CHAPTER 3
RESULTS AND DISCUSSION

The results obtained in this work are discussed below in four sections, viz., (i) soil quality, (ii) drinking water quality, (iii) surface water quality and (iv) quality of paddy husk and grain grown in the impacted area (with special reference to heavy metals).

3.1 Soil Quality of the Study Area

25 surface soil samples were collected from side A and 20 from side B in six seasons from the Mill as shown below:

S/N	Batch	Season
1	B0	2002 premonsoon
2	A1	2002 post monsoon
3	B1	2003 premonsoon
4	A2	2003 postmonsoon
5	B2	2004 premonsoon
6	A3	2004 post monsoon

The results of measurement of various physico-chemical properties are discussed below.

3.1.1. Soil pH

The values of the surface soil pH for side A and side B are given respectively in Tables 3.1(a) and 3.1(b) with basic statistics i.e., the maximum, the minimum, the mean and the standard deviation (SD) of the data. Considering the soil samples of the same batch in different directions or considering the same site for the three batches, the value show very wide ranges. In all the cases, the Control soil had higher pH values compared to those from the impact zone of the Mill where the soil was in some cases strongly acidic. Thus taking all the 25 samples together, the pH was in the ranges of

Batch B0 : 2.5 – 6.8, Batch B1 : 3.5 – 6.4, Batch B2 : 3.6 – 7.0

The basic statistics with respect to each site for the three batches of samples are also very wide (Table 3.1 (a)) showing that pH of the soil had both temporal and spatial variations. Fig. 3.1 shows how the pH changes in different directions from the Mill with distance (Side A).

In side B, pH values were found increasing, as the distance from the mill increased (Table 3.1 (b)). Though the values are not uniform there was an increasing trend. The soil samples were attaining almost normal pH values of Assam soil (5.5-6.5) as the distance from the Mill increased in any direction. The values were found less in the post-monsoon season than the pre-monsoon season. This difference was likely to be due to the effects of rains during the monsoon. In the pre-monsoon season, A3, the pH values in West direction were found to be more in comparison to those for the other seasons.

Fig.3.2 shows how the minimum, the maximum and the mean values of the pH of the soil in side B change from one site to another. The pattern was different in different directions. The most regular pattern was shown in the northern direction, where the spread of pH values increased as distance from the Mill increased (Sites S30 to S33). In the other four directions, the spread of values had a slight tendency to decrease with distance. The mean pH, of course, increased in all the cases as the distance increased and therefore, it again points to an influence of the Mill effluent in reducing the pH of the soil.

3.1.2 Soil Electrical Conductivity (EC)

The electrical conductivity values of the soil samples in different directions from the sides A and B are given in Tables 3.2(a) and 3.2 (b).

The soil samples in study area were very rich in ionic content and more so in Side A. All the samples in north, northwest and west directions received effluent loads from the Mill for which the EC values were more in these directions. The highest value obtained was for the site S20 (3.51 mS/cm) in the west direction for the B1 batch and the lowest was at S2 (0.07 mS/cm) in northeast direction for the B2 batch. Among all the batches, B2 had the lowest values of all the batches. This was because during that period the production of mill was temporarily suspended. In all the cases, the 'Control' sample had the lowest values.

Table 3.1(a). pH of soil samples from side A

Direction	pH	B0	B1	B2	Min	Max	Mean	SD
	Control	7.3	7.1	7.1	7.3	7.1	7.2	0.1
NE	S1	5.4	5.9	6.6	5.4	6.6	6.0	0.6
	S2	5.7	6.4	6.8	5.7	6.8	6.3	0.5
	S3	5.6	6.1	6.2	5.6	6.2	6.0	0.3
	S4	5.6	6.4	6.8	5.6	6.8	6.3	0.6
	S5	5.7	5.6	7.0	5.6	7.0	6.1	0.8
N	S6	4.8	5.0	3.6	3.6	5.0	4.5	0.7
	S7	4.8	4.9	4.3	4.3	4.9	4.7	0.3
	S8	3.7	4.0	4.8	3.7	4.8	4.2	0.6
	S9	3.6	4.0	6.9	3.6	6.9	4.8	1.8
	S10	4.5	4.8	5.7	4.5	5.7	5.0	0.6
NW	S11	4.4	4.8	5.2	4.4	5.2	4.8	0.4
	S12	4.1	5.0	5.4	4.1	5.4	4.8	0.6
	S13	4.3	3.9	5.0	3.9	5.0	4.4	0.6
	S14	3.7	4.4	4.3	3.7	4.4	4.2	0.4
	S15	4.7	5.2	5.1	4.7	5.2	5.0	0.3
W	S16	2.5	4.1	5.0	2.5	5.0	3.9	1.3
	S17	3.2	4.0	5.0	3.2	5.0	4.0	0.9
	S18	3.3	4.2	4.3	3.3	4.3	3.9	0.5
	S19	4.2	4.3	4.3	4.2	4.3	4.3	0.1
	S20	3.3	3.5	4.5	3.3	4.5	3.8	0.7
SW	S21	6.8	5.7	6.2	5.7	6.8	6.2	0.5
	S22	6.5	5.8	6.0	5.8	6.5	6.1	0.3
	S23	6.2	6.3	6.5	6.2	6.5	6.3	0.2
	S24	5.6	5.1	6.0	5.1	6.0	5.6	0.5
	S25	5.1	6.0	6.2	5.1	6.2	5.8	0.6
	Min	2.5	3.5	3.6				
	Max	6.8	6.4	7.0				
	Mean	4.7	5.0	5.5				
	SD	1.1	0.9	1.0				

Table 3.1(b) : pH of soil samples from Side B

Direction	pH	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	7.2	7.1	7.3	7.1	7.3	7.1	7.3	7.2	0.1
S	S26	4.3	4.5	4.2	7.0	4.0	4.0	7.0	4.8	1.3
	S27	4.9	5.7	5.0	7.0	5.1	4.9	7.0	5.5	0.9
	S28	5.0	4.8	5.0	7.0	5.8	4.8	7.0	5.5	0.9
	S29	5.9	6.1	5.8	6.7	5.2	5.2	6.7	5.9	0.5
N	S30	5.2	5.5	5.2	5.3	5.2	5.2	5.5	5.3	0.1
	S31	5.1	5.4	5.0	5.9	5.7	5.0	5.9	5.4	0.4
	S32	5.3	6.5	5.3	6.0	5.5	5.3	6.5	5.7	0.5
	S33	5.3	5.8	5.3	7.2	5.7	5.3	7.2	5.8	0.8
NW	S34	4.2	4.6	4.2	6.2	5.2	4.2	6.2	4.9	0.9
	S35	4.3	4.4	4.4	6.2	5.0	4.3	6.2	4.9	0.8
	S36	5.1	6.0	5.1	7.2	5.6	5.1	7.2	5.8	0.9
	S37	5.4	5.7	5.6	6.9	5.5	5.4	6.9	5.8	0.6
W	S38	4.1	5.5	4.1	7.0	4.9	4.1	7.0	5.1	1.2
	S39	5.0	5.0	4.5	7.0	4.9	4.5	7.0	5.3	1.0
	S40	4.9	6.0	5.0	7.1	5.6	4.9	7.1	5.7	0.9
	S41	6.1	6.7	5.9	6.9	6.0	5.9	6.9	6.3	0.5
SW	S42	4.4	5.5	4.4	6.7	5.0	4.4	6.7	5.2	1.0
	S43	4.0	4.4	4.3	6.6	4.5	4.0	6.6	4.8	1.0
	S44	5.2	6.0	5.1	6.9	5.5	6.9	5.1	5.7	0.7
	S45	5.3	6.0	5.2	6.5	5.4	6.5	5.2	5.7	0.6
	Min	4.0	4.4	4.1	5.3	4.0				
	Max	6.1	6.7	5.9	7.2	6.0				
	Mean	5.0	5.5	4.9	6.7	5.3				
	SD	0.6	0.7	0.5	0.5	0.5				

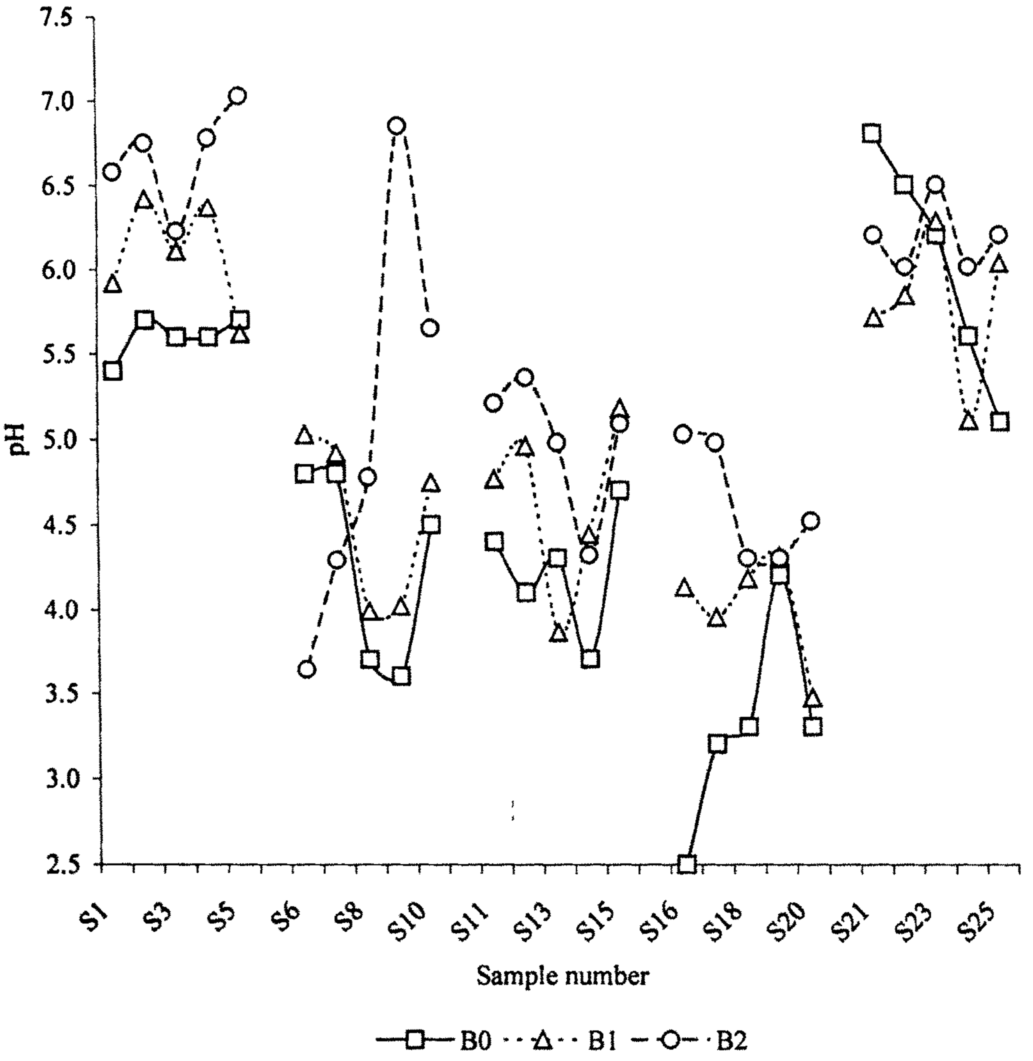


Fig. 3.1. Variation of pH in Side A with distance and direction from the Mill (S1 to S5 NE, S6 to S10 N, S11 to S15 NW, S16 to S20 W, S21 to S25 SW directions)

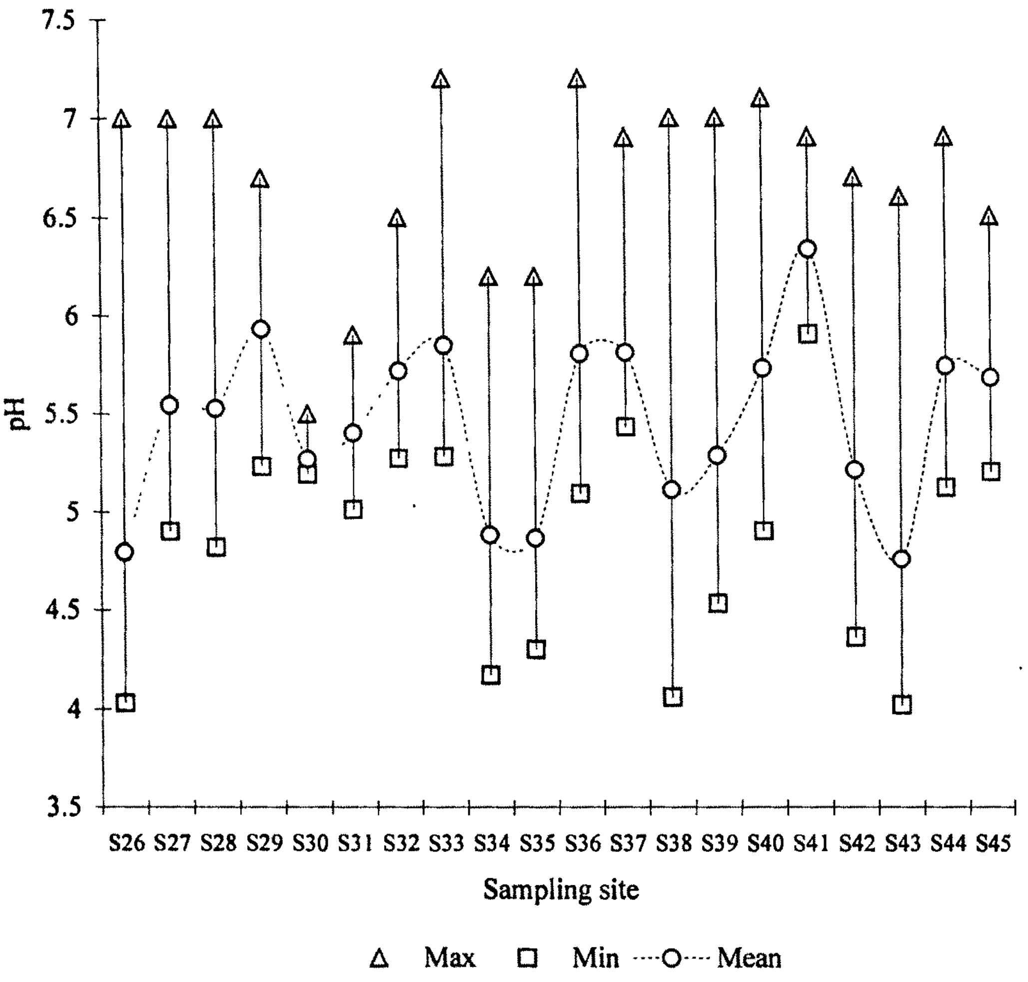


Fig. 3.2. Pattern of variation of the soil pH in Side B with respect to the minimum, the maximum and the mean values measured for all the batches of samples.

Table 3.2(a). Electrical conductivities (mS/cm) of the soil from Side A

Direction	EC	B0	B1	B2	Min	Max	Mean	SD
	Control	0.15	0.19	0.12	0.12	0.19	0.15	0.04
NE	S1	0.23	0.32	0.13	0.13	0.32	0.23	0.10
	S2	0.20	0.31	0.07	0.07	0.31	0.19	0.12
	S3	0.15	0.26	0.11	0.11	0.26	0.17	0.08
	S4	0.13	0.28	0.12	0.12	0.28	0.18	0.09
	S5	0.22	0.26	0.08	0.08	0.26	0.19	0.09
N	S6	1.31	1.48	0.61	0.61	1.48	1.13	0.46
	S7	1.30	1.50	0.67	0.67	1.50	1.16	0.43
	S8	1.37	1.42	0.26	0.26	1.42	1.02	0.66
	S9	2.37	1.89	0.08	0.08	2.37	1.45	1.21
	S10	1.30	1.41	0.15	0.15	1.41	0.95	0.70
NW	S11	1.37	2.02	1.13	1.13	2.02	1.51	0.46
	S12	1.32	1.16	1.03	1.03	1.32	1.17	0.15
	S13	1.32	1.67	0.98	0.98	1.67	1.32	0.35
	S14	1.99	1.07	1.02	1.02	1.99	1.36	0.55
	S15	1.25	1.21	1.01	1.01	1.25	1.16	0.13
W	S16	2.77	2.89	1.06	1.06	2.89	2.24	1.02
	S17	2.61	2.83	0.76	0.76	2.83	2.07	1.14
	S18	2.57	2.02	0.78	0.78	2.57	1.79	0.92
	S19	1.62	2.05	0.89	0.89	2.05	1.52	0.59
	S20	2.39	3.51	0.95	0.95	3.51	2.28	1.28
SW	S21	0.34	0.63	0.86	0.34	0.86	0.61	0.26
	S22	0.39	0.46	0.92	0.39	0.92	0.59	0.29
	S23	0.14	0.32	0.92	0.14	0.92	0.46	0.41
	S24	0.18	0.23	0.98	0.18	0.98	0.46	0.45
	S25	0.42	0.39	0.96	0.39	0.96	0.59	0.32
	Min	0.13	0.19	0.07	0.07	0.19	0.15	0.04
	Max	2.77	3.51	1.13	1.13	3.51	2.28	1.28
	Mean	1.13	1.22	0.64	0.52	1.41	1.00	0.47
	SD	0.90	0.94	0.40	0.39	0.92	0.67	0.37

Table 3.2(b). Electrical conductivities (mS/cm) of the soil from Side B

Direction	EC	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.19	0.19	0.13	0.12	0.15	0.12	0.19	0.16	0.03
S	S26	0.31	0.18	0.29	0.07	0.26	0.07	0.31	0.22	0.10
	S27	0.20	0.04	0.17	0.06	0.21	0.04	0.21	0.14	0.08
	S28	0.16	0.02	0.13	0.08	0.12	0.02	0.16	0.10	0.05
	S29	0.20	0.07	0.21	0.05	0.17	0.05	0.21	0.14	0.07
N	S30	0.41	0.22	0.37	0.26	0.29	0.22	0.41	0.31	0.08
	S31	0.31	0.22	0.33	0.34	0.31	0.22	0.34	0.30	0.05
	S32	0.21	0.04	0.19	0.20	0.20	0.04	0.21	0.17	0.07
	S33	0.20	0.09	0.21	0.07	0.20	0.07	0.21	0.15	0.07
NW	S34	0.76	0.68	0.71	0.16	0.72	0.16	0.76	0.61	0.25
	S35	0.39	0.29	0.40	0.19	0.45	0.19	0.45	0.34	0.10
	S36	0.31	0.08	0.33	0.11	0.40	0.08	0.40	0.25	0.14
	S37	0.37	0.21	0.29	0.07	0.21	0.07	0.37	0.23	0.11
W	S38	0.30	0.28	0.36	0.10	0.31	0.10	0.36	0.27	0.10
	S39	0.41	0.26	0.49	0.11	0.43	0.11	0.49	0.34	0.15
	S40	0.20	0.07	0.24	0.13	0.31	0.07	0.31	0.19	0.09
	S41	0.34	0.13	0.28	0.06	0.30	0.06	0.34	0.22	0.12
SW	S42	0.22	0.17	0.25	0.15	0.21	0.15	0.25	0.20	0.04
	S43	0.13	0.07	0.09	0.04	0.09	0.04	0.13	0.08	0.03
	S44	0.26	0.08	0.23	0.09	0.21	0.08	0.26	0.17	0.08
	S45	0.20	0.15	0.22	0.06	0.22	0.06	0.22	0.17	0.07
	Min	0.13	0.02	0.09	0.04	0.09	0.02	0.13	0.08	0.03
	Max	0.76	0.68	0.71	0.34	0.72	0.22	0.76	0.61	0.25
	Mean	0.29	0.17	0.28	0.12	0.27	0.10	0.31	0.23	0.09
	SD	0.14	0.14	0.14	0.08	0.14	0.06	0.14	0.11	0.05

The EC values of the soil samples in side B, were found to be less in comparison to those for Side A. The maximum value was at S34 (0.76 mS/cm) in the northwest direction in A1 batch and the minimum value was at S28 (0.02 mS/cm) in the southern direction for B1 batch. Most of the soil samples in the pre-monsoon season had less conductivity than the corresponding post monsoon values. This means that the ionic matter in the runoff during the monsoon season has remained in the soil in the post-monsoon period.

For Side A, the variation of the EC values with distance in the different directions is shown in Fig. 3.3 for the first two batches (the last batch B2 was not included as the Mill stopped production before this batch and the EC values came down as seen from Table 3.2(a)). Some uniformity in the change of EC with distance could be observed particularly in N, NW and W directions from the figure. The Mill effluents obviously affect the soil more in these directions.

Similar variations were also observed for the EC of the soil in Side B. This is also shown in Fig. 3.4 with respect to the minimum, the maximum and the mean values taking all the five batches of sampling together. The electrical conductivity was highest at the site nearest to the Mill (in Side B) and then, in most cases, it shows a decreasing trend.

3.1.3 Bulk Density

The bulk density of the surface soil for both the sides, A and B, are given in the Tables 3.3(a) and 3.3(b) with the mean values and the standard deviations. The values were from 0.72 g/cm^3 – 1.32 g/cm^3 for Batch B0, 0.02 g/cm^3 – 0.68 g/cm^3 for B1 and 0.83 g/cm^3 – 1.12 g/cm^3 for B2. In most of the cases, B2 values are higher than the B0 and B1 values. Accumulation of organic matter in the soil lowers the bulk density of the soil near the Mill. The bulk density values further show that the soil samples in north, northwest and west directions have gathered more organic matter compared to soil in the other directions. In every occasion, the "Control' soil was found to possess a higher bulk density than the soil in the study area. It has been shown that organic C content is the strongest contributor to bulk density prediction (Heuscher et al., 2005).

