg). The "Control" sample had 1.4 mg/kg of lead, which was more than the literature range (0.01 - 1.0 mg/kg). Uptake of Pb in plants is regulated by pH, particle size and cation exchange capacity of the soil as well as by root exudation and other physico-chemical parameters (Lokeshwari and Chandrappa, 2006).

The amount of Zn present in all the samples was high, except R5 (18.77 mg/kg). The maximum value was obtained at R1 (61.6 mg/kg) and the minimum at R5 (18.77 mg/kg). The value for the "Control" sample (13.3 mg/kg) was within the literature range. Vegetable crops are generally sensitive to high zinc levels, while grasses usually tolerate high levels of available soil zinc (Vitosh et al., 1994).

The grain samples did not have detectable amounts of As and Hg. It is to be noted that very high concentrations of Pb, Zn, As and Cd in paddy soil and the elevated Cd level in rice could pose a problem for human health (Rogan et al., 2007)

3.4.2 Rice Husks

The rice husks were found to contain more of the different metals than the rice grains from the study area with one or two exceptions (Table 3.79). As was present only in the samples, H2 and H4, whereas Hg was present only in one sample, H2. The ranges are as follows:

Al	172 (H5) – 203.27 (H2) mg/kg
As	BDL – 0.006 (H2) mg/kg
Cd	1.12 (H5) – 3.4 (H4) mg/kg
Cr	2.9 (H2) – 5.9 (H3) mg/kg
Cu	8.7 (H5) – 21.2 (H2) mg/kg
Fe	52.1 (H5) – 142 (H1) mg/kg
Hg	BDL - 0.006 (H2) mg/kg
Mn	90.41 (H4)- 353.7 (H2) mg/kg
Ni	1.3 (H5) – 5.3 (H1) mg/kg
Pb	3.43 (H4) – 11.74 (H1) mg/kg
Zn	21(H4) – 92 (H1) mg/kg

Table 3.79. Metals present in the rice husk (mg/kg)

Metal	Content (mg/kg) in Rice Husk samples					
	H1	H2	H3	H4	H5	CH
Al	195.00	203.27	169.50	179.00	172.00	62.00
As	BDL	0.05	BDL	0.40	BDL	BDL
Cd	2.96	2.48	2.40	3.40	1.12	0.60
Cr	5.00	2.90	5.90	4.60	5.40	1.60
Cu	14.80	21.20	16.40	10.00	8.70	3.50
Fe	142.00	114.20	68.00	78.50	52.10	46.00
Hg	BDL	0.01	BDL	BDL	BDL	BDL
Mn	89.16	353.70	148.60	90.41	260.90	59.00
Ni	5.30	2.70	4.80	2.09	1.30	1.04
Pb	11.74	7.22	6.20	3.43	7.20	3.60
Zn	92.00	61.00	75.60	21.00	18.45	20.00

Conclusions

From the study it is evident that the grain samples near to the Mill (R1) has substantial amount of different metals. Though no distinct trend was observed for variation with distance from the Mill, it can be inferred that the grains were richer in the different metals, which may be due to the use of the Mill effluent for irrigation in the nearby agricultural land.

CHAPTER 4

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The present study investigated the impacts of the effluents and other wastes of Textile Mill on quality of soil and water in the surrounding areas. All the results have been discussed in relation to soil and water from a 'Control' site and also on the basis of available permissible values. Degradation of both soil and water quality was a general observation, and the following specific impacts have been identified from the work:

(i) There was an increase in the pH of the soil in the vicinity of the Mill, thus the normally acidic soil was turned into near neutral conditions.

(ii) The soil was getting enriched with both ionic matter and hydrophobic organic matter resulting in high electrical conductivity and lower bulk density. The accumulation of the organic matter nearer to the Mill has been shown to give rise to reduction in water holding capacity and increase in hydraulic conductivity of the soil. The considerable organic load of the soil was also confirmed by high values of 'loss on ignition' as measured by the XRF.

(iii) The soil texture was dominated by sand in conformity with high hydraulic conductivity and low water holding capacity. XRD patterns of the soil samples also supported the same.

(iv) The toxic organic contaminant, oil and grease, had a directional presence and the values were not much alarming.

(v) The soil was rich in nitrogen and phosphorus, the major crop nutrients, and therefore, the soil had not lost its nutritive character.