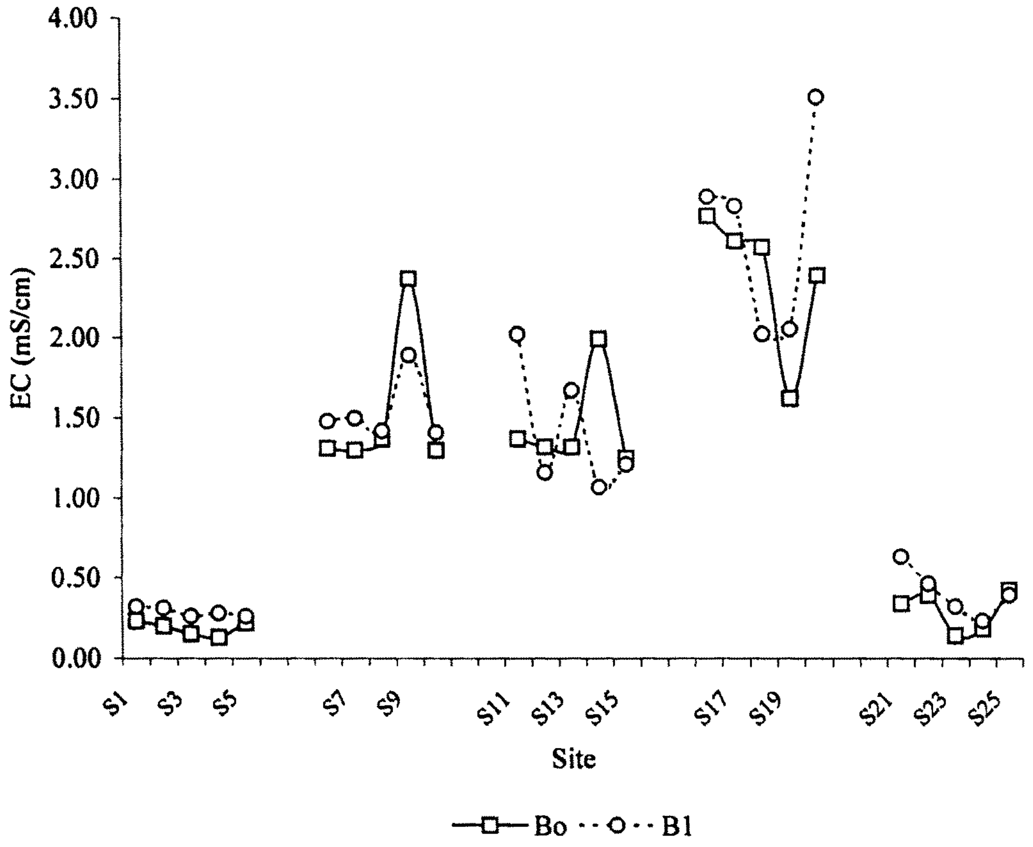


Fig. 3.3. Variation of electrical conductivity of soil (Side A) during the batches B0 and B1 (both pre-monsoon).

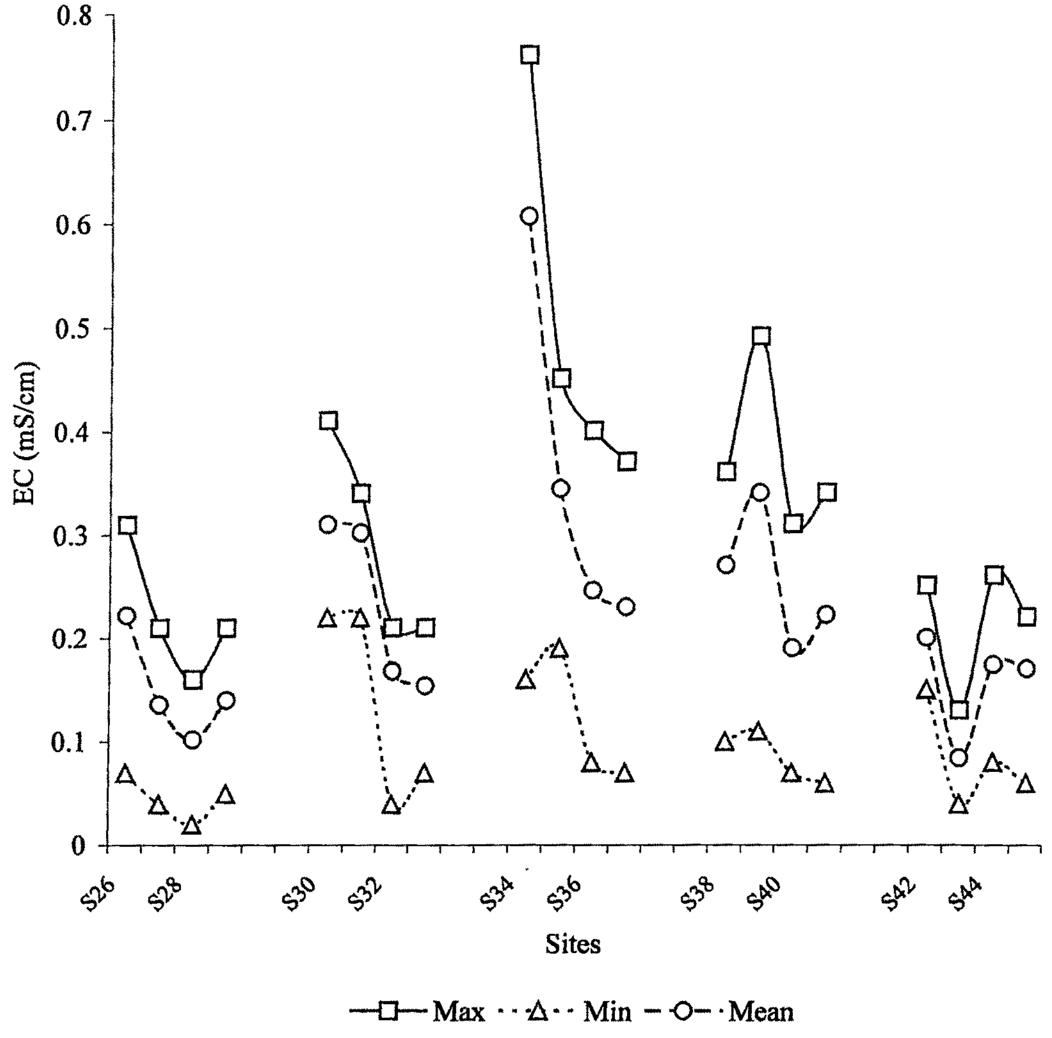


Fig. 3.4. Variation of the minimum, the maximum and the mean values of electrical conductivity of soil (Side B) for all the batches

Table 3.3(a). Bulk density (g/cm^3) of the soil in Side A

Direction	BD	B0	B1	B2	Min	Max	Mean	SD
	Control	1.32	1.23	1.06	1.06	1.32	1.20	0.13
NE	S1	0.93	0.94	0.95	0.93	0.95	0.94	0.01
	S2	0.95	0.97	0.93	0.93	0.97	0.95	0.02
	S3	0.97	1.02	0.98	0.97	1.02	0.99	0.03
	S4	1.02	1.07	1.10	1.02	1.10	1.06	0.04
	S5	1.04	1.08	1.03	1.03	1.08	1.05	0.03
N	S6	0.72	0.76	0.83	0.72	0.83	0.77	0.06
	S7	0.78	0.77	0.89	0.77	0.89	0.81	0.07
	S8	0.73	0.79	0.93	0.73	0.93	0.82	0.10
	S9	0.78	0.81	0.89	0.78	0.89	0.83	0.06
	S10	0.77	0.81	0.91	0.77	0.91	0.83	0.07
NW	S11	0.72	0.85	0.96	0.72	0.96	0.84	0.12
	S12	0.74	0.88	1.04	0.74	1.04	0.89	0.15
	S13	0.78	0.89	1.03	0.78	1.03	0.90	0.13
	S14	0.80	0.82	1.04	0.80	1.04	0.89	0.14
	S15	0.80	0.78	1.09	0.78	1.09	0.89	0.17
W	S16	0.78	0.74	1.12	0.74	1.12	0.88	0.21
	S17	0.78	0.77	0.88	0.77	0.88	0.81	0.06
	S18	0.78	0.83	0.94	0.78	0.94	0.85	0.08
	S19	0.85	0.85	0.87	0.85	0.87	0.86	0.01
	S20	0.81	0.78	1.02	0.78	1.02	0.87	0.13
SW	S21	0.82	0.92	0.91	0.82	0.92	0.88	0.06
	S22	0.85	0.94	0.97	0.85	0.97	0.92	0.06
	S23	0.90	0.96	0.95	0.90	0.96	0.94	0.03
	S24	0.88	0.97	1.01	0.88	1.01	0.95	0.07
	S25	0.92	1.13	1.01	0.92	1.13	1.02	0.11
	Min	0.72	0.74	0.83	0.83	0.72	0.77	0.01
	Max	1.04	1.13	1.12	1.13	1.03	1.06	0 21
	Mean	0.84	0.89	0.97	0.98	0.83	0.90	0.08
	SD	0.09	0.11	0.08	0.08	0.09	0.08	0.05

Table 3.3(b). Bulk density (g/cm^3) of the soil in Side B

Direction	BD	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	1.24	1.23	1.20	1.06	1.24	1.06	1.24	1.19	0.08
S	S26	0.96	1.11	0.92	1.21	0.99	0.92	1.21	1.04	0.12
	S27	1.10	1.23	0.97	1.26	1.00	0.97	1.26	1.11	0.13
	S28	1.16	1.22	1.11	1.30	1.03	1.03	1.30	1.16	0.10
	S29	1.38	1.34	1.20	1.30	1.16	1.16	1.38	1.28	0.09
N	S30	0.92	1.27	0.84	1.36	0.97	0.84	1.36	1.07	0.23
	S31	0.91	1.30	0.95	1.40	1.00	0.91	1.40	1.11	0.22
	S32	1.10	1.56	0.98	1.51	1.15	0.98	1.56	1.26	0.26
	S33	0.92	1.59	0.96	1.53	1.22	0.92	1.59	1.24	0.31
NW	S34	0.90	1.08	0.85	1.20	0.89	0.85	1.20	0.98	0.15
	S35	0.91	1.12	0.96	1.25	1.06	0.91	1.25	1.06	0.13
	S36	1.03	1.43	1.01	1.38	0.97	0.97	1.43	1.16	0.22
	S37	1.20	1.38	1.14	1.36	0.98	0.98	1.38	1.21	0.17
W	S38	0.83	1.21	0.80	1.30	1.01	0.80	1.30	1.03	0.22
	S39	0.92	1.28	0.96	1.26	1.04	0.92	1.28	1.09	0.17
	S40	1.30	1.35	1.00	1.29	1.15	1.00	1.35	1.22	0.14
	S41	1.32	1.33	1.10	1.28	1.02	1.02	1.33	1.21	0.14
SW	S42	0.92	1.20	0.90	1.25	1.08	0.90	1.25	1.07	0.16
	S43	0.87	1.19	0.97	1.24	1.07	0.87	1.24	1.07	0.15
	S44	1.10	1.26	0.98	1.30	1.12	0.98	1.30	1.15	0.13
	S45	1.06	1.59	1.20	1.53	1.24	1.16	1.59	1.28	0.31
	Min	0.83	1.08	0.80	1.06	0.89	0.80	1.20	0.98	0.08
	Max	1.38	1.59	1.20	1.53	1.24	1.16	1.59	1.28	0.31
	Mean	1.05	1.30	1.00	1.31	1.07	0.96	1.34	1.14	0.17
	SD	0.16	0.15	0.12	0.11	0.10	0.09	0.12	0.09	0.07

As the Side B is further away from the Mill, the soil samples in this side have less organic load in comparison to Side A, but the values exhibit same trends as in Side A with distance. In B1 and B2 batches (pre-monsoon), the bulk density ranges from 1.08 – 1.59 g/cm^3 and 0.89 – 1.24 g/cm^3 respectively whereas in A1, A2 and A3 seasons (post-monsoon), the ranges are 0.83 – 1.38 g/cm^3, 0.8 – 1.2 g/cm^3 and 0.89 – 1.24 g/cm^3 respectively. It was generally observed that the values during the pre-monsoon were higher than those during the post-monsoon period.

The above trends can be clearly seen from Fig. 3.5.

3.1.4 Water holding capacity (WHC)

The water holding capacity values of the soil samples in different directions for both the sides, A and B, are given in Table 3.4(a) and 3.4(b). The values show significant changes with distance and direction. The ranges of values are

- 51.1 (S7 in north direction) – 81% (S15 in northwest direction) in B0 batch
- 54.9 (S 6 in northeast direction) – 79.8% ((S10 in north direction) in B1 batch
- 56.4 (S6 in north direction) – 79.2% (S10 in north direction) in B2 batch.

The mean values for all the batches are very similar. The values obtained for the "Control "are more than the field samples. Samples S6 and S7 in northern direction and S11 in northwestern direction had low values in B1 batch and B2 batch. This is likely to be due to the presence of hydrophobic matter contributed by the Mill effluent. During the pre-monsoon season, no distinct spatial variation was observed.

The standard deviations of the measured values for all the three seasons with respect to the different sites in Side A are not much except for a few of the locations. Thus, the variation of the values from one season to another was tolerable. When the standard deviations for each of the three seasons taking all the sampling sites together are computed (Table 3.4(a) bottom row), the values do not differ much from one another as they remain in the range of 6 – 7.

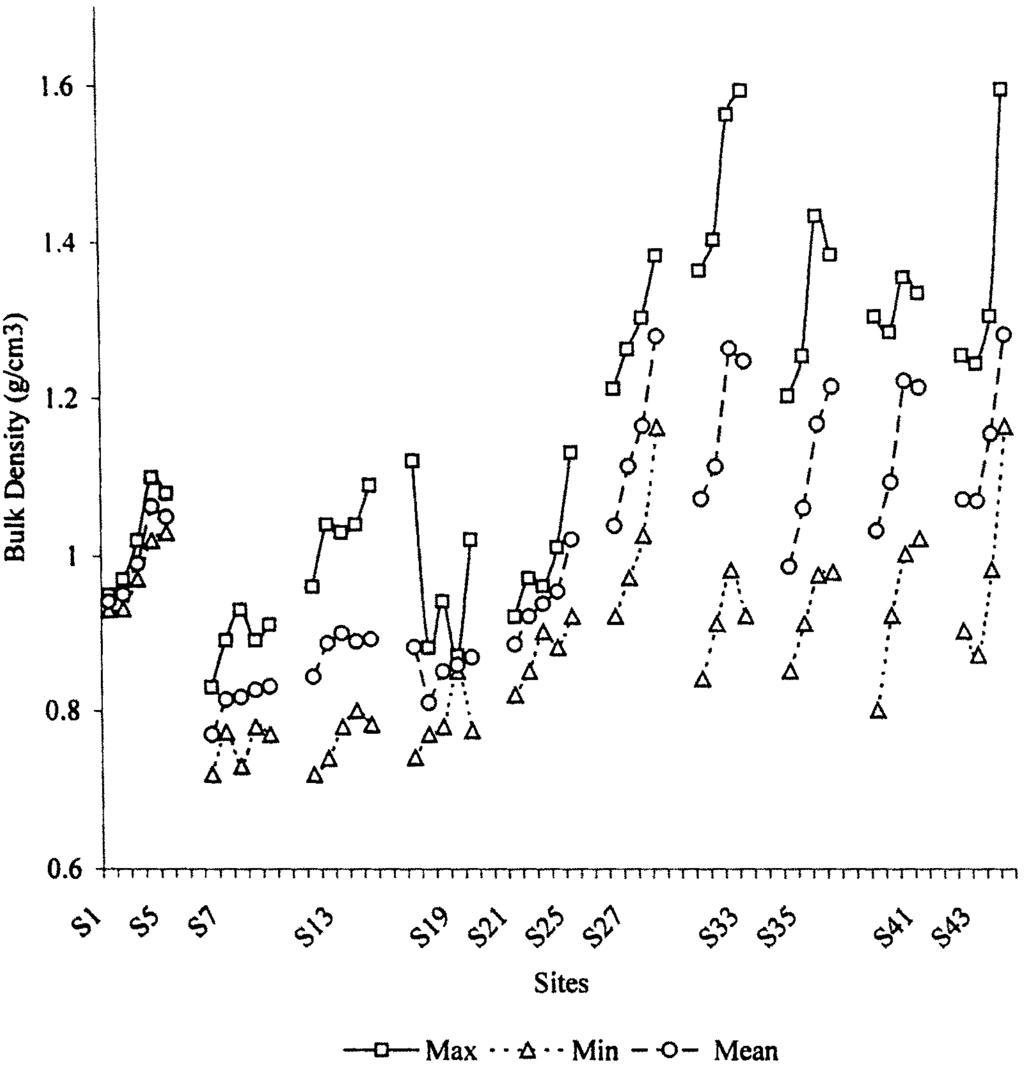


Fig. 3.5. Variation of the minimum, the maximum and the mean values of Bulk Density of the soil for all the batches with respect to sampling sites in different directions

Table 3.4 (a). Water holding capacities of the soil samples of the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	81.8	82.0	84.0	81.8	84.0	82.6	1.2
NE	S1	60.2	61.4	63.5	60.2	63.5	61.7	1.7
	S2	62.1	62.6	64.4	62.1	64.4	63.0	1.2
	S3	64.2	63.1	64.2	63.1	64.2	63.8	0.6
	S4	65.1	63.2	64.4	63.2	65.1	64.2	1.0
	S5	62.0	64.9	66.2	62.0	66.2	64.4	2.2
N	S6	79.2	54.9	56.4	54.9	79.2	63.5	13.6
	S7	51.1	63.5	64.2	51.1	64.2	59.6	7.4
	S8	64.1	75.6	74.5	64.1	75.6	71.4	6.3
	S9	73.0	75.8	76.2	73.0	76.2	75.0	1.7
	S10	62.0	79.8	79.2	62.0	79.8	73.7	10.1
NW	S11	70.5	56.9	60.2	56.9	70.5	62.5	7.1
	S12	80.0	67.8	65.6	65.6	80.0	71.1	7.8
	S13	70.5	70.3	71.4	70.3	71.4	70.7	0.6
	S14	71.0	64.8	65.5	64.8	71.0	67.1	3.4
	S15	81.0	71.9	72.0	71.9	81.0	75.0	5.2
W	S16	70.0	69.1	70.0	69.1	70.0	69.7	0.5
	S17	70.5	70.3	71.5	70.3	71.5	70.8	0.6
	S18	70.2	72.9	74.8	70.2	74.8	72.6	2.3
	S19	70.3	71.8	73.8	70.3	73.8	72.0	1.8
	S20	73.5	66.4	64.5	64.5	73.5	68.1	4.7
SW	S21	68.4	72.9	74.5	68.4	74.5	71.9	3.2
	S22	69.3	70.5	71.5	69.3	71.5	70.4	1.1
	S23	70.3	71.8	72.4	70.3	72.4	71.5	1.1
	S24	72.6	74.2	76.0	72.6	76.0	74.3	1.7
	S25	76.4	74.6	76.0	74.6	76.4	75.7	0.9
	Min	51.1	54.9	56.4				
	Max	81.0	79.8	79.2				
	Mean	69.1	68.4	69.3				
	SD	6.8	6.1	5.8				

Table 3.4 (b). Water holding capacities of the soil samples of the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	80.7	82.0	81.2	84.0	80.7	80.7	84.0	81.7	1.4
S	S26	57.1	64.8	56.9	65.0	60.1	56.9	65.0	60.8	4.0
	S27	61.1	69.7	60.1	70.0	62.2	60.1	70.0	64.6	4.8
	S28	64.1	74.1	63.4	76.7	63.0	63.0	76.7	68.2	6.6
	S29	64.1	78.4	63.3	78.7	63.2	63.2	78.7	69.5	8.2
N	S30	59.4	67.0	61.1	70.3	63.0	59.4	70.3	64.2	4.5
	S31	60.3	62.9	61.4	64.5	62.6	60.3	64.5	62.3	1.6
	S32	64.2	68.5	66.2	71.0	65.7	64.2	71.0	67.1	2.6
	S33	68.5	69.8	67.6	70.8	70.2	67.6	70.8	69.4	1.3
NW	S34	60.3	71.6	60.0	72.4	62.5	60.0	72.4	65.3	6.1
	S35	60.8	65.6	59.4	66.8	66.1	59.4	66.8	63.7	3.4
	S36	61.6	70.9	60.5	71.0	66.0	60.5	71.0	66.0	5.0
	S37	63.8	75.6	64.1	76.6	69.3	63.8	76.6	69.9	6.1
W	S38	65.3	64.4	64.6	65.5	63.3	63.3	65.5	64.6	0.9
	S39	64.0	62.3	63.9	64.5	64.7	62.3	64.7	63.9	0.9
	S40	61.8	72.7	60.9	74.4	61.8	60.9	74.4	66.3	6.6
	S41	67.1	76.7	68.5	75.9	69.2	67.1	76.7	71.5	4.5
SW	S42	62.8	71.5	61.2	70.8	62.3	61.2	71.5	65.7	5.0
	S43	58.6	68.1	60.5	70.4	63.3	58.6	70.4	64.2	5.0
	S44	64.3	75.1	62.6	76.0	64.6	62.6	76.0	68.5	6.5
	S45	64.4	78.8	63.5	80.1	66.8	63.5	80.1	70.7	8.1
	Min	57.1	62.3	56.9	64.5	60.1				
	Max	68.5	78.8	68.5	80.1	70.2				
	Mean	62.7	70.4	62.5	71.6	64.5				
	SD	2.8	5.0	2.9	4.8	2.7				

In side B, the values of Water Holding Capacity are in the following ranges:

- 57.1 (S26, in south direction) – 68.5 % (S33, north) in A1 batch
- 62.3 (S39, west) – 78.8 % (S45, southwest) in B1 batch,
- 56.9 (S26, south) – 67.6 % (S33, north) in A2 batch,
- 64.5 (S39, west and S 31 in north) – 80.1 % (S45, south west) B2 batch,
- 60.1 (S26, south) – 70.2 % (S33, north) A3 batch.

The standard deviations of the values with season as the variable and also with site as the variable are less in Side B compared to Side A indicating that differences in water holding capacity away from the Mill get minimized.

It was observed that the values obtained were lower during the post-monsoon season than the pre-monsoon values. The soil, which remains soaked in runoff during the rainy season, thus loses some amount of its capacity to retain water. In side B, the site, S26, nearest to the Mill in the southern direction had the least value of water holding capacity. With distance from the mill increasing, the water holding capacity gains in value as the impact of the organic waste of the Mill on soil becomes reduced.

The directional trends in WHC values away from the Mill in both the side A and the side B are shown with respect to the average values for the pre-monsoon season in Fig. 3.6. The trends were not uniform. The values are likely to depend on various factors including the topography of the area. For example, if there is a depression in the soil, more of the contaminants are likely to accumulate at the same leading to a consequent change in the value of a parameter. Thus, in side B, the average WHC had the lowest value not close to the Mill (distance 150 m), but at a point, which was at a distance of 200 m in all the directions, indicating preferential accumulation of hydrophobic matter at this distance. In side A, the situation was different in each direction. In N and SW directions, WHC decreased between the first two points (distance of 20 m), then it increased continuously in SW direction, but decreased again in N direction after a distance of 80 m from the Mill. In NW direction, WHC increased away from the Mill, decreased again and finally again increased. In W direction, WHC almost continuously increased away from the Mill, but decreased as the earthen dam was approached. Such variations are not unlikely since WHC is determined by a complex interplay of physical and chemical parameters of the soil.

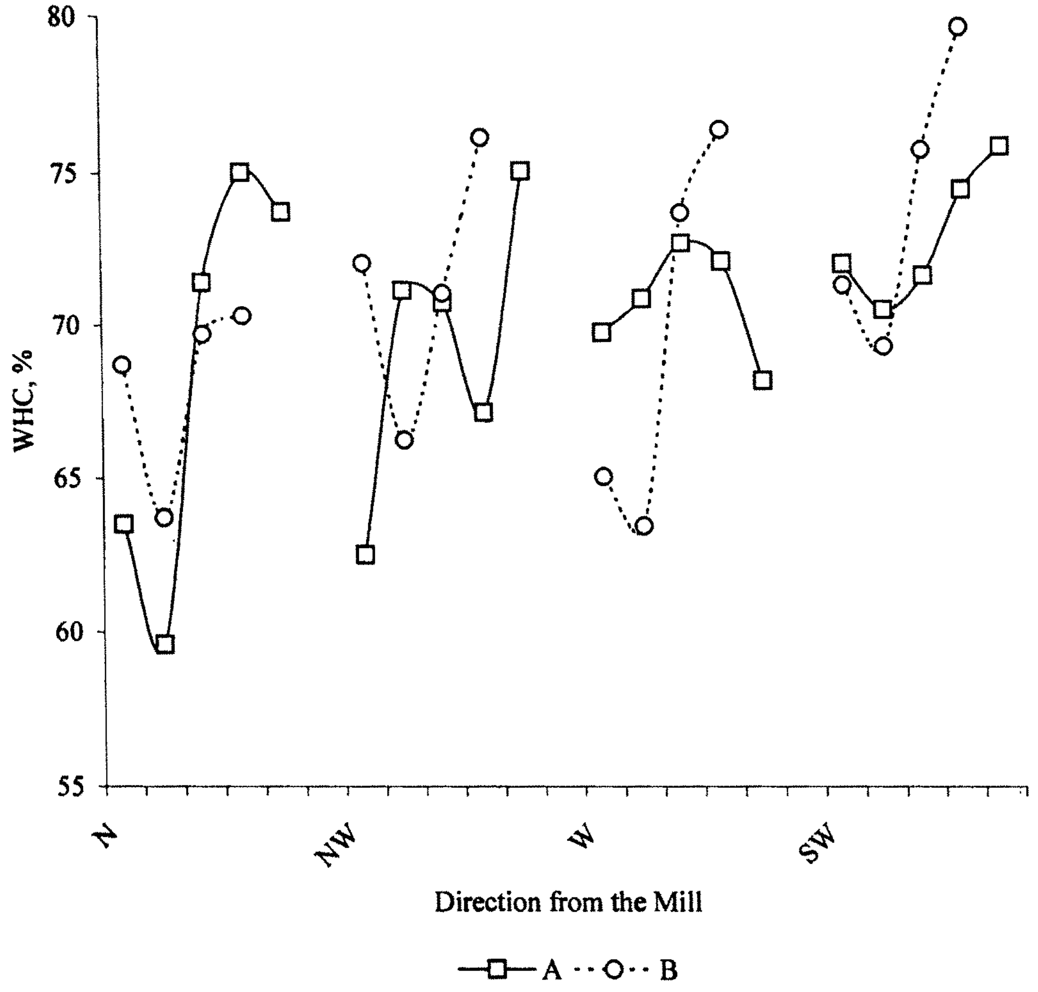


Fig. 3.6. Directional trends in average water holding capacity of the soil for Sides A and B (along N North, NW Northwest, W West and SW Southwest; points from left to right in each direction indicates increasing distance) in the pre-monsoon season.

3.1.5 Hydraulic Conductivity

The hydraulic conductivity values of the soil from side A and side B of the study area are shown in Tables 3.5(a) and 3.5(b). The data also show the minimum, the maximum, the mean and the standard deviation of the values measured for various sites along different directions. The high values of hydraulic conductivity around the Mill in side A are consistent with the observation that the large amount of hydrophobic organic wastes dumped by the Mill in its vicinity has led to a loss of capacity of the soil to retain water. The predominantly sandy nature of the soil near the Mill has also led to increased hydraulic conductivity. The maximum mean value obtained was at S7 (3.7 cm/min) and the minimum at S9 (2.4 cm/min) in north direction. The values exhibited a general tendency to decrease away from the Mill but the trends were not uniform. The Control sample had lower hydraulic conductivity than the soil samples from the study area.

In side B, the values of the hydraulic conductivity were in the following ranges:

- 0.19 – 0.37 cm/min in A1 batch
- 0.20 – 0.37 cm/min in B1 batch
- 0.20 – 0.38 cm/min in A2 batch
- 0.21 – 0.36 cm/min in B2 batch
- 0.21 – 0.35 cm/min in A3 batch

Against these ranges of values, the mean value of the 'Control' soil was 0.19 cm/min. In the Side B also, the hydraulic conductivity values decreased with distance indicating that away from the Mill, the water's capacity to retain water was more.

Another significant observation from Tables 3.5(a) and (b) is that the standard deviations for the hydraulic conductivity computed with respect to sampling season and with respect to distance in different directions for both Side A and Side B were very small and thus, there was not much temporal (Fig. 3.7) and spatial variation (Fig. 3.8) in the values.

Table 3.5(a): Hydraulic conductivity (cm/min) of soil samples in the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.180	0.170	0.175	0.170	0.180	0.175	0.005
NE	S1	0.360	0.340	0.291	0.291	0.360	0.330	0.036
	S2	0.364	0.350	0.302	0.302	0.364	0.339	0.033
	S3	0.341	0.321	0.360	0.321	0.360	0.341	0.020
	S4	0.313	0.327	0.295	0.295	0.327	0.312	0.016
	S5	0.324	0.316	0.311	0.311	0.324	0.317	0.007
N	S6	0.214	0.461	0.427	0.214	0.461	0.367	0.134
	S7	0.347	0.382	0.375	0.347	0.382	0.368	0.019
	S8	0.310	0.281	0.264	0.264	0.310	0.285	0.023
	S9	0.275	0.219	0.228	0.219	0.275	0.241	0.030
	S10	0.358	0.306	0.341	0.306	0.358	0.335	0.027
NW	S11	0.276	0.386	0.374	0.276	0.386	0.345	0.060
	S12	0.230	0.373	0.385	0.230	0.385	0.329	0.086
	S13	0.280	0.369	0.328	0.280	0.369	0.326	0.045
	S14	0.263	0.374	0.364	0.263	0.374	0.334	0.061
	S15	0.245	0.318	0.362	0.245	0.362	0.308	0.059
W	S16	0.266	0.324	0.327	0.266	0.327	0.306	0.034
	S17	0.263	0.303	0.325	0.263	0.325	0.297	0.031
	S18	0.270	0.284	0.304	0.270	0.304	0.286	0.017
	S19	0.269	0.295	0.285	0.269	0.295	0.283	0.013
	S20	0.258	0.319	0.286	0.258	0.319	0.288	0.031
SW	S21	0.350	0.272	0.373	0.272	0.373	0.332	0.053
	S22	0.317	0.294	0.306	0.294	0.317	0.306	0.012
	S23	0.301	0.263	0.372	0.263	0.372	0.312	0.055
	S24	0.294	0.254	0.286	0.254	0.294	0.278	0.021
	S25	0.261	0.252	0.293	0.252	0.293	0.269	0.022
	Min	0.214	0.219	0.228				
	Max	0.364	0.461	0.427				
	Mean	0.294	0.319	0.327				
	SD	0.043	0.053	0.046				

Table 3.5(b): Hydraulic conductivity (cm/min) of the soil samples in the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.18	0.17	0.18	0.175	0.19	0.17	0.19	0.18	0.01
S	S26	0.35	0.29	0.31	0.27	0.28	0.27	0.35	0.30	0.03
	S27	0.27	0.27	0.29	0.27	0.25	0.25	0.29	0.27	0.01
	S28	0.19	0.20	0.21	0.21	0.21	0.19	0.21	0.20	0.01
	S29	0.21	0.21	0.20	0.21	0.24	0.20	0.24	0.22	0.01
N	S30	0.33	0.36	0.34	0.35	0.34	0.33	0.36	0.35	0.01
	S31	0.34	0.37	0.36	0.36	0.35	0.34	0.37	0.36	0.01
	S32	0.21	0.24	0.24	0.23	0.22	0.21	0.24	0.23	0.01
	S33	0.21	0.22	0.21	0.21	0.23	0.21	0.23	0.21	0.01
NW	S34	0.37	0.25	0.38	0.33	0.34	0.25	0.38	0.33	0.05
	S35	0.35	0.27	0.35	0.34	0.32	0.27	0.35	0.33	0.03
	S36	0.25	0.25	0.26	0.24	0.24	0.24	0.26	0.25	0.01
	S37	0.26	0.26	0.27	0.26	0.27	0.26	0.27	0.26	0.00
W	S38	0.29	0.31	0.29	0.30	0.30	0.29	0.31	0.30	0.01
	S39	0.30	0.32	0.32	0.31	0.33	0.30	0.33	0.31	0.01
	S40	0.23	0.24	0.24	0.21	0.25	0.21	0.25	0.23	0.01
	S41	0.25	0.24	0.26	0.25	0.26	0.24	0.26	0.25	0.01
SW	S42	0.35	0.30	0.31	0.32	0.31	0.30	0.35	0.32	0.02
	S43	0.33	0.31	0.30	0.29	0.31	0.29	0.33	0.31	0.01
	S44	0.28	0.25	0.27	0.23	0.25	0.23	0.28	0.26	0.02
	S45	0.26	0.25	0.26	0.21	0.26	0.21	0.26	0.25	0.02
	Min	0.19	0.20	0.20	0.21	0.21				
	Max	0.37	0.37	0.38	0.36	0.35				
	Mean	0.28	0.27	0.28	0.27	0.28				
	SD	0.05	0.05	0.05	0.05	0.04				

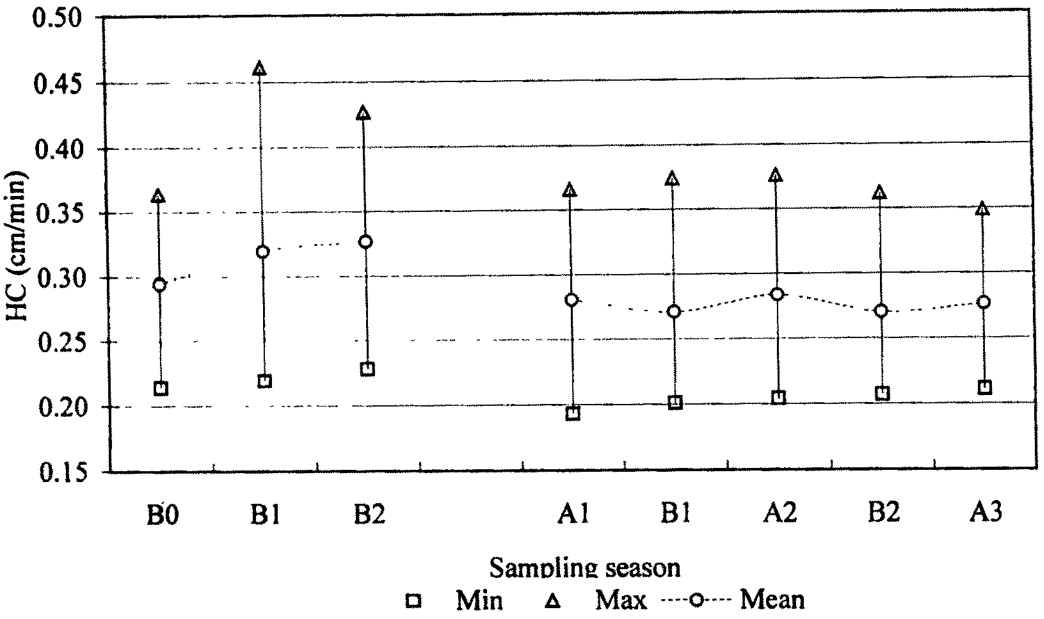


Fig. 3.7. Temporal trends in the minimum, the maximum and the mean values of hydraulic conductivity of the soil for Side A (first three sets from the left) and Side B.

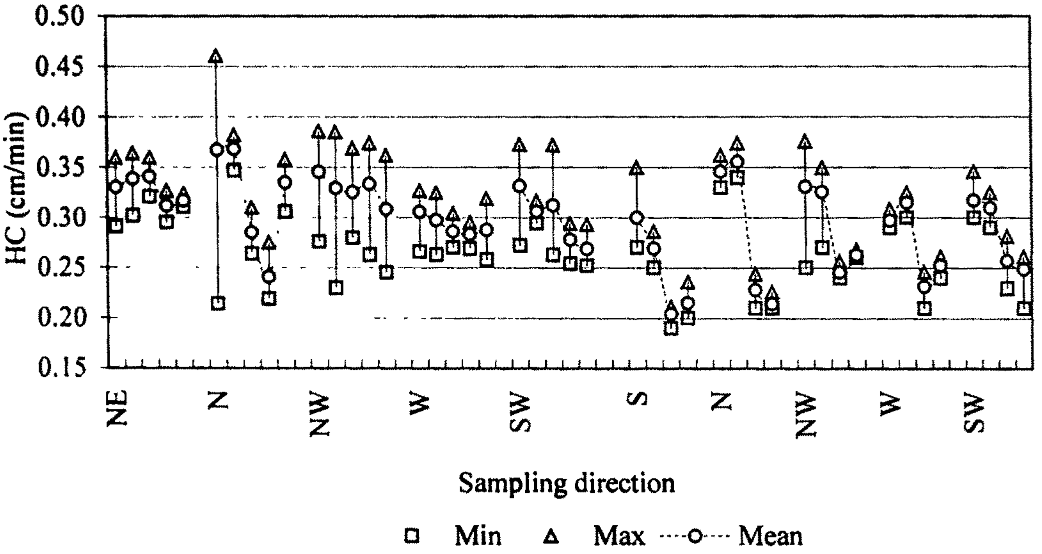


Fig. 3.8. Spatial trends in the minimum, the maximum and the mean values of hydraulic conductivity of the soil for Sides A (first five sets from the left) and B (along NE Northeast, N North, NW Northwest, W West, SW Southwest; S South. The points from left to right in each direction indicate increasing distance from the Mill).

3.1.6 Soil texture and chemical composition

The soil texture is an important property that determines the available amount of soil particles of different sizes. The texture is determined by the relative composition of sand, clay and silt in the soil and the measured values are given respectively in Tables 3.6 (a) and (b) (sand), (c) and (d) (silt), and (e) and (f) (Clay) for the two sides A and B.

In the present study, the soil is rich with sand. For Side A, sand percentage in the soil was from 66.9 – 74.75 in B0 batch, 65.8 – 73.0 in B1 batch and 64.0 – 70.6 % in B2 batch. The values decreased from B0 batch to B2 batch. The maximum mean value was obtained at S11 (72.3 %) in the northwest direction and the minimum at S10 (65.6 %) in the north direction. The sandy nature of soil may be due to (i) deposition of fly ash, which contain silica or (ii) sand used in brick manufacturing near the Mill in the northern side.

In side B, the amount of sand present in the soil was comparatively less than that in side B. The range of values in this side for all the samples and for all the seasons was from 54.0 – 71.4 %. The seasonal variation was almost uniform. The maximum mean value was at S43 (68.9 %) in the SW direction.

The silt content of the soil in Side A of the study area is within the range of 9.8 (S6) - 23.3 % (S25) for all the samples and for all the three batches. In most of the cases the values have an increasing trend with distance away from the Mill.

In side B, the silt present in the soil was comparatively more than that in side A. The values were from 11.8 – 26.6 %. The mean value for each season in this side was more in the pre-monsoon season than in the post-monsoon season. The standard variation of data in the last pre-monsoon season (B2) was maximum (3.82 maximum value).

The soil clay is a dominant factor in fine textured soil. Chemically, the clay fraction of the soil is composed mostly of secondary minerals. Because of the large specific surface area, clay is the most reactive fraction of the soil and determines the physical and chemical properties (Biswas and Mukherjee, 1989). In the present study, the clay percentage was within the range of 13.0 – 16.6 % in B0 batch, 10.8 – 14.8 % in B1 batch, 10.6 – 14.7 % in B2 batch. The "Control " value was more in some cases. The variation with distance was not observed.

Table 3.6 (a). Sand content (%) of the soil samples from the Study Area (Side A)

Direction	Season	Bo	B1	B2	Min	Max	Mean	SD
	Control	65.8	65.2	64.4	64.4	65.8	65.1	0.7
NE	S1	72.6	70.8	69.4	69.4	72.6	70.9	1.6
	S2	72.4	69.0	68.0	69.0	72.4	69.8	2.3
	S3	73.0	70.2	68.3	68.3	73.0	70.5	2.4
	S4	74.0	71.2	69.5	71.2	74.0	71.6	2.3
	S5	74.7	69.4	66.3	66.3	74.7	70.1	4.2
N	S6	74.2	70.2	69.6	70.2	74.2	71.3	2.5
	S7	69.1	68.9	68.2	72.2	69.1	68.7	0.5
	S8	67.8	67.0	66.8	71.6	67.8	67.2	0.5
	S9	67.0	67.1	65.4	70.1	67.1	66.5	1.0
	S10	66.9	65.8	64.0	69.0	66.9	65.6	1.5
NW	S11	73.5	73.0	70.3	70.3	73.5	72.3	1.7
	S12	72.8	71.0	70.6	70.6	72.8	71.5	1.2
	S13	73.4	70.0	70.6	69.2	73.4	71.3	1.8
	S14	70.3	70.2	69.3	70.2	70.3	69.9	0.6
	S15	69.3	68.0	67.4	70.4	69.3	68.2	1.0
W	S16	71.4	70.8	69.7	70.8	71.4	70.6	0.9
	S17	70.9	68.7	68.6	71.2	70.9	69.4	1.3
	S18	70.0	68.3	65.5	72.0	70.0	67.9	2.3
	S19	67.5	67.4	66.4	73.9	67.5	67.1	0.6
	S20	67.0	66.0	65.5	70.1	67.0	66.2	0.8
SW	S21	70.1	69.6	68.5	68.5	70.1	69.4	0.8
	S22	68.4	68.0	67.6	70.2	68.4	68.0	0.4
	S23	69.5	69.0	69.7	70.2	69.7	69.4	0.4
	S24	69.0	69.6	68.7	69.6	69.6	69.1	0.5
	S25	67.0	66.6	65.5	71.2	67.0	66.4	0.8
	Min	66.9	65.8	64.0				
	Max	74.7	73.0	70.6				
	Mean	70.5	69.1	67.9				
	SD	2.7	1.9	2.0				

Table 3.6 (b). Sand content (%) of the soil samples from the Study Area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	65.0	65.2	65.4	64.4	64.6	64.4	65.4	64.9	0.4
S	S26	66.8	65.5	68.2	64.4	71.3	64.4	71.3	67.2	2.7
	S27	64.2	60.5	62.6	62.2	61.4	60.5	64.2	62.2	1.4
	S28	57.8	59.5	56.6	57.5	55.6	55.6	59.5	57.4	1.4
	S29	55.4	56.2	56.6	55.4	56.7	55.4	56.7	56.1	0.6
N	S30	70.1	64.0	68.2	63.8	65.6	63.8	70.1	66.4	2.7
	S31	64.3	59.6	60.6	60.3	61.3	59.6	64.3	61.2	1.8
	S32	60.2	59.6	59.0	59.3	57.4	57.4	60.2	59.1	1.1
	S33	59.1	58.4	58.4	58.9	58.0	58.0	59.1	58.6	0.4
NW	S34	66.3	65.0	65.5	66.3	68.3	65.0	68.3	66.3	1.3
	S35	64.2	64.3	64.6	65.7	63.8	63.8	65.7	64.5	0.7
	S36	60.1	60.6	59.6	61.4	61.5	59.6	61.5	60.6	0.8
	S37	60.5	60.0	59.6	59.7	60.4	59.6	60.5	60.0	0.4
W	S38	65.1	64.2	64.6	63.5	63.3	63.3	65.1	64.1	0.8
	S39	65.5	64.0	64.2	62.2	66.4	62.2	66.4	64.5	1.6
	S40	65.1	64.6	64.0	63.7	61.2	61.2	65.1	63.7	1.5
	S41	60.1	58.8	58.0	55.4	56.7	55.4	60.1	57.8	1.8
SW	S42	66.3	69.2	69.0	71.4	67.6	66.3	71.4	68.7	1.9
	S43	67.0	68.4	69.5	69.4	70.1	67.0	70.1	68.9	1.2
	S44	56.6	56.8	56.4	57.1	56.4	56.4	57.1	56.7	0.3
	S45	54.0	54.2	54.2	52.3	55.4	52.3	55.4	54.0	1.1
	Min	54.0	54.2	54.2	52.3	55.4				
	Max	70.1	69.2	69.5	71.4	71.3				
	Mean	62.4	61.7	62.0	61.5	61.9				
	SD	4.4	4.0	4.7	4.8	5.0				