(vi) All the four major cations, Ca, Mg, Na and K, had considerable presence in the soil with the contents much more near the Mill. The soil was very rich in Al and Fe. The measurement of major oxides by XRF was in agreement with the presence of these metals in the soil in large amounts.

(vii) Trace metals, which were conspicuous by appreciable presence, are As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn.

In general, it was observed that the earthen dam behind the Mill had divided the area into two zones viz., the affected zone between the Mill and the dam, and the less affected zone beyond the dam. The dam had served as a physical barrier in preventing the contaminants from the Mill to areas far beyond. The experimental data showed important variations from one season to another, particularly with respect to pre-monsoon and post-monsoon seasons, but significant trends were very few. This may be due to irregular and intermittent inflow of the effluent and also due to absence of a particular pattern of discharge.

The quality of the drinking water in and around the textile mill did reflect the changes in the physico-chemical quality of the soil. In general, it was seen that

(i) The pH, EC, alkalinity and solids present in the water were within the permissible limits and therefore, the influence of the Textile Mill effluent has not yet reached the position of critical interference.

(ii) The water was characterized by considerable presence of the cations, Ca, Mg, Na and K, being compensated by comparative presence of Cl, NO_3 and SO_4. All the contents of the cations and anions were within the permissible limits. The only concern was the presence of fluoride in very high concentration in some of the drinking water sources, which might have impact on human health. However, the source of fluoride could not be definitely ascertained and no conclusion could be drawn whether the large amounts were due to the Mill effluent. The water was rich with PO_4 content which would be likely to stimulate growth of undesirable algae, weeds, herbs, microorganisms, etc. leading to deterioration of water quality.

(iii) The toxic organic contaminant, phenol, which usually was contributed by industrial effluents, was present in some of the drinking water sources.

(iv) Huge amount of iron was present in all the samples. The seasonal variation was distinct. The maximum value was obtained in the pre-monsoon season and the minimum in the post-monsoon season for all the samples.

(v) Among the toxic heavy metals, As and Hg were absent in most of the sources. Two other toxic metals, Cd and Cr, were however present in all the sources with concentration of more than the permissible limit. The presence of copper and zinc was low and not significant.

(vi) The water was also found to be contaminated with Mn, Ni, and Pb – the level of contamination being dependent on the source, the sampling season, etc.

The surface water was not much different from the drinking water with respect to quality. It contained large amounts of dissolved solids, and was having significantly high amounts of phenol, and oil and grease.

It was also seen that the rice crops grown in the study area had accumulated appreciable amounts of metals in them as seen from the analysis of rice grains and husks. Significantly, the husks were seen to be richer in the metals than the grains with one or two exceptions.

Suggestions for further work

The present work is exploratory in nature and it definitely established that an industry could have significant chemical impact on the soil and water in the vicinity. The study has clearly opened up the following areas for further research:

(i) Work needs to be carefully carried out to find out the patterns of distribution of various pollutants temporally and spatially. Of particular importance will be the investigation of downward spread of the pollutants, which depends on soil permeability and other factors. This will be helpful in establishing the groundwater infiltration potential.

(ii) The organic pollutants need to be identified in details with respect to the specific composition. The role of soil in their accumulation as well as degradation can be evaluated by identifying some of the components and then carefully studying their fate over time and distance.

(iii) The properties of the soil and those of the water need to be correlated by using careful sampling and analysis strategies as well as using statistical packages.

(iv) The intake of pollutants by the crops needs a detailed study under different conditions by simulation in the laboratory and then correlating the same with results from a field study.

(v) Another study is required to identify the exact sources of the pollutants and then, to design appropriate prevention/remediation techniques.

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List of Publications

a) Published research paper in Indian Journal of Environmental Protection, Vol 27, Number 10, October 2007.

b) Published research paper in Indian Journal of Environmental Protection, Vol 27, Number 7, July 2007.

c) Full paper published in the proceeding of National Seminar on Pollution in Urban Industrial Environment, at RRL (CSIR), Bhubaneswar, from 2nd and 3rd December 2004; Published by Allied Publishers Private Limited, New Delhi. pp 117-124.

d) One paper accepted for publication in the Jr. of Industrial Pollution Control (Ref JIPC/2006/138 dated 27.4.2007).