Table 3.6 (c). Silt content (%) of the soil samples from the Study Area (Side A)

Direction	Season	Bo	B1	B2	Min	Max	Mean	SD
	Control	18.8	19.0	19.4	18.8	19.4	19.1	0.3
NE	S1	11.4	16.6	17.2	11.4	17.2	15.1	3.2
	S2	13.0	18.2	18.5	13.0	18.5	16.6	3.1
	S3	13.3	17.0	18.3	13.3	18.3	16.2	2.6
	S4	13.0	15.6	18.2	13.0	18.2	15.6	2.6
	S5	11.3	18.2	19.1	11.3	19.1	16.2	4.3
N	S6	9.8	17.0	19.2	9.8	19.2	15.3	4.9
	S7	14.6	19.9	21.2	14.6	21.2	18.6	3.5
	S8	16.5	21.8	22.6	16.5	22.6	20.3	3.3
	S9	17.5	20.3	22.2	17.5	22.2	20.0	2.4
	S10	18.1	20.0	21.3	18.1	21.3	19.8	1.6
NW	S11	10.5	13.2	16.3	10.5	16.3	13.3	2.9
	S12	10.6	16.6	17.2	10.6	17.2	14.8	3.6
	S13	10.0	17.6	16.7	10.0	17.6	14.8	4.2
	S14	13.2	15.6	17.3	13.2	17.3	15.4	2.1
	S15	14.2	17.8	19.1	14.2	19.1	17.0	2.5
W	S16	12.1	15.0	18.7	12.1	18.7	15.3	3.3
	S17	12.5	18.9	20.2	12.5	20.2	17.2	4.1
	S18	13.4	20.5	23.0	13.4	23.0	19.0	5.0
	S19	15.9	21.8	22.1	15.9	22.1	19.9	3.5
	S20	16.4	22.8	21.7	16.4	22.8	20.3	3.4
SW	S21	13.3	15.6	17.5	13.3	17.5	15.5	2.1
	S22	15.0	19.6	20.0	15.0	20.0	18.2	2.8
	S23	13.9	18.2	18.8	13.9	18.8	17.0	2.7
	S24	14.4	18.9	18.7	14.4	18.9	17.3	2.5
	S25	16.4	22.2	23.3	16.4	23.3	20.6	3.7
	Min	9.8	13.2	16.3				
	Max	18.8	22.8	23.3				
	Mean	13.8	18.4	19.5				
	SD	2.5	2.4	2.1				

Table 3.6 (d). Silt content (%) of the soil samples from the Study Area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	18.60	19.00	18.60	19.44	19.18	18.60	19.44	18.96	0.37
S	S26	16.80	21.20	16.30	22.64	15.40	15.40	22.64	18.47	3.23
	S27	17.16	20.70	18.40	21.30	18.36	17.16	21.30	19.18	1.74
	S28	22.34	20.70	23.40	22.05	22.66	20.70	23.40	22.23	0.99
	S29	19.30	18.90	18.80	20.98	19.47	18.80	20.98	19.49	0.88
N	S30	16.20	22.80	17.80	21.80	17.97	16.20	22.80	19.31	2.83
	S31	19.15	14.60	13.60	13.39	13.22	13.22	19.15	14.79	2.49
	S32	16.96	16.40	16.40	18.56	16.74	16.40	18.56	17.01	0.90
	S33	15.54	15.40	15.60	15.10	16.80	15.10	16.80	15.69	0.65
NW	S34	15.08	13.50	14.50	13.20	13.11	13.11	15.08	13.88	0.87
	S35	16.35	26.60	15.20	13.86	14.60	13.86	26.60	17.32	5.27
	S36	22.40	23.50	22.20	23.80	18.19	18.19	23.80	22.02	2.25
	S37	21.15	21.60	21.00	21.58	18.84	18.84	21.60	20.83	1.15
W	S38	16.62	18.80	18.20	17.94	20.10	16.62	20.10	18.33	1.27
	S39	18.00	20.90	18.60	21.16	15.32	15.32	21.16	18.80	2.39
	S40	16.70	16.60	17.20	18.65	18.10	16.60	18.65	17.45	0.90
	S41	22.32	22.80	23.20	24.16	21.86	21.86	24.16	22.87	0.88
SW	S42	13.56	13.00	12.60	13.12	11.75	11.75	13.56	12.81	0.68
	S43	16.45	15.00	13.30	15.29	13.30	13.30	16.45	14.67	1.36
	S44	18.65	17.40	17.80	18.30	19.28	17.40	19.28	18.29	0.73
	S45	23.39	23.60	22.80	24.86	22.54	22.54	24.86	23.44	0.90
	Min	13.56	13.00	12.60	13.12	11.75				
	Max	23.39	26.60	23.40	24.86	22.66				
	Mean	18.22	19.19	17.88	19.10	17.47				
	SD	2.72	3.73	3.24	3.82	3.15				

Table 3.6 (e). Clay content (%) of the soil samples from the Study Area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	15.4	15.8	16.2	15.4	16.2	15.8	0.4
NE	S1	16	12.6	13.4	12.6	16.0	14.0	1.8
	S2	14.6	12.8	13.5	12.8	14.6	13.6	0.9
	S3	13.7	12.8	13.4	12.8	13.7	13.3	0.5
	S4	13	13.2	12.3	12.3	13.2	12.8	0.5
	S5	14	12.4	14.6	12.4	14.6	13.7	1.1
N	S6	16	12.8	11.2	11.2	16.0	13.3	2.4
	S7	16.3	11.2	10.6	10.6	16.3	12.7	3.1
	S8	15.7	11.2	10.6	10.6	15.7	12.5	2.8
	S9	15.5	12.6	12.4	12.4	15.5	13.5	1.7
	S10	15	14.2	14.7	14.2	15.0	14.6	0.4
NW	S11	16	13.8	13.4	13.4	16.0	14.4	1.4
	S12	16.6	12.4	12.2	12.2	16.6	13.7	2.5
	S13	16.6	12.4	12.7	12.4	16.6	13.9	2.3
	S14	16.5	14.2	13.4	13.4	16.5	14.7	1.6
	S15	16.5	14.2	13.5	13.5	16.5	14.7	1.6
W	S16	16.5	14.2	11.6	11.6	16.5	14.1	2.5
	S17	16.6	12.4	11.2	11.2	16.6	13.4	2.8
	S18	16.6	11.2	11.5	11.2	16.6	13.1	3.0
	S19	16.6	10.8	11.5	10.8	16.6	13.0	3.2
	S20	16.6	11.2	12.8	11.2	16.6	13.5	2.8
SW	S21	16.6	14.8	14	14	16.6	15.1	1.3
	S22	16.6	12.4	12.4	12.4	16.6	13.8	2.4
	S23	16.6	12.8	11.5	11.5	16.6	13.6	2.7
	S24	16.6	11.5	12.6	11.5	16.6	13.6	2.7
	S25	16.6	11.2	11.2	11.2	16.6	13.0	3.1
	Min	13	10.8	10.6				
	Max	16.6	14.8	14.7				
	Mean	15.92	12.61	12.49				
	SD	1.05	1.15	1.17				

Table 3.6 (f). Clay content (%) of the soil samples from the Study Area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	16.40	15.80	16.00	16.20	16.20	15.80	16.40	16.11	0.24
S	S26	16.40	13.30	15.50	13.00	13.35	13.00	16.40	14.31	1.54
	S27	18.64	18.80	19.00	16.50	20.28	16.50	20.28	18.64	1.36
	S28	19.86	19.80	20.00	20.45	21.70	19.80	21.70	20.36	0.79
	S29	25.30	24.90	24.60	24.30	23.80	23.80	25.30	24.58	0.57
N	S30	13.70	13.20	14.00	14.40	16.40	13.20	16.40	14.34	1.23
	S31	16.55	25.80	25.80	26.30	25.50	16.55	26.30	23.99	4.17
	S32	22.84	24.00	24.60	22.14	25.90	22.14	25.90	23.90	1.48
	S33	25.36	26.20	26.00	26.00	25.20	25.20	26.20	25.75	0.44
NW	S34	18.62	21.50	20.00	20.54	18.60	18.60	21.50	19.85	1.25
	S35	19.45	19.10	20.20	20.40	21.60	19.10	21.60	20.15	0.97
	S36	17.50	15.90	18.20	14.80	20.30	14.80	20.30	17.34	2.12
	S37	18.35	18.40	19.40	18.70	20.80	18.35	20.80	19.13	1.02
W	S38	18.28	17.00	17.20	18.61	16.60	16.60	18.61	17.54	0.86
	S39	16.50	15.10	17.20	16.68	18.30	15.10	18.30	16.76	1.16
	S40	18.20	18.80	18.80	17.63	20.70	17.63	20.70	18.83	1.15
	S41	17.58	18.40	18.80	20.46	21.40	17.58	21.40	19.33	1.56
SW	S42	20.14	17.80	18.40	15.50	20.70	15.50	20.70	18.51	2.06
	S43	16.55	16.60	17.20	15.30	16.60	15.30	17.20	16.45	0.70
	S44	24.75	25.80	25.80	24.60	24.30	24.30	25.80	25.05	0.70
	S45	22.61	22.20	23.00	22.86	22.10	22.10	23.00	22.55	0.40
	Min	13.70	13.20	14.00	13.00	13.35				
	Max	25.36	26.20	26.00	26.30	25.90				
	Mean	19.36	19.63	20.19	19.46	20.71				
	SD	3.24	4.08	3.58	4.01	3.35				

In side B, the clay present in the soil samples for the different seasons are as follows:

- 13.7 – 25.56 % in A1 batch
- 13.2 – 26.2 % in B1 batch
- 14.0 – 26 % in A2 batch
- 13.0 – 26.3 % in B2 batch
- 13.4 – 25.9 % in A3 batch.

From the above observations, it is revealed that the side B had more clay content in comparison to side A. The variation was more in both the pre-monsoon seasons (B1 and B2) than the post- monsoon season. In some cases, the "Control" value was more than that of the study samples.

The soil was rich in SiO_2, Al_2O_3 and Fe_2O_3 with considerable presence of the other oxides. X-ray Fluorescence analysis of the chemical composition of the soil for three typical soil samples from the study area showed the following composition:

Sample	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI
1	54.53	16.01	8.82	0.04	2.47	1.05	1.95	3.88	0.77	0.25	10.43
2	68.70	14.21	3.70	0.03	1.26	1.11	1.80	3.49	0.47	0.01	5.32
3	66.59	14.69	3.69	0.03	1.24	1.10	1.72	3.50	0.43	0.02	6.87
Mean	63.27	14.97	5.40	0.03	1.66	1.09	1.82	3.62	0.56	0.09	7.54

The soil thus contains > 60 % silica, ~15 % alumina and 5.4 % iron oxide. The other oxides present are in the order of $K_2O > Na_2O > MgO > CaO > TiO_2 > P_2O_5 > MnO$. The soil has considerable value of LOI (Loss on Ignition) with mean value of 7.5 % indicating that the soil from the study area had considerable load of organics.

In order to identify the clay minerals present in the soil, X-ray diffraction patterns were recorded for the control soil sample (Fig. 3.9(a)) and four other typical soil samples from the study area (Fig. 3.9 (b), (c), (d), and (e). It is seen that the XRD patterns are identical.

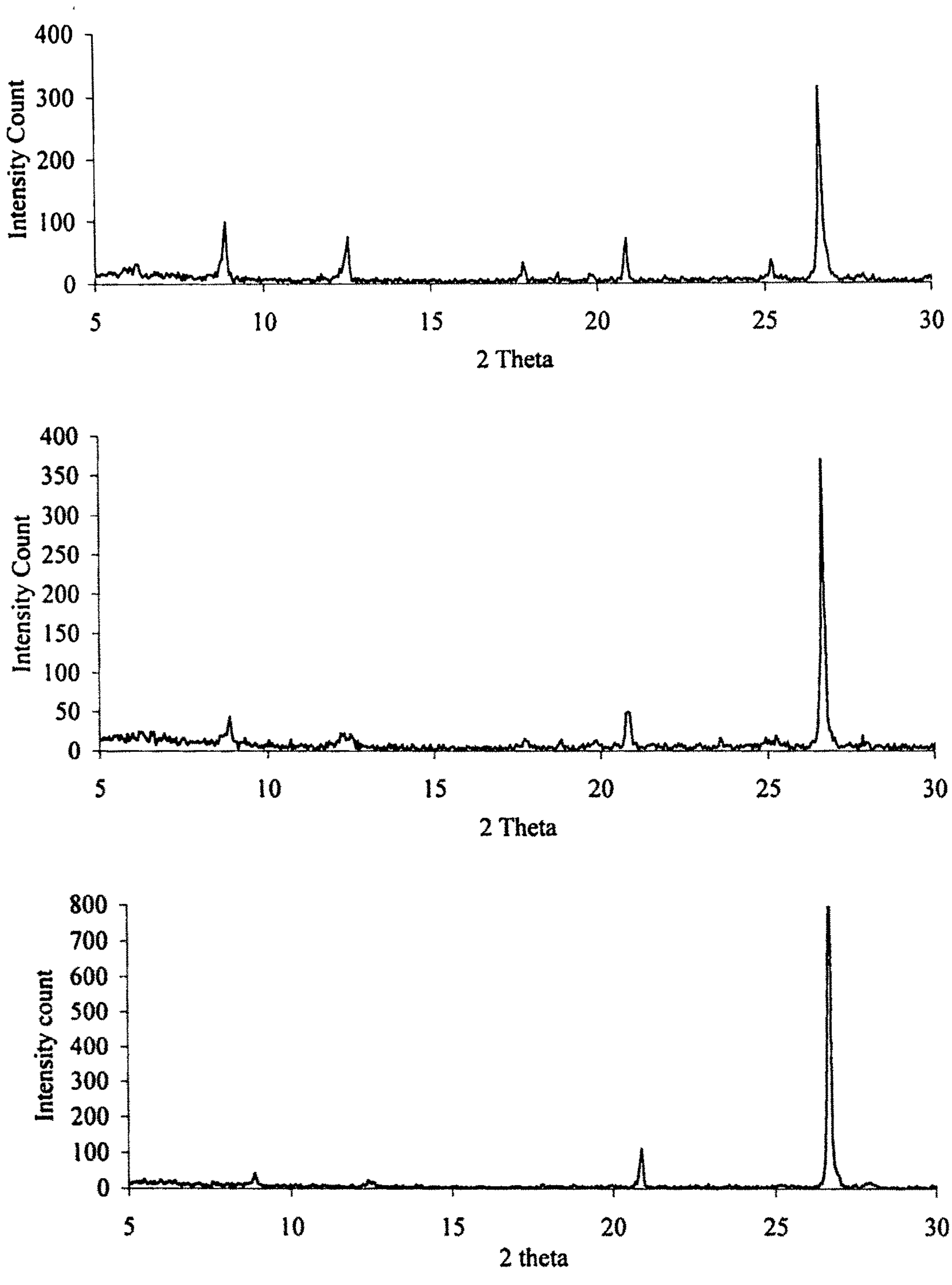
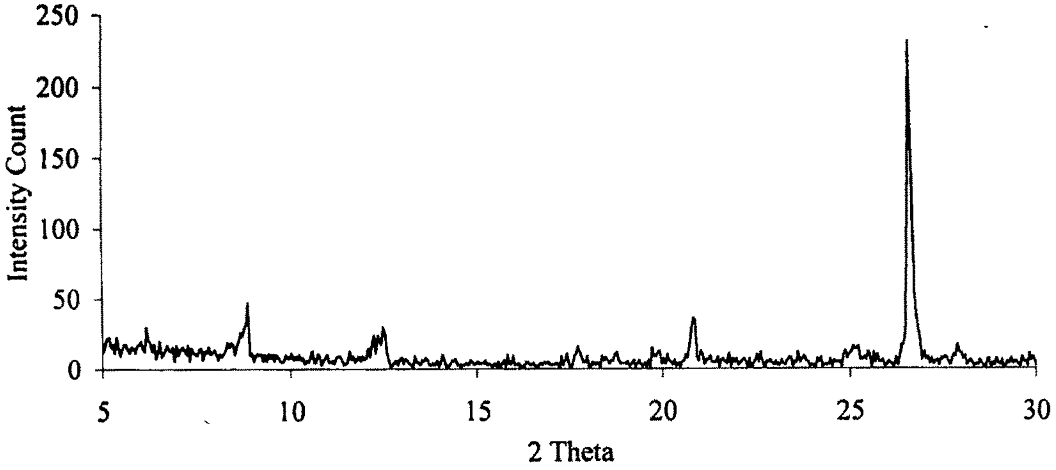


Fig. 3.9. XRD patterns of soil samples from the study area (a) Control soil (top), (b) Sample 1 (middle), (c) Sample 2 (bottom).



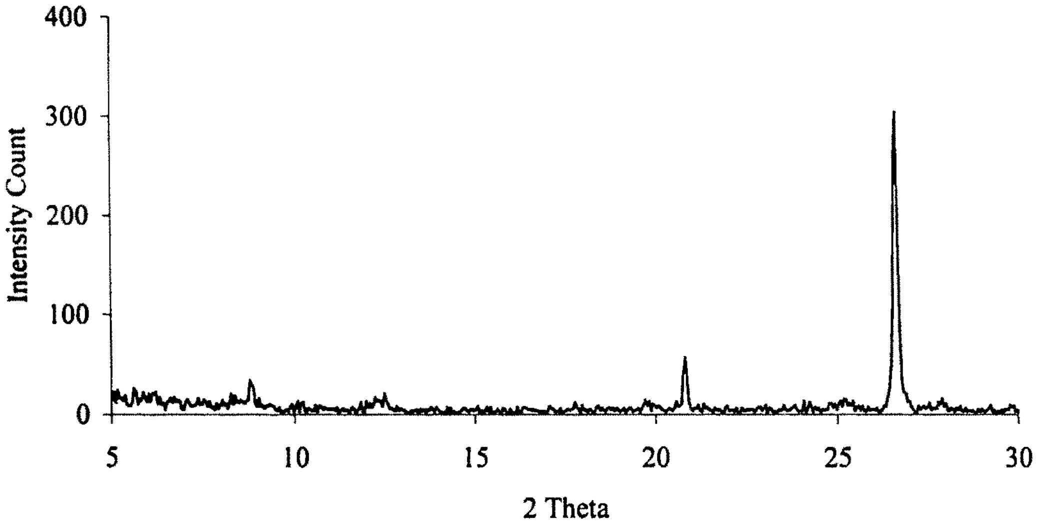


Fig. 3.9 continued. XRD patterns of soil samples from the study area (d) Sample 3 (top), and (e) Sample 4 (bottom).

The major diffraction peaks, the corresponding'd' spacings and the possible mineral assignments are given below. It is seen that the most prominent XRD peak in all the samples has a d-spacing of 3.34 (2θ = 26.60 °) which may be assigned to either illite or quartz (assignment has been done following standard XRD data of Jasmond and Mering 1979; Brindley 1961, 1980; Carroll 1970; Bailey 1980, Moore and Reynolds 1989). All the other XRD peaks are of low or medium intensity, which are most likely to be due to the presence of kaolinite in the soil. Since the texture analysis shows that the sol of the study area is largely sandy in nature, the absence of large amount of clay minerals is not surprising. The XRD patterns further show that with regard to mineral composition, the soil samples are identical with one another, and not much different from the 'Control' sample.

Soil sample	Diffraction peak (2θ degrees)	Peak Intensity	'd' spacing (Å)	Assignment
Control	8.84	Medium	9.99	Not assigned
	12.48	Medium	7.08	Kaolinite
	20.80	Medium	4.25	Kaolinite or feldspar
	26.60	High	3.34	Illite or quartz
1	20.80	Medium	4.26	Kaolinite or feldspar
	26.60	High	3.34	Illite or quartz
2	20.86	Medium	4.25	Kaolinite or feldspar
	26.66	High	3.34	Illite or quartz
3	8.84	Medium	9.98	Not assigned
	12.51	Medium	7.06	Kaolinite
	20.80	Medium	4.26	Kaolinite or feldspar
	26.60	High	3.34	Illite or quartz
4	20.82	Medium	4.26	Kaolinite or feldspar
	26.60	High	3.34	Illite or quartz

3.1.7 Organic Matter (OM)

The organic matter present in the soil samples is given in Table 3.7 (a) and 3.7 (b) for Side A and Side B.

High accumulation of organic matter in some samples of side A indicates release of organic matter from the Mill along with the effluent. In northern (range 3.24 – 4.62 %), northwest (range 3.76 – 4.96 %) and western (range 2.41 – 4.56 %) directions, the amount of organic matter was more in comparison to the other two directions (northeast 1.34 – 2.59 % and southwest 1.1 – 2.76 %). There is a trend of decreasing values with distance away from the Mill. The mean value is low in B2 batch (pre monsoon) in comparison to the other two batches (B0 and B1). The maximum value was obtained at S11 (4.96 %) in NW direction in B0 batch. In all the cases, the control value was less than those from the study area.

The accumulation of humic matter on the surface soil (Kumari et al., 2001) accompanied by dumping of organically rich wastes is usually responsible for higher organic matter content of the surface soil. This has been found to be true in the present case.

As the side B is at a larger distance from the Mill, it is likely that the soil in side B is getting less organic load from the Mill because of resistance of the earthen dam to free flow of surface water from Side A to B. The values of organic matter in side B are in the following ranges:

- A1: 0.63 – 2.8 %
- B1: 0.66 – 1.82 %
- A2: 0.61 – 2.34 %
- B2: 0.68 – 1.78 %
- A3: 0.65 – 2.01 %

The values decreased from A1 batch (first post-monsoon) to A3 batch (third post-monsoon). In the pre-monsoon season, the rainwater come in contact with effluent water and spread the same throughout the vast area, thus the organic matter is distributed over a wide area decreasing its content.

Table 3.7 (a). Organic Matter content (%) of the soil from the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.97	0.97	1.03	0.97	1.03	0.99	0.04
NE	S1	2.59	2.49	2.20	2.20	2.59	2.43	0.20
	S2	1.93	2.01	1.98	1.93	2.01	1.97	0.04
	S3	1.69	1.63	1.80	1.63	1.80	1.71	0.09
	S4	1.54	1.41	1.34	1.34	1.54	1.43	0.10
	S5	1.56	1.52	1.40	1.40	1.56	1.49	0.08
N	S6	3.25	4.09	3.92	3.25	4.09	3.75	0.44
	S7	4.62	3.87	3.24	3.24	4.62	3.91	0.69
	S8	4.17	3.73	3.64	3.64	4.17	3.85	0.28
	S9	4.56	3.96	3.78	3.78	4.56	4.10	0.41
	S10	3.95	3.64	3.65	3.64	3.95	3.75	0.18
NW	S11	4.96	4.16	3.98	3.98	4.96	4.37	0.52
	S12	4.08	4.13	4.11	4.08	4.13	4.11	0.03
	S13	4.03	3.94	4.21	3.94	4.21	4.06	0.14
	S14	3.70	4.03	4.01	3.70	4.03	3.91	0.19
	S15	3.90	4.04	3.97	3.90	4.04	3.97	0.07
W	S16	4.56	4.22	4.06	4.06	4.56	4.28	0.26
	S17	4.01	4.17	4.06	4.01	4.17	4.08	0.08
	S18	3.91	3.83	2.98	2.98	3.91	3.57	0.52
	S19	2.41	3.74	3.24	2.41	3.74	3.13	0.67
	S20	3.41	3.79	3.02	3.02	3.79	3.41	0.39
SW	S21	2.41	2.76	2.14	2.14	2.76	2.44	0.31
	S22	2.24	2.48	2.11	2.11	2.48	2.28	0.19
	S23	2.37	2.50	2.06	2.06	2.50	2.31	0.23
	S24	1.10	2.03	1.76	1.10	2.03	1.63	0.48
	S25	2.19	1.23	1.21	1.21	2.19	1.54	0.56
	Min	1.10	1.23	1.21				
	Max	4.96	4.22	4.21				
	Mean	3.17	3.18	2.95				
	SD	1.15	1.04	1.04				

Table 3.7 (b). Organic Matter content (%) of the soil from the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	1.10	0.97	1.12	1.03	1.16	0.97	1.16	1.08	0.08
S	S26	1.86	1.58	1.73	1.50	1.70	1.50	1.86	1.67	0.14
	S27	1.76	1.14	1.69	1.16	1.45	1.14	1.76	1.44	0.29
	S28	1.22	1.18	0.97	1.20	0.94	0.94	1.22	1.10	0.14
	S29	0.63	1.06	0.61	1.10	0.65	0.61	1.10	0.81	0.25
N	S30	2.58	1.15	2.04	1.17	1.86	1.15	2.58	1.76	0.61
	S31	1.79	1.02	1.62	1.08	1.65	1.02	1.79	1.43	0.36
	S32	0.82	0.69	0.79	0.73	0.75	0.69	0.82	0.76	0.05
	S33	0.76	0.71	0.72	0.68	0.70	0.68	0.76	0.71	0.03
NW	S34	2.80	1.82	2.34	1.78	1.76	1.76	2.80	2.10	0.46
	S35	1.37	1.61	1.19	1.56	1.03	1.03	1.61	1.35	0.25
	S36	1.01	0.75	0.94	0.78	0.90	0.75	1.01	0.87	0.11
	S37	0.95	0.66	0.94	0.72	0.90	0.66	0.95	0.83	0.13
W	S38	2.24	1.50	2.11	1.62	2.01	1.50	2.24	1.90	0.32
	S39	1.42	1.18	1.32	1.10	1.01	1.01	1.42	1.21	0.17
	S40	0.80	0.93	0.73	1.03	0.65	0.65	1.03	0.83	0.15
	S41	0.79	0.94	0.82	0.87	0.78	0.78	0.94	0.84	0.07
SW	S42	1.80	1.15	1.86	1.10	1.32	1.10	1.86	1.45	0.36
	S43	1.74	1.22	1.73	1.12	1.10	1.10	1.74	1.38	0.32
	S44	1.74	1.03	1.70	0.93	1.20	0.93	1.74	1.32	0.38
	S45	1.65	0.73	1.60	0.75	1.30	0.73	1.65	1.21	0.45
	Min	0.63	0.66	0.61	0.68	0.65				
	Max	2.80	1.82	2.34	1.78	2.01				
	Mean	1.49	1.10	1.37	1.10	1.18				
	SD	0.62	0.33	0.53	0.32	0.43				

As distance increases from the mill, the organic matter in the soil also decreases showing that the Mill has a certain area of influence beyond which the organic matter content is not dependent on the contributions from the Mill. In some cases, the soil away from the Mill even shows less organic matter than that of the 'Control'. This indicates that the 'Control' soil might be receiving some organic supplement in the form of cow dung etc., while no such thing has happened in the area surrounding the Mill except for receiving organically rich effluent.

The mean values in B1 and B2 batches are found to be the same. Here also, the values are higher in the post-monsoon season compared to those in the pre-monsoon season. A similar observation was also reported by Khound (2002). The suspended and dissolved organic matter present in the effluent of the mill as well as the solid wastes deposited on the soil near the mill might have led to an enrichment of soil organic matter (Srivastava, 2001).

The general trend of the values indicates a decrease away from the Mill although the trend is not uniform in all the directions. The decreasing trend is shown for the pre-monsoon season in two directions for side A and for all the seasons in four directions for side B in Fig.3.10

3.1.8. Oil and Grease

In the present study, most of the soil samples in Side A do not have oil and grease. The soil samples of northeast side were free from oil and grease. In northern side, S6 had oil and grease in B1 and B2 batch whereas S8 in B0 batch. The sample S11 in B2, S12 in B0 and S13 in B1 batch in northwest direction had oil and grease. In western direction, S17 in B0 and B2, S18 in B1 contain oil and grease. In southwestern direction, S21 in B0, S22 in B1, S24 in B2 batches had oil and grease. In all the cases, where oil and grease was found, the value was 100 mg/kg. The control sample was free from oil and grease.

In side B, the same situation was observed like side A. In some samples (S26 in A1 & A2, S34 in B2 & A3, S38 in A1 & A2, S39 in A3, S42 in A1 and B1), 100 mg/kg of oil and grease was obtained. All these samples are nearer to the Mill. The samples in the northern direction were found free from oil and grease. No seasonal variation was observed.

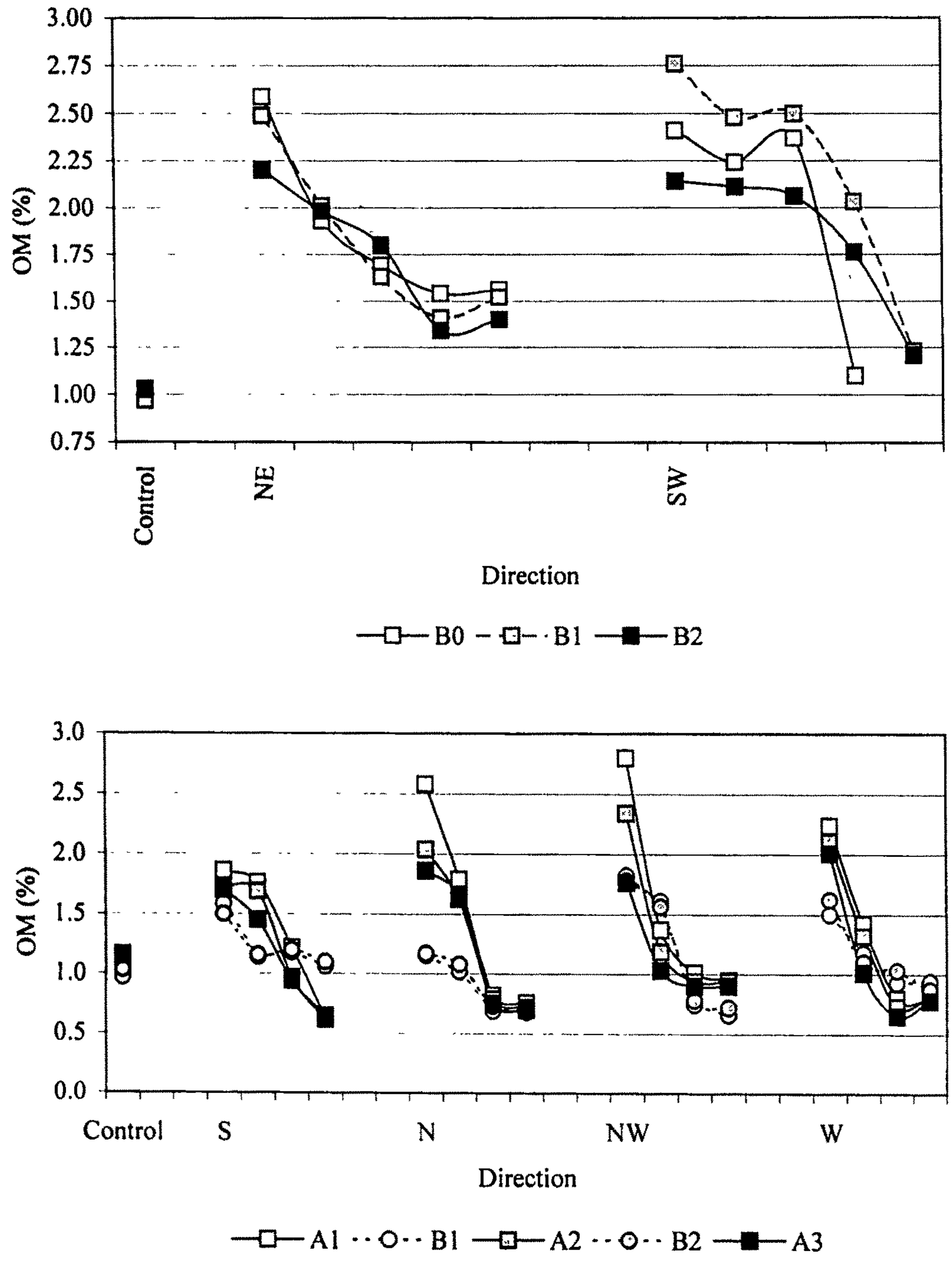


Fig. 3.10. Directional trends in organic matter content of the soil for Side A (top, only the three pre-monsoon seasons) and side B (bottom, all the seasons) in a few directions from the Mill along with the values for the 'Control' soil samples.

3.1.9 Total nitrogen

The total nitrogen present in the soil samples in the study area is given in Tables 3.8(a) and 3.8(b) for Side A and Side B respectively. Total nitrogen in the soil is contributed by inorganic and organic nitrogen compounds, which may be moderately toxic in nature. They are also the most common constituents of organic wastes (Vellidis et al., 1996).

In the study area, Side A was rich in nitrogen. For the pre-monsoon season, the values are in the ranges of 0.037 - 0.262 % (B0), 0.035 - 0.215 % (B1) and 0.034 - 0.22 % (B2). The corresponding values for the 'Control' sample are 0.035, 0.032 and 0.03 % respectively. The soil samples in north, northwest and west directions have comparatively more nitrogen than the other two directions (northeast and southwest). The sample, S11, in northwest direction, which is very near to the Mill, shows the highest amount of nitrogen (mean value 0.224 %). Almost in every direction, the values have a decreasing trend away from the Mill.

The nitrogen content was comparatively less in the Side B than the side A. Among the five seasons, the season A1 had highest range of values 0.07 - 0.18 %. The mean values for the pre-monsoon seasons of B1 (0.08 %) and B2 (0.076 %) were less than that of the post-monsoon seasons, A1 (0.11 %), A2 (0.097 %) and A3 (0.079 %).

It was found that the nitrogen content of the soil did not bear a perfect linear relationship to soil organic matter content. The plots of organic matter vs. total nitrogen for Side A had the regression coefficient (R) of 0.27 (NE direction), 0.15 (N direction), 0.50 (W direction), 0.60 (SW direction) and 0.47 (NW direction). Similarly, the regression coefficients for organic matter vs. total nitrogen content plots for Side B are 0.53 (S direction), 0.75 (N direction), 0.73 (NW direction), 0.31 (W direction), and 0.61 (SW direction). Thus, although considerable linearity was shown in W and SW directions in Side A, and S, N, NW and SW directions in Side B, the relationship between the two parameters was weak in the other directions. The results indicate that although the organic nitrogen compounds in soil are the major contributor to the soil nitrogen content, there are still other contributors of significant amounts. The results also indicate directional differential variations in the two parameters. Soil microbes make nitrogen available to plants by breaking down organic matter and steadily releasing two inorganic forms of nitrogen – ammonium and nitrate, which leads to a strong correlation between soil organic matter and the total nitrogen content.

3.1.10 Available Phosphorus

The values of available phosphorus along with the maximum, the minimum, the mean and the standard deviation for each season and each site are given in Table 3.9(a) and 3.9(b). In side A, the available phosphorus content was in the ranges of B0: 0.1 – 1.8 mg/kg, B1: 0.1 – 9.2 mg/kg and B2: 0.1 – 7.9 mg/kg. The "Control" sample had available phosphorous content of 0.09, 0.1 and 0.09 mg/kg in the three seasons, which were lower than the values from the study area. Some samples in all batches showed low values. During the first pre-monsoon season (B0), the soil samples had the lowest phosphorus content in comparison to the other two seasons. Of all the measurements, the maximum value was obtained at S17 (9.2 mg/kg) in the west direction from the Mill in the second pre monsoon season (B1) and the lowest value at S21 (0.1 mg/kg) and S25 0.1 mg/kg) in the southwest direction. It is found that the north, northwest and west directions had more phosphorus content in comparison to other two directions viz. northeast and southwest.

In side B, the available phosphorus measured in the different seasons was from 0.2– 3.35 mg/kg (A1), 0.09– 3.4 mg/kg (B1), 0.16 - 3.40 mg/kg A2), 0.09– 3.02 mg/kg (B2), 0.3– 3.00 mg/kg (A3). The highest value obtained was at S30 (the mean value 3.17 mg/kg) in the north direction and the lowest at S29 (the mean value 0.19 mg/kg) in the south direction. In all the directions, soil samples away from the Mill had lower phosphorous value with a few exceptions. Seasonal variation for all the sites was not distinct.

Variation patterns for available P with direction and distance are shown in Fig. 3.11.

3.1.11 Exchangeable Cations

(i) Calcium

The amounts of calcium in different seasons in side A and B are given in Tables 3.10(a) and 3.10(b). The values in Side A are within the ranges of 17 – 82 meq/kg (B0), 21.7 – 86.1 meq/kg (B1) and 20.1– 76.5 meq/kg (B2). In all the cases, the 'Control' values were lower than the values from the study area. This indicates that the calcium salts have influenced the study area soil composition. The mean value in B1 is more than that of the other two pre monsoon seasons. The highest value obtained was for S17 (west direction) in B1 season. This sample has also got the maximum mean value (81.5 meq/kg) among all the seasons. This site is very near to the Mill. The lowest value was measured at S2 (17 meq/kg) in the northeast

Table 3.8(a). Total Nitrogen content (%) of the soil (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.035	0.032	0.030	0.030	0.035	0.032	0.003
NE	S1	0.059	0.083	0.080	0.059	0.083	0.074	0.013
	S2	0.048	0.094	0.089	0.048	0.094	0.077	0.025
	S3	0.046	0.084	0.080	0.046	0.084	0.070	0.021
	S4	0.037	0.070	0.070	0.037	0.070	0.059	0.019
	S5	0.037	0.070	0.070	0.037	0.070	0.059	0.019
N	S6	0.110	0.215	0.220	0.110	0.220	0.182	0.062
	S7	0.134	0.208	0.210	0.134	0.210	0.184	0.043
	S8	0.116	0.083	0.080	0.080	0.116	0.093	0.020
	S9	0.148	0.067	0.070	0.067	0.148	0.095	0.046
	S10	0.094	0.035	0.034	0.034	0.094	0.054	0.034
NW	S11	0.262	0.200	0.210	0.200	0.262	0.224	0.033
	S12	0.241	0.176	0.174	0.174	0.241	0.197	0.038
	S13	0.220	0.143	0.140	0.140	0.220	0.168	0.045
	S14	0.196	0.090	0.110	0.090	0.196	0.132	0.056
	S15	0.078	0.110	0.110	0.078	0.110	0.099	0.018
W	S16	0.203	0.197	0.210	0.197	0.210	0.203	0.007
	S17	0.216	0.099	0.110	0.099	0.216	0.142	0.065
	S18	0.154	0.052	0.063	0.052	0.154	0.090	0.056
	S19	0.126	0.060	0.065	0.060	0.126	0.084	0.037
	S20	0.129	0.066	0.063	0.063	0.129	0.086	0.037
SW	S21	0.173	0.117	0.120	0.117	0.173	0.137	0.032
	S22	0.160	0.068	0.064	0.064	0.160	0.097	0.054
	S23	0.163	0.070	0.069	0.069	0.163	0.101	0.054
	S24	0.049	0.063	0.060	0.049	0.063	0.057	0.007
	S25	0.082	0.042	0.045	0.042	0.082	0.056	0.022
	Min	0.037	0.035	0.034				
	Max	0.262	0.215	0.220				
	Mean	0.131	0.102	0.105				
	SD	0.067	0.055	0.057				

Table 3.8 (b). Total Nitrogen content (%) of the soil (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.045	0.032	0.045	0.030	0.041	0.030	0.045	0.039	0.007
S	S26	0.16	0.086	0.1	0.078	0.160	0.078	0.160	0.117	0.040
	S27	0.09	0.114	0.06	0.092	0.070	0.060	0.114	0.085	0.021
	S28	0.07	0.072	0.06	0.076	0.063	0.060	0.076	0.068	0.007
	S29	0.1	0.020	0.05	0.024	0.050	0.020	0.100	0.049	0.032
N	S30	0.15	0.154	0.14	0.110	0.100	0.100	0.154	0.131	0.024
	S31	0.14	0.104	0.12	0.110	0.090	0.090	0.140	0.113	0.019
	S32	0.106	0.041	0.09	0.036	0.040	0.036	0.106	0.063	0.033
	S33	0.08	0.039	0.07	0.040	0.063	0.039	0.080	0.058	0.018
NW	S34	0.13	0.112	0.14	0.109	0.120	0.109	0.140	0.122	0.013
	S35	0.08	0.091	0.07	0.092	0.070	0.070	0.092	0.081	0.011
	S36	0.12	0.083	0.068	0.090	0.053	0.053	0.120	0.083	0.025
	S37	0.12	0.067	0.06	0.065	0.060	0.060	0.120	0.074	0.026
W	S38	0.14	0.107	0.1	0.100	0.078	0.078	0.140	0.105	0.022
	S39	0.12	0.102	0.14	0.100	0.110	0.100	0.140	0.114	0.016
	S40	0.1	0.064	0.13	0.070	0.100	0.064	0.130	0.093	0.027
	S41	0.1	0.077	0.1	0.065	0.060	0.060	0.100	0.080	0.019
SW	S42	0.18	0.120	0.13	0.120	0.176	0.120	0.180	0.145	0.030
	S43	0.13	0.072	0.17	0.080	0.078	0.072	0.170	0.106	0.043
	S44	0.1	0.076	0.11	0.070	0.050	0.050	0.110	0.081	0.024
	S45	0.07	0.039	0.09	0.040	0.030	0.030	0.090	0.054	0.025
	Min	0.070	0.020	0.050	0.024	0.030				
	Max	0.180	0.154	0.170	0.120	0.176				
	Mean	0.114	0 082	0.100	0.078	0.081				
	SD	0.030	0 033	0.034	0.027	0.038				

Table 3.9 (a). Available phosphorous content (mg/kg) of the soil of the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.09	0.10	0.09	0.09	0.10	0.09	0.01
NE	S1	0.10	0.90	0.89	0.10	0.90	0.63	0.46
	S2	0.10	0.60	0.65	0.10	0.65	0.45	0.30
	S3	0.20	1.10	1.23	0.20	1.23	0.84	0.56
	S4	0.30	1.00	1.36	0.30	1.36	0.89	0.54
	S5	0.30	0.80	1.01	0.30	1.01	0.70	0.36
N	S6	0.50	3.20	2.86	0.50	3.20	2.19	1.47
	S7	0.50	2.90	3.10	0.50	3.10	2.17	1.45
	S8	1.00	3.60	3.80	1.00	3.80	2.80	1.56
	S9	0.50	1.10	1.09	0.50	1.10	0.90	0.34
	S10	0.60	1.20	1.30	0.60	1.30	1.03	0.38
NW	S11	0.90	5.30	5.43	0.90	5.43	3.88	2.58
	S12	1.00	4.10	4.68	1.00	4.68	3.26	1.98
	S13	1.80	1.30	2.01	1.30	2.01	1.70	0.36
	S14	0.60	1.60	1.80	0.60	1.80	1.33	0.64
	S15	0.40	0.90	1.10	0.40	1.10	0.80	0.36
W	S16	0.90	3.60	3.20	0.90	3.60	2.57	1.46
	S17	1.10	9.20	7.89	1.10	9.20	6.06	4.35
	S18	1.80	2.60	3.20	1.80	3.20	2.53	0.70
	S19	0.60	2.20	2.10	0.60	2.20	1.63	0.90
	S20	0.40	2.20	1.80	0.40	2.20	1.47	0.95
SW	S21	0.10	1.60	1.10	0.10	1.60	0.93	0.76
	S22	0.20	1.10	0.98	0.20	1.10	0.76	0.49
	S23	0.40	0.80	0.75	0.40	0.80	0.65	0.22
	S24	0.20	0.80	0.63	0.20	0.80	0.54	0.31
	S25	0.40	0.10	0.10	0.10	0.40	0.20	0.17
	Min	0.10	0.10	0.10				
	Max	1.80	9.20	7.89				
	Mean	0.60	2.15	2.16				
	SD	0.47	1.95	1.79				

Table 3.9 (b). Available phosphorous content (mg/kg) of the soil of the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.0
S	S26	2.36	2.92	2.36	3.02	3.00	2.36	3.02	2.73	0.34
	S27	1.14	0.60	1.14	1.10	0.92	0.60	1.14	0.98	0.23
	S28	0.80	0.48	0.80	0.71	0.69	0.48	0.80	0.70	0.13
	S29	0.23	0.09	0.23	0.10	0.30	0.09	0.30	0.19	0.09
N	S30	3.35	3.40	3.40	2.83	2.90	2.83	3.40	3.17	0.28
	S31	2.28	1.44	2.28	1.69	1.70	1.44	2.28	1.88	0.38
	S32	1.20	1.22	1.20	1.35	1.30	0.56	2.80	1.47	0.94
	S33	0.56	2.80	0.56	1.65	1.76	1.20	1.35	1.25	0.07
NW	S34	0.48	0.72	0.60	0.76	2.70	0.48	2.70	1.05	0.93
	S35	0.42	0.60	0.40	0.65	1.40	0.40	1.40	0.69	0.41
	S36	0.40	0.52	0.32	0.62	1.60	0.32	1.60	0.69	0.52
	S37	0.48	0.56	0.48	0.60	1.27	0.48	1.27	0.68	0.33
W	S38	1.12	1.52	1.12	1.10	1.60	1.10	1.60	1.29	0.25
	S39	1.28	0.60	1.28	1.02	1.10	1.28	0.60	1.06	0.28
	S40	0.64	0.20	0.64	0.16	1.76	0.16	1.76	0.68	0.65
	S41	0.48	0.20	0.48	0.18	1.80	0.18	1.80	0.63	0.67
SW	S42	0.68	1.60	0.68	1.40	1.55	0.68	1.60	1.18	0.46
	S43	0.56	2.60	0.56	1.90	1.90	0.56	2.60	1.61	0.74
	S44	0.20	1.36	0.18	1.76	1.64	0.20	0.80	0.56	0.26
	S45	0.20	1.20	0.16	1.60	1.50	0.50	1.60	1.10	0.48
	Min	0.20	0.09	0.16	0.10	0.30				
	Max	3.35	3.40	3.40	3.02	3.00				
	Mean	0.94	1.23	0.94	1.21	1.62				
	SD	0.83	0.99	0.84	0.80	0.67				

direction from the Mill in the first pre-monsoon season (B0). Distance variation in this side A was not seen.

In side B, all the soil samples have much lower values of calcium in comparison to Side A. In the first post monsoon season (A1), the values were from 10.3 – 21.6 meq/kg (Control 10.9 meq/kg), second pre monsoon (B1) 7.2 - 21.3 meq/kg (Control 14.3 meq/kg), second post monsoon (A2) 10.4– 20 meq/kg (Control 10.2 meq/kg), third pre-monsoon (B2) 10.3– 16.7 meq/kg (Control 13.5 meq/kg) and third post monsoon (A3) 9.7– 21.4 meq/kg (Control 12.4 meq/kg). Since most of the samples have got calcium content less than the values of the Control sample, the soil samples in this side B have either no influence or less influence from the effluent of the Mill. In the last three seasons, (second post monsoon, A2; third pre monsoon, B2; and third post monsoon, A3), the mean values are less than the first two seasons (first post monsoon, A1 and second pre monsoon, B1). The maximum mean value was obtained at S41 (17.5 meq/kg) in the west direction.

(ii) Magnesium

Magnesium is one of the common metals present in soil. This metal is normally found along with calcium in all soils. In the present study, the values of magnesium content (Tables 3.11 (a) and 3.11 (b) for Side A and Side B respectively) were less than those of calcium. The tables also show the maximum, the minimum, the mean and the standard deviation of the magnesium content for various seasons as well as for various sites along different directions. The maximum value was measured for the first pre-monsoon season at S18 (34.4 meq/kg) in the west direction and the minimum value at S19 (1.16 meq/kg) in the same season. No distinct variation of value was seen in a particular direction with distance from the Mill. The mean values in the B1 and B2 batches are more than that of the B0 batch. This pattern bears similarity to those of calcium. Some samples have low value than the 'Control' value, which was also observed with calcium.

In side B, the Mg values are from 0.4 – 13.2 meq/kg in A1, 0.4 – 16.8 meq/kg in B1, 0.3 – 12.7 meq/kg in A2, 0.2– 13.1 meq/kg in B2 and 0.2 – 11.0 meq/kg in A3 batch. It was observed that the 'Control' sample had more Mg than some of the values from the study area. No distinct distance variation of the values was observed. The maximum mean value observed in this side B was at S 42 (12.9 meq/kg) in the southwest direction and the minimum

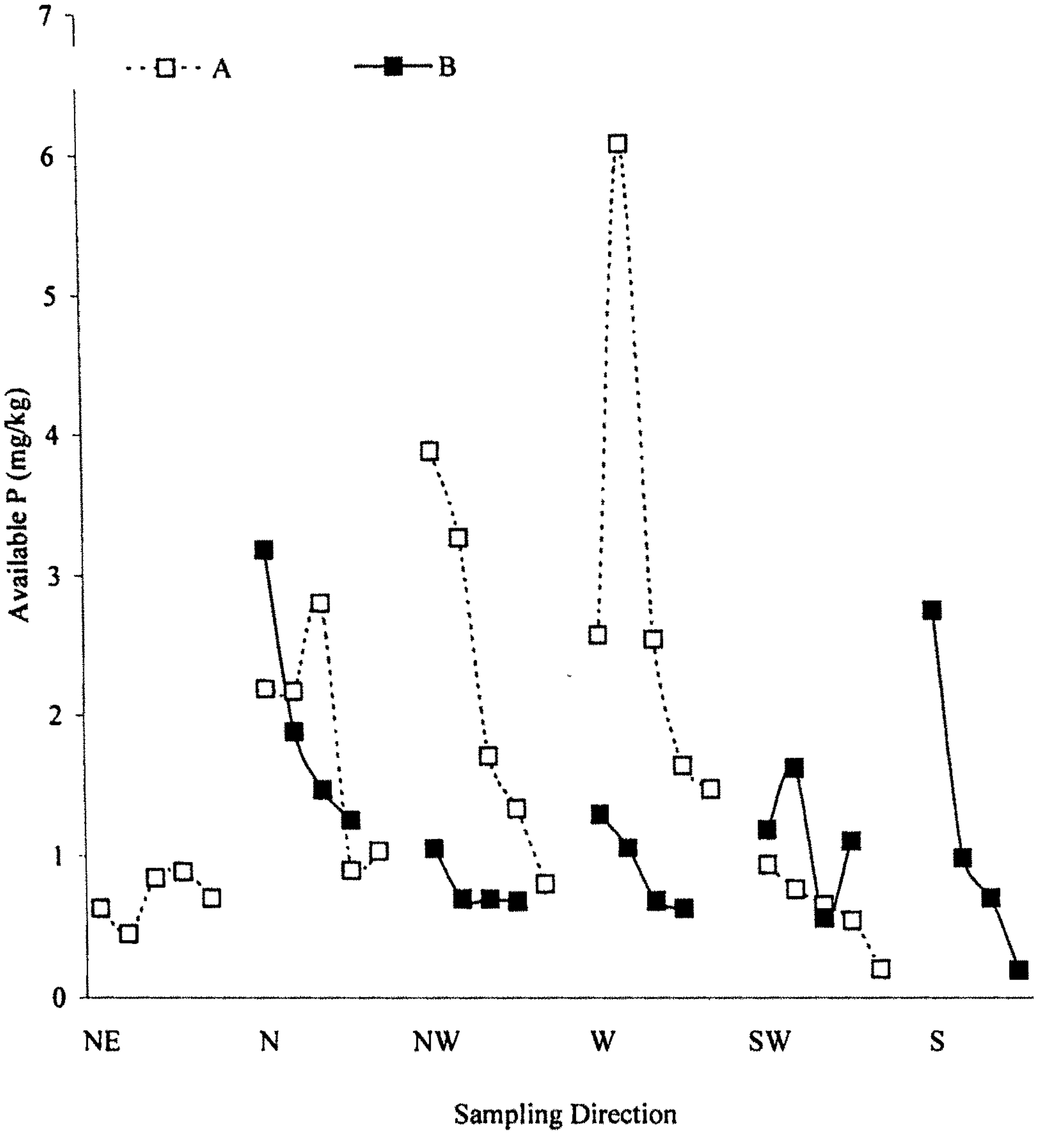


Fig. 3.11. Variation of mean values of available P with direction and distance for Side A and Side B.

Table 3.10(a). Calcium content (meq/kg) of the soil from the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	16.8	14.3	13.5	13.5	16.8	14.9	1.7
NE	S1	22.8	30.6	28.6	22.8	30.6	27.3	4.1
	S2	17.0	26.3	26.2	17.0	26.3	23.2	5.3
	S3	18.4	25.4	24.3	18.4	25.4	22.7	3.8
	S4	23.0	21.7	20.1	20.1	23.0	21.6	1.5
	S5	18.0	29.5	30.1	18.0	30.1	25.9	6.8
N	S6	42.4	58.2	52.8	42.4	58.2	51.1	8.0
	S7	28.0	40.9	42.4	28.0	42.4	37.1	7.9
	S8	30.8	31.5	30.6	30.6	31.5	31.0	0.5
	S9	32.0	30.1	30.3	30.1	32.0	30.8	1.0
	S10	25.0	28.4	24.9	24.9	28.4	26.1	2.0
NW	S11	48.4	69.6	65.4	48.4	69.6	61.1	11.2
	S12	48.0	62.1	60.6	48.0	62.1	56.9	7.7
	S13	36.0	40.4	43.4	36.0	43.4	39.9	3.7
	S14	42.4	52.1	50.3	42.4	52.1	48.3	5.2
	S15	44.8	45.5	40.4	40.4	45.5	43.6	2.8
W	S16	72.4	73.9	69.2	69.2	73.9	71.8	2.4
	S17	82.0	86.1	76.5	76.5	86.1	81.5	4.8
	S18	51.0	59.3	54.5	51.0	59.3	54.9	4.2
	S19	26.8	31.8	28.9	26.8	31.8	29.2	2.5
	S20	67.5	60.4	53.2	53.2	67.5	60.4	7.2
SW	S21	26.0	25.2	22.2	22.2	26.0	24.5	2.0
	S22	22.0	24.9	19.8	19.8	24.9	22.2	2.6
	S23	24.0	32.3	30.4	24.0	32.3	28.9	4.3
	S24	22.4	30.8	23.6	22.4	30.8	25.6	4.5
	S25	39.5	31.3	28.5	28.5	39.5	33.1	5.7
	Min	17.0	21.7	19.8				
	Max	82.0	86.1	76.5				
	Mean	18.0	18.8	17.4				
	SD	17.6	18.0	16.7				

Table 3.10 (b). Calcium content (meq/kg) of the soil from the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	10.9	14.3	10.2	13.5	12.4	10.2	14.3	12.6	1.7
S	S26	15.3	16.3	11.2	16.7	12.6	11.2	16.7	14.8	2.4
	S27	13.8	18.3	12.6	14.5	12.8	12.6	18.3	15.0	2.3
	S28	13.2	18.1	11.3	10.6	13.7	10.6	18.1	14.2	2.9
	S29	10.7	18.0	14.9	10.3	12.8	10.3	18.0	14.1	3.2
N	S30	21.6	14.0	11.0	10.5	9.7	9.7	21.6	14.7	4.9
	S31	13.8	12.7	11.5	12.0	21.4	11.5	21.4	15.5	4.1
	S32	12.6	17.1	12.0	12.2	10.2	10.2	17.1	13.6	2.6
	S33	10.3	10.0	20.0	14.2	10.2	10.0	20.0	14.1	4.3
NW	S34	16.5	11.6	10.4	11.4	11.6	10.4	16.5	13.0	2.4
	S35	16.6	8.8	11.8	10.5	11.2	8.8	16.6	12.6	2.9
	S36	11.8	21.3	15.4	15.2	16.3	11.8	21.3	16.9	3.4
	S37	10.8	14.5	16.4	13.8	13.6	10.8	16.4	14.2	2.0
W	S38	17.6	10.0	12.3	15.8	10.6	10.0	17.6	14.0	3.3
	S39	13.1	11.0	13.6	12.5	10.7	10.7	13.6	12.4	1.3
	S40	12.6	14.0	16.0	11.6	13.1	11.6	16.0	13.9	1.7
	S41	16.1	20.5	16.3	14.6	17.0	14.6	20.5	17.5	2.2
SW	S42	16.5	9.2	12.6	13.4	13.8	9.2	16.5	13.7	2.6
	S43	15.2	7.2	14.2	14.3	12.8	7.2	15.2	13.1	3.2
	S44	13.4	15.0	15.0	15.4	15.4	13.4	15.4	14.9	0.8
	S45	13.8	18.0	17.0	12.2	13.6	12.2	18.0	15.4	2.5
	Min	10.3	7.2	10.4	10.3	9.7				
	Max	21.6	21.3	20.0	16.7	21.4				
	Mean	14.3	14.3	13.8	13.1	13.2				
	SD	2.7	4.1	2.5	2.0	2.8				

was at S43 and S44 (0.4 meq/kg) in the same direction. The maximum mean value obtained was in the second pre-monsoon (B1) season (4.9 meq/kg) and the minimum (3.9 meq/kg) in the third post monsoon season (A3). High level of Mg usually promotes higher development of exchangeable sodium in irrigated soil (Yadav and Khera, 1993)

A comparison of the minimum, the mean and the maximum values of Ca and Mg for side B is shown in Fig. 3.12. It is clear that Ca-content in the soil always outweigh the corresponding Mg-content.

(iii) Sodium

The sodium contents of the soil in the study area are given in the Tables 3.12 (a) and 3.12 (b) for the two sides A and B respectively. The soil was also rich in sodium.

In Side A, the first pre-monsoon season (B0) had Na in the range 0.24– 2.83 meq/100g, the second pre-monsoon (B1) 0.30 – 3.64 meq /100 g and the third pre-monsoon (B2) 0.34– 2.85 meq/100 g. The control sample had 0.10, 0.11 and 0.12-meq/100 g of Na in B0, B1 and B2 batches respectively. The samples near to the Mill have more Na content in comparison to those away from it with a few exceptions. The maximum amount of Na was found at S16 (mean value 3.11 meq/100 g) in the west direction and the minimum at S5 (mean value 0.35 meq/100 g) in the northeast direction.

The soil in Side B was found to have more sodium than that of the Side B. The values are in the following ranges:

- A1 batch 1.20 – 6.36 meq/100 g
- B1 batch 2.07 – 3.16 meq/100 g
- A2 batch 1.15 – 3.18 meq/100 g
- B2 batch 2.25 – 5.84 meq/100 g
- A3 batch 1.16 – 3.44 meq/100 g.

The maximum value was obtained at S36 (mean value 4.14 meq/100 g) in the northwest direction and the minimum at S43 (mean value 1.78 meq/100 g) in the southwest direction. The seasonal variation was not distinct and the distance variation was not uniform. In all the cases, the 'Control' soil had lower values than the samples from the study area.

Table 3.11 (a). Magnesium contents (meq/kg) of the soil in the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	5.02	5.37	5.18	5.02	5.37	5.19	0.18
NE	S1	21.80	26.00	26.30	21.80	26.30	24.70	2.52
	S2	13.40	16.60	15.80	13.40	16.60	15.27	1.67
	S3	4.40	5.90	6.10	4.40	6.10	5.47	0.93
	S4	6.80	7.00	6.30	6.30	7.00	6.70	0.36
	S5	4.00	6.20	6.10	4.00	6.20	5.43	1.24
N	S6	4.00	8.10	7.20	4.00	8.10	6.43	2.15
	S7	4.80	7.20	8.20	4.80	8.20	6.73	1.75
	S8	12.00	21.40	18.60	12.00	21.40	17.33	4.83
	S9	14.00	18.50	18.30	14.00	18.50	16.93	2.54
	S10	17.00	16.10	16.30	16.10	17.00	16.47	0.47
NW	S11	3.20	6.30	9.20	3.20	9.20	6.23	3.00
	S12	3.20	5.90	5.40	3.20	5.90	4.83	1.44
	S13	12.80	19.40	17.20	12.80	19.40	16.47	3.36
	S14	11.60	13.00	13.90	11.60	13.90	12.83	1.16
	S15	7.20	20.10	16.00	7.20	20.10	14.43	6.59
W	S16	4.00	11.30	10.10	4.00	11.30	8.47	3.91
	S17	4.00	10.60	10.30	4.00	10.60	8.30	3.73
	S18	34.40	30.10	28.40	28.40	34.40	30.97	3.09
	S19	1.60	9.30	10.30	1.60	10.30	7.07	4.76
	S20	9.00	16.70	15.80	9.00	16.70	13.83	4.21
SW	S21	15.20	16.30	15.40	15.20	16.30	15.63	0.59
	S22	21.60	20.80	18.70	18.70	21.60	20.37	1.50
	S23	8.40	11.50	10.50	8.40	11.50	10.13	1.58
	S24	14.80	14.20	13.70	13.70	14.80	14.23	0.55
	S25	10.80	13.20	10.80	10.80	13.20	11.60	1.39
	Min	1.60	5.90	5.40				
	Max	34.40	30.10	28.40				
	Mean	10.56	14.07	13.40				
	SD	7.61	6.60	6.00				

Table 3.11 (b). Magnesium contents (meq/kg) of the soil in the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	5.5	5.4	5.3	5.2	5.0	5.0	5.5	5.3	0.2
S	S26	6.1	6.0	5.6	5.3	5.1	5.1	6.1	5.6	0.4
	S27	5.3	10.0	5.4	9.1	6.7	5.3	10.0	7.3	2.1
	S28	2.4	0.8	1.8	1.4	0.9	0.8	2.4	1.5	0.7
	S29	1.9	4.8	1.3	5.7	5.1	1.3	5.7	3.7	2.0
N	S30	5.6	4.0	5.1	6.3	5.8	4.0	6.3	5.4	0.9
	S31	4.3	0.4	4.1	1.6	0.8	0.4	4.3	2.2	1.8
	S32	4.1	12.8	3.5	8.5	7.3	3.5	12.8	7.2	3.8
	S33	0.9	1.2	0.8	2.6	1.9	0.8	2.6	1.5	0.7
NW	S34	11.2	12.9	10.3	13.1	10.2	10.2	13.1	11.5	1.4
	S35	7.2	6.8	6.6	4.3	3.5	3.5	7.2	5.7	1.7
	S36	1.5	0.9	1.0	1.1	0.9	0.9	1.5	1.1	0.3
	S37	0.8	0.4	0.8	0.8	0.8	0.4	0.8	0.7	0.2
W	S38	13.0	13.2	12.7	11.5	10.2	10.2	13.2	12.1	1.3
	S39	2.0	2.0	1.5	3.6	2.3	1.5	3.6	2.3	0.8
	S40	2.4	0.4	2.3	0.5	0.9	0.4	2.4	1.3	1.0
	S41	1.9	2.8	2.1	2.1	1.6	1.6	2.8	2.1	0.4
SW	S42	13.2	16.8	12.5	10.9	11.0	10.9	16.8	12.9	2.4
	S43	0.7	0.4	0.7	0.2	0.3	0.2	0.7	0.4	0.2
	S44	0.6	0.4	0.5	0.3	0.2	0.2	0.6	0.4	0.2
	S45	0.4	0.8	0.3	0.7	0.4	0.3	0.8	0.5	0.2
	Min	0.4	0.4	0.3	0.2	0.2				
	Max	13.2	16.8	12.7	13.1	11.0				
	Mean	4.3	4.9	3.9	4.5	3.8				
	SD	4.1	5.4	3.9	4.1	3.6				

(iv) Potassium

Potassium is one of the alkaline metals present in soil, comparatively with lesser amount than sodium. K contents of the soil samples in the present work are given in Table 3.13 (a) and 3.13 (b) respectively for the Sides, A and B.

The value were in the ranges of: first pre- monsoon (B0) 0.106 – 0.386 meq/100 g, second pre-monsoon (B1) 0.113 – 0.450 meq/100 g and third pre-monsoon (B2) 0.085 – 0.420 meq/100 g. In these three seasons, the "Control" soil sample had the values of 0.063 meq/100 g, 0.059 meq/100 g and 0.053 meq/100 g in for the seasons B0, B1 and B2 respectively. There is no distinct distance variation of the K-content. The maximum value was obtained at S14 (mean value 0.419 meq/100 g) in the northwest direction and the minimum value was at S22 (mean value 0.101 meq/100 g) in the southwest direction. The samples in the northeast direction have less K compared to the other directions.

In side B, the soil samples had more K content than those on side A. This trend is identical to that of Na. The K-values for the batch B0 were less than those of the B1 batch, but this decreasing trend was not seen in the batch, B2. The soil samples further away from the mill had less K-content. The maximum value was obtained at S36 in the northwest direction (mean value 0.21 meq/100 g) and the minimum at S31 (mean value 0.072 meq/100 g) in the North direction. It is observed that the values decreased from A1 batch to A3 batch, the exception being at B2 batch. The values show maximum variation in A1 batch (SD 0.226) and minimum at A2 batch (SD 0.102).

Since sodium and potassium occur simultaneously, a comparison of their mean values in soil from Side A and Side B is given in Fig. 3.13 and Fig. 3.14 respectively. These also show that the sodium content outweigh the potassium content in all the cases. Potassium is an essential element, but excess sodium may lead to development of toxicity in soil for plants and it is to be noted that the excess sodium in the soil near the Mill might have been contributed by the effluent release.

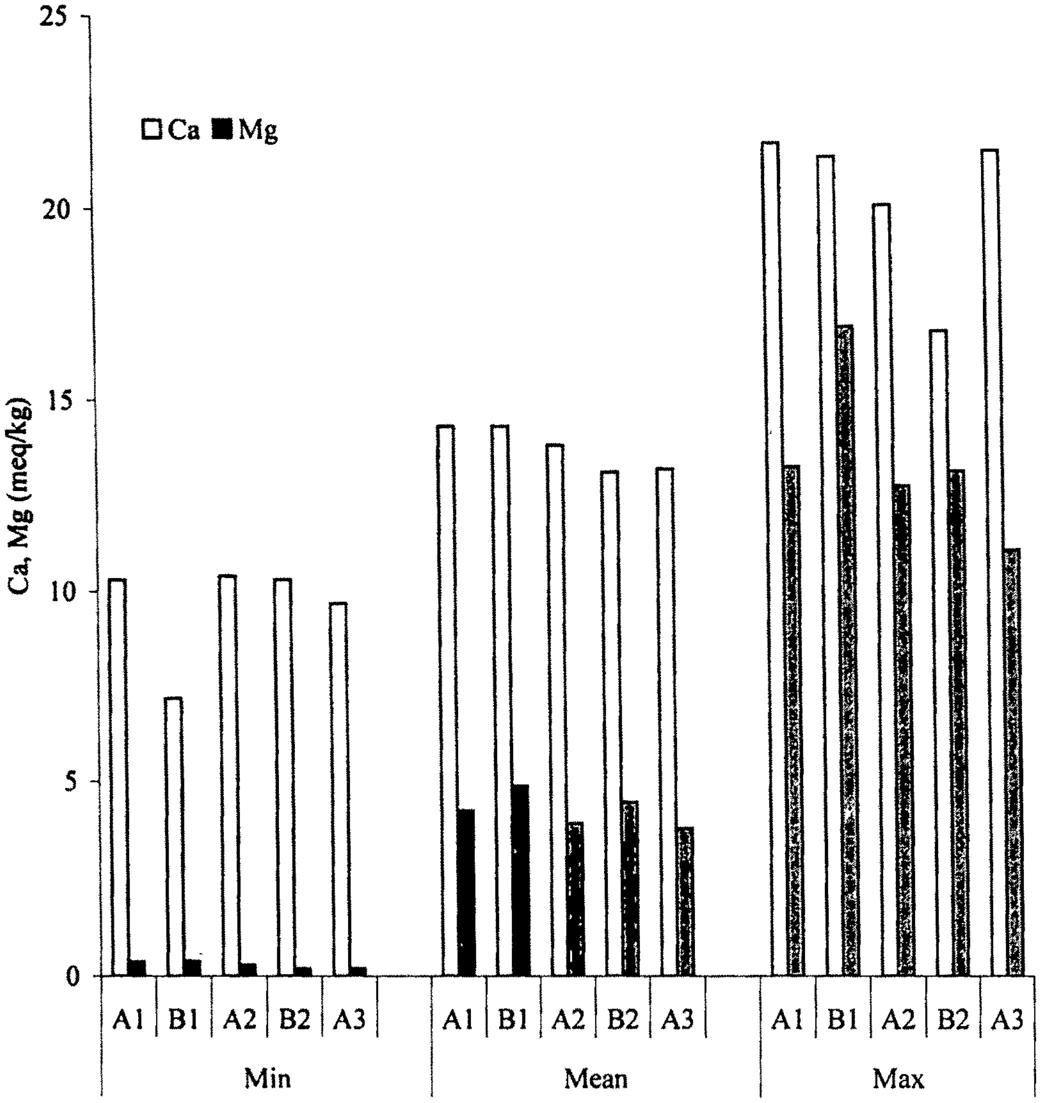


Fig. 3.12. Comparison of Ca- and Mg-contents of the Side B soil

Table 3.12 (a). Sodium content (meq/100 g) of the soil samples of the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.10	0.11	0.12	0.10	0.12	0.11	0.01
NE	S1	1.06	1.13	1.06	1.06	1.13	1.08	0.04
	S2	0.74	0.85	0.53	0.53	0.85	0.71	0.16
	S3	0.58	0.71	0.62	0.58	0.71	0.64	0.07
	S4	0.71	0.60	0.49	0.49	0.71	0.60	0.11
	S5	0.24	0.30	0.52	0.24	0.52	0.35	0.15
N	S6	2.76	2.76	1.98	1.98	2.76	2.50	0.45
	S7	1.66	2.42	1.86	1.66	2.42	1.98	0.39
	S8	1.84	1.67	1.12	1.12	1.84	1.54	0.38
	S9	1.36	1.88	1.27	1.27	1.88	1.50	0.33
	S10	1.56	2.58	1.93	1.56	2.58	2.02	0.52
NW	S11	1.51	1.71	1.11	1.11	1.71	1.44	0.31
	S12	1.28	1.65	1.03	1.03	1.65	1.32	0.31
	S13	2.11	2.40	1.84	1.84	2.40	2.12	0.28
	S14	1.69	1.62	1.04	1.04	1.69	1.45	0.36
	S15	1.68	0.78	1.02	0.78	1.68	1.16	0.47
W	S16	2.83	3.64	2.85	2.83	3.64	3.11	0.46
	S17	1.43	1.03	0.86	0.86	1.43	1.11	0.29
	S18	1.14	1.11	0.73	0.73	1.14	0.99	0.23
	S19	1.26	1.09	0.62	0.62	1.26	0.99	0.33
	S20	1.46	0.96	1.01	0.96	1.46	1.14	0.28
SW	S21	1.27	1.19	0.84	0.84	1.27	1.10	0.23
	S22	1.42	1.22	1.08	1.08	1.42	1.24	0.17
	S23	1.65	0.80	0.34	0.34	1.65	0.93	0.66
	S24	1.33	0.83	0.65	0.65	1.33	0.94	0.35
	S25	1.39	0.84	0.74	0.74	1.39	0.99	0.35
	Min	0.24	0.30	0.34				
	Max	2.83	3.64	2.85				
	Mean	1.44	1.43	1.09				
	SD	0.58	0.80	0.59				

Table 3.12 (b). Sodium content (meq/100 g) of the soil samples of the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.13	0.11	0.13	0.12	0.12	0.11	0.13	0.12	0.01
S	S26	3.65	2.16	2.51	3.64	1.16	1.16	3.65	2.62	1.06
	S27	2.50	2.20	2.80	2.85	1.44	1.44	2.85	2.36	0.58
	S28	2.50	2.20	2.62	2.70	2.93	2.20	2.93	2.59	0.27
	S29	2.76	2.80	2.72	2.83	2.52	2.52	2.83	2.73	0.12
N	S30	4.21	2.32	2.13	2.26	2.59	2.13	4.21	2.70	0.86
	S31	4.20	2.07	2.41	2.48	2.11	2.07	4.20	2.65	0.88
	S32	2.65	2.22	2.26	2.86	2.67	2.22	2.86	2.53	0.28
	S33	2.40	3.16	3.18	3.06	2.83	2.40	3.18	2.93	0.33
NW	S34	5.02	2.88	2.11	2.53	2.24	2.11	5.02	2.96	1.19
	S35	3.90	2.76	2.65	2.25	2.10	2.10	3.90	2.73	0.71
	S36	6.36	3.10	3.17	4.63	3.44	3.10	6.36	4.14	1.39
	S37	3.02	3.10	3.16	5.84	2.37	2.37	5.84	3.50	1.35
W	S38	3.20	2.13	2.16	3.26	2.55	2.13	3.26	2.66	0.55
	S39	3.40	2.14	2.18	3.18	2.45	2.14	3.40	2.67	0.58
	S40	2.40	2.50	2.60	3.03	2.37	2.37	3.03	2.58	0.27
	S41	2.20	2.18	2.30	3.06	2.62	2.18	3.06	2.47	0.37
SW	S42	3.10	2.20	1.15	2.80	2.45	1.15	3.10	2.34	0.75
	S43	1.60	2.18	1.30	2.42	1.39	1.30	2.42	1.78	0.50
	S44	1.20	2.35	1.54	3.17	2.61	1.20	3.17	2.17	0.80
	S45	1.46	2.80	2.00	2.83	2.70	1.46	2.83	2.36	0.61
	Max	1.20	2.07	1.15	2.25	1.16				
	Min	6.36	3.16	3.18	5.84	3.44				
	Mean	3.09	2.47	2.35	3.08	2.38				
	SD	1.24	0.38	0.57	0.84	0.54				

Table 3.13 (a). Potassium contents (meq/100 g) of the soil of the study area (side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.063	0.059	0.053	0.053	0.063	0.058	0.005
NE	S1	0.185	0.206	0.186	0.185	0.206	0.192	0.012
	S2	0.251	0.298	0.290	0.251	0.298	0.280	0.025
	S3	0.126	0.263	0.243	0.126	0.263	0.211	0.074
	S4	0.216	0.311	0.341	0.216	0.341	0.289	0.065
	S5	0.160	0.213	0.231	0.160	0.231	0.201	0.037
N	S6	0.320	0.301	0.362	0.301	0.362	0.328	0.031
	S7	0.348	0.390	0.285	0.285	0.390	0.341	0.053
	S8	0.285	0.317	0.304	0.285	0.317	0.302	0.016
	S9	0.272	0.267	0.263	0.263	0.272	0.267	0.005
	S10	0.126	0.298	0.150	0.126	0.298	0.191	0.093
NW	S11	0.110	0.312	0.174	0.110	0.312	0.199	0.103
	S12	0.124	0.373	0.200	0.124	0.373	0.232	0.128
	S13	0.349	0.328	0.130	0.130	0.349	0.269	0.121
	S14	0.386	0.450	0.420	0.386	0.450	0.419	0.032
	S15	0.361	0.301	0.263	0.263	0.361	0.308	0.049
W	S16	0.163	0.142	0.080	0.080	0.163	0.128	0.043
	S17	0.348	0.319	0.310	0.310	0.348	0.326	0.020
	S18	0.283	0.315	0.139	0.139	0.315	0.246	0.094
	S19	0.136	0.152	0.160	0.136	0.160	0.149	0.012
	S20	0.238	0.298	0.143	0.143	0.298	0.226	0.078
SW	S21	0.294	0.300	0.241	0.241	0.300	0.278	0.032
	S22	0.106	0.113	0.085	0.085	0.113	0.101	0.015
	S23	0.214	0.298	0.164	0.164	0.298	0.225	0.068
	S24	0.168	0.263	0.115	0.115	0.263	0.182	0.075
	S25	0.284	0.319	0.120	0.120	0.319	0.241	0.106
	Min	0.106	0.113	0.080				
	Max	0.386	0.450	0.420				
	Mean	0.234	0.286	0.216				
	SD	0.090	0.075	0.091				

Table 3.13 (b). Potassium contents (meq/100 g) of the soil of the study area (side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.071	0.059	0.061	0.053	0.058	0.053	0.071	0.060	0.007
S	S26	0.690	0.130	0.158	0.614	0.140	0.130	0.690	0.346	0.280
	S27	0.560	0.250	0.146	0.073	0.100	0.073	0.560	0.226	0.199
	S28	0.360	0.260	0.391	0.290	0.160	0.160	0.391	0.292	0.091
	S29	0.100	0.520	0.437	0.470	0.202	0.100	0.520	0.346	0.184
N	S30	0.350	0.050	0.080	0.084	0.150	0.050	0.350	0.143	0.121
	S31	0.320	0.078	0.072	0.110	0.120	0.072	0.320	0.140	0.103
	S32	0.140	0.285	0.196	0.243	0.150	0.140	0.285	0.203	0.062
	S33	0.100	0.354	0.238	0.365	0.260	0.100	0.365	0.263	0.107
NW	S34	0.820	0.105	0.140	0.116	0.170	0.105	0.820	0.270	0.308
	S35	0.570	0.152	0.100	0.216	0.120	0.100	0.570	0.232	0.194
	S36	0.240	0.560	0.241	0.543	0.210	0.210	0.560	0.359	0.176
	S37	0.140	0.680	0.306	0.714	0.280	0.140	0.714	0.424	0.257
W	S38	0.380	0.106	0.116	0.102	0.140	0.102	0.380	0.169	0.119
	S39	0.530	0.143	0.105	0.181	0.110	0.105	0.530	0.214	0.179
	S40	0.220	0.690	0.164	0.300	0.120	0.120	0.690	0.299	0.229
	S41	0.100	0.700	0.221	0.429	0.110	0.100	0.700	0.312	0.254
SW	S42	0.620	0.104	0.086	0.120	0.120	0.086	0.620	0.210	0.230
	S43	0.300	0.110	0.130	0.126	0.100	0.100	0.300	0.153	0.083
	S44	0.100	0.200	0.116	0.230	0.130	0.100	0.230	0.155	0.057
	S45	0.130	0.220	0.135	0.510	0.170	0.130	0.510	0.233	0.159
	Min	0.100	0.050	0.072	0.073	0.100				
	Max	0.820	0.700	0.437	0.714	0.280				
	Mean	0.339	0.285	0.179	0.292	0.153				
	SD	0.224	0.221	0.101	0.195	0.050				

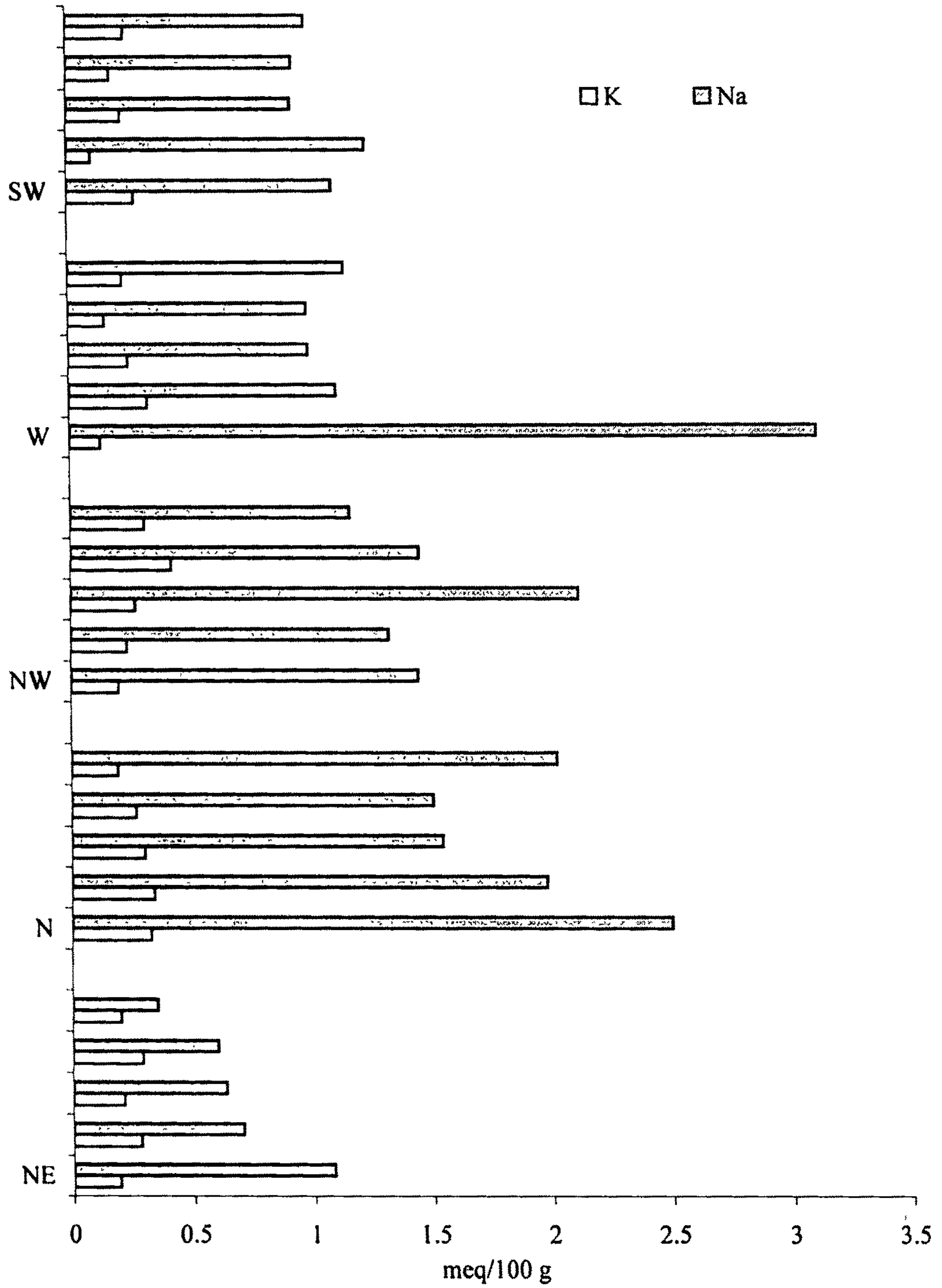


Fig. 3.13. Variation of mean contents of sodium and potassium with distance from the Mill along the different directions for Side A

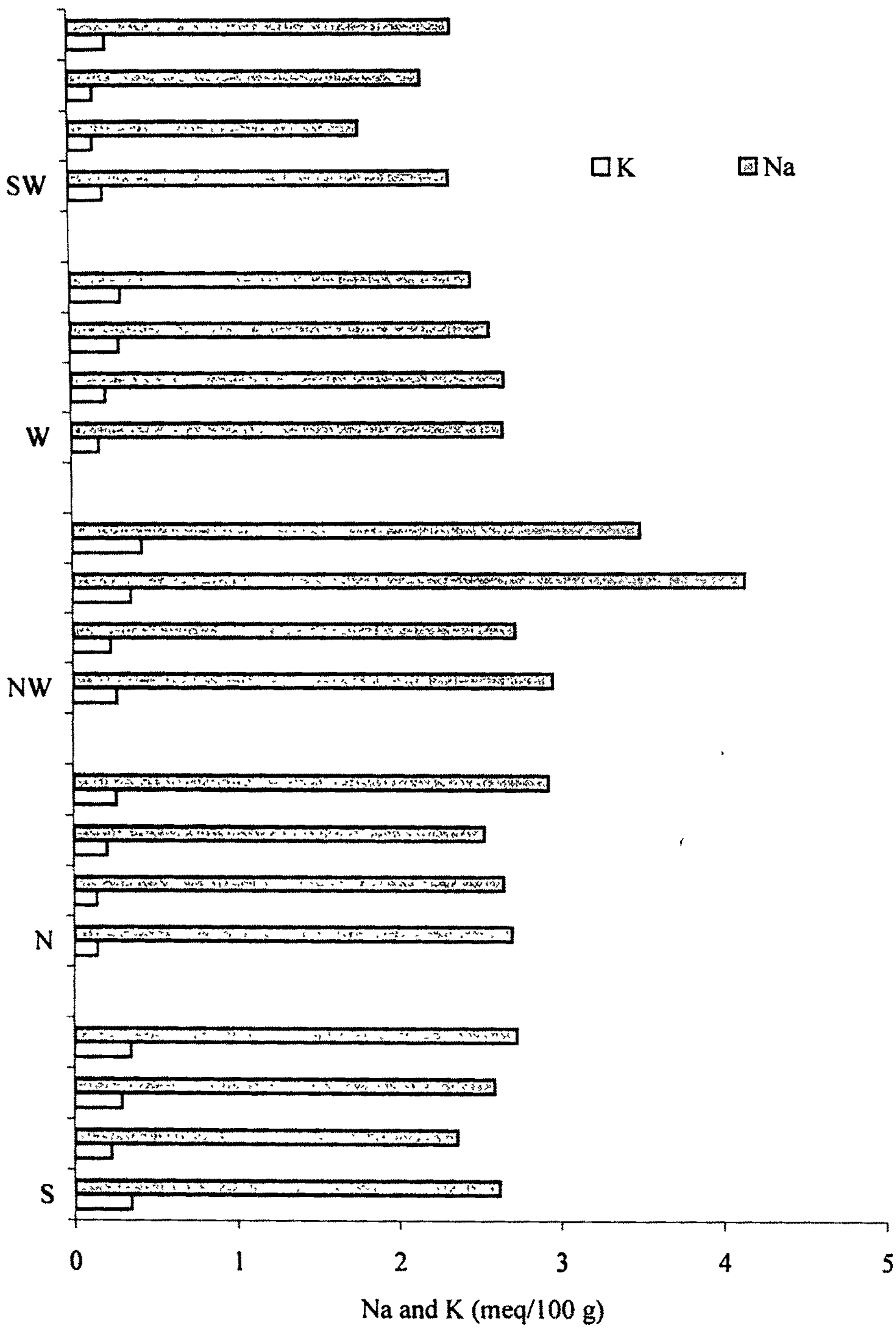


Fig. 3.14. Variation of mean contents of sodium and potassium with distance from the Mill along the different directions for Side B

3.1.12. Trace Metals

Inorganic pollutants like toxic heavy metals, namely Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn are ubiquitous and play an extremely important role in the environment A wide range of contaminants from industrial activities, sewage sludge disposal, metal processing and energy production may pollute soils. Prasanthi et al. (2001) observed high content of trace metals near an industry.

Industrial effluents and municipal wastewaters usually contain high amount of heavy metals such as As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn (Larsen et al., 1975; Arora et al., 1985; Irshad et al., 1997.). Their continuous use on agricultural land may result in metal accumulation in surface soil (Gupta et al., 1986). Some heavy metals are essential trace amounts, namely Zn, Cu, Fe, Mn, Mo and Co for plants and in addition Cr, Ni, Sn for animals; whereas As, Cd, Hg and Pb have not been known to have any function for either plants or animals (Greenland and Hayes, 1981). Higher concentration of these metals in the ecosystem may lead to an excessive accumulation of metals, becoming toxic to plants and possible danger to human health problem. A number of cases of health problems related to environment Cd and Hg poisoning and elevated levels of Pb in the blood of infants have been reported (Singh and Steinnes, 1994).

Some of the metals are phytotoxic and some are toxic to both plants and animals through their entry into food chain (Khalid and Tinsly, 1980; Sameni *et al.*, 1987; Roads and Manning 1989). Anthropogenic pollution by heavy metals and their phytotoxicities has been reported by many other investigators (Chen, 1991, Sheppard, 1992)

For a few elements, determined in this study, a comparison of the contents for "Control" sample with average for world soils (Bowen, 1966; Angelone and Bini, 1992) is given below:

Metals	Average content World soil (mg/kg)
Cu	20
Mn	850
Ni	40
Pb	10
Zn	50

No such average ranges have been reported for soils of India in the available literature.
The results obtained in the present work are discussed below:

(a) Aluminium (Al)

The Al contents of the soil are given in Table 3.14(a) and (b). The study reveals that the soil in the study area is very rich in Al. There is distinct variation of the values for all the samples from B0 to B2 batch in side A. The values are in the following ranges:

- 10.0 – 89.0 g/kg in B0 batch
- 10.0 – 77.0 g/kg in B1 batch
- 10.0 – 68.0 g/kg in B2 batch.

A decreasing trend away from the Mill indicates that the effluent discharges from the Mill have a direct impact on Al-content of the surrounding soil. The variation along the distance from the Mill is not uniform at any direction. In side B, the amount of Al present in soil samples has comparatively low value than side A which is not surprising since the Side A is closest to the Mill receiving the discharges.

In side B, the values are from 9.0 – 41.0 g/kg in A1 batch, 8.0 – 56.0 g/kg in B1 batch, 7.0 – 29.0 g/kg in A2 batch, 7.0 – 45.0 g/kg in B2 batch and 6.0 – 33.0 g/kg in A3 batch. The entire site has very high content of Al. The values of Al in most of the soil samples in this side decreased from B1 to B2, similarly as in side A. The distance variation from the Mill was not uniform. The variations of the values from season to season of all the samples are also not uniform. Excess Al^{3+} concentration in soil is caused by low soil pH (<5). The concentration of Al in soil thus depends on soil pH as well as the concentration of organic and inorganic compounds that can form complexes with Al (Dobermann and Fairhurst, 2000). The concentration of soluble Al in soil water is very small (Manahan, 1975) but that fraction is easily mobile and exchangeable and plays an important role in soil fertility.

Table 3.14 (a) Al-contents of the soil in Side A (g/kg)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.58	0.55	0.53	0.53	0.58	0.55	0.026
NE	S1	13	10	10	10	13	11	2
	S2	12	10	9	9	12	10	2
	S3	13	13	10	10	13	12	2
	S4	14	10	9	9	14	11	3
	S5	10	10	11	10	11	10	1
N	S6	79	70	56	56	79	68	12
	S7	72	71	53	53	72	65	11
	S8	57	55	42	42	57	51	8
	S9	54	51	23	23	54	43	17
	S10	26	21	19	19	26	22	4
NW	S11	63	61	56	56	63	60	4
	S12	61	60	48	48	61	56	7
	S13	53	49	34	34	53	45	10
	S14	48	45	35	35	48	43	7
	S15	38	37	30	30	38	35	4
W	S16	89	77	68	68	89	78	11
	S17	46	43	41	41	46	43	3
	S18	52	50	40	40	52	47	6
	S19	43	37	30	30	43	37	7
	S20	43	36	29	29	43	36	7
SW	S21	46	40	34	34	46	40	6
	S22	15	15	10	10	15	13	3
	S23	16	13	10	10	16	13	3
	S24	16	15	10	10	16	14	3
	S25	16	13	10	10	16	13	3
	Min	10	10	9				
	Max	89	77	68				
	Mean	40	36	29				
	SD	23	22	18				

Table 3.14 (b). Al-content of the soil in Side B (g/kg)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.58	0.55	0.54	0.55	0.53	0.53	0.58	0.55	0.019
S	S26	28	30	27	23	7	7	30	23	9
	S27	26	35	29	25	22	22	35	27	5
	S28	19	21	22	17	10	10	22	18	5
	S29	13	15	12	10	7	7	15	11	3
N	S30	30	30	24	20	10	10	30	23	8
	S31	21	18	14	13	10	10	21	15	4
	S32	10	8	8	7	6	6	10	8	1
	S33	9	8	7	8	8	7	9	8	1
NW	S34	24	8	12	13	8	8	24	13	7
	S35	16	20	15	13	8	8	20	14	4
	S36	15	18	15	10	7	7	18	13	4
	S37	10	12	10	10	10	10	12	10	1
W	S38	16	17	18	16	13	13	18	16	2
	S39	22	20	15	12	12	12	22	16	5
	S40	15	20	14	12	19	12	20	16	3
	S41	41	56	21	45	33	21	56	39	13
SW	S42	35	30	28	18	17	17	35	26	8
	S43	12	12	12	11	8	8	12	11	2
	S44	12	10	10	10	9	9	12	10	1
	S45	12	10	8	8	6	6	12	9	2
	Min	9	8	7	7	6				
	Max	41	56	29	45	33				
	Mean	19	20	16	15	11				
	SD	9	12	7	9	7				

(b) Arsenic (As)

Table 3.15 (a) and Table 3.15 (b) are representing the values of arsenic in soil in Side A and Side B respectively. The values decreased from season B0 to B2. In most of the cases, as the distance increased from the Mill, the values showed a decrease. The "Control" sample was free from As. The maximum value was obtained at S11 (mean value 16.44 μg/kg) in NW direction. In side B, the distant samples in N and S direction were free from As in all the seasons. In the first two seasons (A1 and B1), the values were found more in comparison to other seasons. Most of the samples in NW, SW and W directions had considerable values. The distance variation was very much distinct. The maximum mean value (4.99(μg/kg) was obtained at B1 season

(c) Cadmium (Cd)

It has been estimated that anthropogenic emissions of Cd are in the range of 30,000 t per year (Sanita di Toppi and Gabberielli, 1999). In Table 3.16 (a) and 3.16 (b), the Cd contents for all the samples for each of the batches are given for side A and side B respectively. The permissible limit of Cd in the surface soil is 3 mg/kg (Bansal, 1998). However, Cd is a very mobile element in the environment (Cieæko et al., 2004).

The soil samples in the directions, N (range 1-3 mg/kg), NW (range 1.3 – 3.6 mg/kg) and W (range 1.6 – 3.2 mg/kg) have more Cd content in comparison to NE (range 0.9 – 3.2 mg/kg) and SW (range 1.4 – 2.7 mg/kg) directions. The maximum value obtained was at S11 (3.6 mg/kg), which was very near to the effluent discharge point from the Mill, in B1 batch. The values in B1 batch were more in comparison to other two seasons (B0 and B2). The standard deviation values show that there is large consistency of values (0.7) among the site for all the batches.

The dyes used in printing and dyeing of textile materials contain Cd. Again fly ash dumping may also contribute to the increased value of Cd around the Mill, since fly ash contains 5 – 10 mg/kg of Cd (Gillham and Simpson, 1973). Interestingly, the soil samples have more Cd in

Side B in comparison to those of Side A. The reason is not clear, however, it is likely that due to natural or other reasons, the Cd-wastes are accumulating in the Side B.

The sample S38 in the west direction had the maximum mean value (18.5 mg/kg) and S45 in SW had the least mean value (3.3 mg/kg). In most of the cases, the values away from the Mill exhibited a decreasing trend. Another observation was that the Cd-content decreased from A1 season to A3 season. In all the cases the "Control" has low Cd content.

(d) Chromium (Cr)

The values of Cr in side A and B are given in Table 3.17 (a) and 3.17 (b). The Cr present in the soil samples indicates contribution of the effluent of the Mill release to the surrounding area. In this study, Cr does not show any directional trend. The ranges of Cr in the present study in side A are as follows:

- 24.7 - 298.8 mg/kg in B0 batch
- 48 – 288 mg/kg in B1 batch
- 41.5 – 257 mg/kg in B2 batch

The maximum value was obtained at S15 (298.8 mg/kg) in NW direction and the minimum at S5 (24.7 mg/kg) in NE direction. The maximum permissible limit of Cr in soil is 100 mg/kg (Sastry et al., 2001). Except S1 (NE direction), S22 and S24 (SW direction), almost all the samples in side A have more Cr than the maximum permissible limit. No distinct seasonal variation or distance variation was observed in this side. Chromium can strongly attach to soil and only a small amount can dissolve in water and move deeper in the soil to underground water.

Table 3.15 (a). As content of the soil in Side A (μg/kg)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	BDL	BDL	BDL	BDL	BDL	BDL	BDL
NE	S1	10.05	6.34	2.38	2.38	10.05	6.26	3.84
	S2	9.01	4.30	1.20	1.20	9.01	4.84	3.93
	S3	2.44	0.64	0.03	0.03	2.44	1.04	1.26
	S4	1.65	0.74	BDL	0.74	1.65	1.20	0.64
	S5	0.95	0.35	0.30	0.30	0.95	0.53	0.36
N	S6	19.27	14.85	5.07	5.07	19.27	13.06	7.27
	S7	13.70	3.26	5.81	3.26	13.70	7.59	5.44
	S8	6.52	6.04	2.78	2.78	6.52	5.11	2.03
	S9	1.28	2.11	1.50	1.28	2.11	1.63	0.43
	S10	1.95	1.05	0.46	0.46	1.95	1.15	0.75
NW	S11	27.01	13.36	8.95	8.95	27.01	16.44	9.42
	S12	23.80	20.50	4.70	4.70	23.80	16.33	10.21
	S13	14.84	9.11	4.62	4.62	14.84	9.52	5.12
	S14	6.05	2.74	BDL	2.74	6.05	4.40	2.34
	S15	0.86	0.22	0.13	0.13	0.86	0.40	0.40
W	S16	10.03	9.46	9.50	9.46	10.03	9.66	0.32
	S17	3.30	2.74	1.55	1.55	3.30	2.53	0.89
	S18	5.17	6.31	5.50	5.17	6.31	5.66	0.59
	S19	1.62	2.14	1.96	1.62	2.14	1.91	0.26
	S20	0.56	0.92	0.85	0.56	0.92	0.78	0.19
SW	S21	9.16	10.20	8.54	8.54	10.20	9.30	0.84
	S22	8.87	6.72	4.28	4.28	8.87	6.62	2.30
	S23	2.03	1.11	1.07	1.07	2.03	1.40	0.54
	S24	4.23	1.06	1.10	1.06	4.23	2.13	1.82
	S25	1.14	0.95	0.66	0.66	1.14	0.92	0.24
	Min	0.56	0.22	BDL				
	Max	27.01	20.50	9.50				
	Mean	7.42	5.09	3.17				
	SD	7.37	5.28	2.94				

Table 3.15 (b). As-content of the soil in Side B (μg/mg)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
S	S26	0.004	0.002	0.002	0.001	0.001	0.001	0.004	0.002	0.001
	S27	0.010	0.001	0.001	BDL	BDL	0.001	0.010	0.004	0.005
	S28	0.000	BDL	0.000	BDL	BDL	0.000	0.000	BDL	BDL
	S29	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
N	S30	14.521	11.080	8.306	1.375	BDL	1.375	14.521	8.821	5.577
	S31	4.360	2.015	1.168	0.640	0.002	0.002	4.360	1.637	1.692
	S32	1.073	0.980	0.630	BDL	BDL	0.630	1.073	0.894	0.234
	S33	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
NW	S34	15.040	21.780	9.640	0.008	0.010	0.008	21.780	9.296	9.506
	S35	7.035	19.760	3.260	BDL	0.008	0.008	19.760	7.516	8.653
	S36	3.214	0.453	0.005	0.001	BDL	0.001	3.214	0.918	1.545
	S37	1.250	0.950	1.070	0.850	0.023	0.023	1.250	0.829	0.474
W	S38	6.042	2.850	1.530	0.615	0.008	0.008	6.042	2.209	2.395
	S39	4.260	1.580	0.973	0.540	0.084	0.084	4.260	1.487	1.645
	S40	0.130	0.078	0.005	0.004	BDL	0.004	0.130	0.054	0.061
	S41	0.080	0.006	0.006	0.005	0.003	0.003	0.080	0.020	0.034
SW	S42	10.530	11.280	11.320	9.750	0.041	0.041	11.320	8.584	4.819
	S43	9.420	7.920	3.629	1.852	0.970	0.970	9.420	4.758	3.735
	S44	3.550	2.060	0.663	0.037	0.019	0.019	3.550	1.266	1.523
	S45	4.020	2.054	1.680	0.805	0.056	0.056	4.020	1.723	1.501
	Min	BDL	BDL	BDL	BDL	BDL				
	Max	15.040	21.780	11.320	9.750	0.970				
	Mean	4.697	4.991	2.438	1.177	0.102				
	SD	4.879	6.979	3.567	2.533	0.274				

Table 3.16 (a). Cadmium (Cd) contents of the soil in Side A (mg/kg)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.6	0.6	0.6	0.6	0.6	0.6	0.0
NE	S1	1.2	1.6	1.9	1.2	1.9	1.6	0.4
	S2	2.7	2.8	3.2	2.7	3.2	2.9	0.2
	S3	1.6	1.1	1.2	1.1	1.6	1.3	0.3
	S4	0.9	1.5	1.2	0.9	1.5	1.2	0.3
	S5	1.0	1.2	2.8	1.0	2.8	1.7	1.0
N	S6	2.6	3.0	2.8	2.6	3.0	2.8	0.2
	S7	1.3	1.1	1.0	1.0	1.3	1.1	0.2
	S8	1.0	1.1	1.6	1.0	1.6	1.2	0.3
	S9	1.5	2.0	1.8	1.5	2.0	1.8	0.3
	S10	1.8	2.0	1.9	1.8	2.0	1.9	0.1
NW	S11	3.4	3.6	3.5	3.4	3.6	3.5	0.1
	S12	1.5	2.0	3.3	1.5	3.3	2.3	0.9
	S13	1.7	2.0	1.7	1.7	2.0	1.8	0.2
	S14	1.7	1.8	1.7	1.7	1.8	1.7	0.1
	S15	1.9	1.8	1.3	1.3	1.9	1.7	0.3
W	S16	3.1	3.2	2.9	2.9	3.2	3.1	0.1
	S17	1.6	2.6	2.2	1.6	2.6	2.1	0.5
	S18	2.3	3.0	2.5	2.3	3.0	2.6	0.4
	S19	2.9	2.5	2.6	2.5	2.9	2.7	0.2
	S20	2.1	2.8	2.7	2.1	2.8	2.5	0.4
SW	S21	2.7	2.5	2.0	2.0	2.7	2.4	0.4
	S22	1.6	2.3	2.2	1.6	2.3	2.0	0.4
	S23	1.7	2.5	2.3	1.7	2.5	2.2	0.4
	S24	1.8	2.0	1.5	1.5	2.0	1.8	0.3
	S25	1.4	2.0	1.8	1.4	2.0	1.7	0.3
	Min	0.9	1.1	1.0				
	Max	3.4	3.6	3.5				
	Mean	1.9	2.2	2.1				
	SD	0.7	0.7	0.7				

Table 3.16 (b). Cadmium (Cd) content of the soil in Side B (mg/kg)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.0
S	S26	12.4	11.3	6.6	6.2	9.8	6.2	12.4	9.3	2.8
	S27	11.4	9.6	8.2	8.0	5.1	5.1	11.4	8.5	2.3
	S28	4.6	2.1	4.1	4.0	4.2	2.1	4.6	3.8	1.0
	S29	5.2	6.8	5.2	4.7	3.2	3.2	6.8	5.0	1.3
N	S30	20.5	10.1	11.4	8.1	7.1	7.1	20.5	11.4	5.3
	S31	10.4	11.0	10.0	6.9	5.1	5.1	11.0	8.7	2.6
	S32	9.3	9.0	11.0	7.5	5.6	5.6	11.0	8.5	2.1
	S33	7.0	7.2	9.2	6.2	4.7	4.7	9.2	6.9	1.6
NW	S34	21.7	18.0	13.6	11.8	6.8	6.8	21.7	14.4	5.7
	S35	20.7	18.0	19.0	13.2	12.5	12.5	20.7	16.7	3.6
	S36	19.7	16.3	16.8	7.2	6.0	6.0	19.7	13.2	6.2
	S37	10.0	8.7	5.5	3.7	4.2	3.7	10.0	6.4	2.8
W	S38	26.3	19.9	18.4	16.7	11.2	11.2	26.3	18.5	5.5
	S39	18.1	18.3	14.1	12.0	11.7	11.7	18.3	14.8	3.2
	S40	8.3	5.7	15.0	3.1	4.3	3.1	15.0	7.3	4.7
	S41	5.9	8.4	9.2	8.5	5.0	5.0	9.2	7.4	1.8
SW	S42	13.5	10.9	10.4	12.0	11.2	10.4	13.5	11.6	1.2
	S43	16.6	15.7	13.8	13.0	13.1	13.0	16.6	14.4	1.6
	S44	14.7	11.0	7.1	3.6	4.8	3.6	14.7	8.2	4.6
	S45	3.9	2.8	2.6	3.5	3.8	2.6	3.9	3.3	0.6
	Min	3.9	2.1	2.6	3.1	3.2				
	Max	26.3	19.9	19.0	16.7	13.1				
	Mean	13.0	11.0	10.6	8.0	7.0				
	SD	6.5	5.2	4.7	3.9	3.3				

In side B, the Cr values were low in comparison to the other side A. The samples in the directions NW (range 68 – 142.5 mg/kg), W (range 86.8 – 142.6 mg/kg) and SW (range 86 – 116.7 mg/kg) have more Cr in comparison to N (range 30 – 102.5 mg/kg) and S (range 56.3 – 116.2 mg/kg) directions. The maximum mean value was obtained at S34 (125.5 mg/kg) in the NW direction. A decreasing trend was observed as distance increased from the Mill.

(e) Copper (Cu)

The copper present in soils of the study area are presented in Table 3.18 (a) and Table 3.18 (b) for Sides A and B respectively. The minimum, the maximum, the mean and the standard deviation of the values are also given. It is observed that the values increase from first pre - monsoon season, B0 to the second pre – monsoon, B1 and then decrease. The soil appears to be rich in Cu. The sample S2 had the maximum mean value (389.5 mg/kg) and S25 had the minimum (77.5 mg/kg). In all the seasons the "Control" sample had very low Cu-content (11.7 mg/kg).

In Side B, huge amount of copper was measured in most of the samples in all the directions. The maximum value was obtained at S26 (1203 mg/kg) in the south direction. Most of the samples in A1 season had very high values but in the other four seasons, the values decreased. As the distance increased from the Mill, the values had a decreasing trend. Almost all the samples in both the sides have more than the average for world soils 20mg/kg .

Copper forms complexes with organic matter present in soil (Miller and Donahue, 1992). Copper toxicity was mainly influenced by pH and, to a lesser extent, by organic matter and clay content (Daoust et.al 2006). Cu toxicity increases in the presence of Ca and Mn (Mathias and Cummings, 1973).

(f) Iron (Fe)

The iron contents of the soil in the study area are given in the Tables 3.19 (a) and 3.19 (b) for the two sides A and B respectively. It is observed that huge amounts of iron are present in the soils of the study area. The samples in every direction had sufficient amount of iron. The amount of iron had a decreasing trend from B0 to B2 season. The distance variation was not uniform. The maximum value was obtained at S6 (mean value 20.30 g/kg) and the minimum

Table 3.17 (a). Chromium (Cr) content of the soil in Side A (mg/kg)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	15.4	15.2	16.0	15.2	16.0	15.5	0.4
NE	S1	102.6	118.0	105.0	102.6	118.0	108.5	8.3
	S2	67.2	84.0	89.0	67.2	89.0	80.1	11.4
	S3	70.5	76.0	70.0	70.0	76.0	72.2	3.3
	S4	25.8	48.0	68.0	25.8	68.0	47.3	21.1
	S5	24.7	52.0	41.5	24.7	52.0	39.4	13.8
N	S6	143.8	136.0	132.0	132.0	143.8	137.3	6.0
	S7	128.5	142.0	128.0	128.0	142.0	132.8	7.9
	S8	252.0	174.0	127.0	127.0	252.0	184.3	63.1
	S9	119.5	139.0	122.0	119.5	139.0	126.8	10.6
	S10	100.5	127.0	116.0	100.5	127.0	114.5	13.3
NW	S11	231.0	258.0	231.0	231.0	258.0	240.0	15.6
	S12	248.3	253.0	246.0	246.0	253.0	249.1	3.6
	S13	285.9	261.0	257.0	257.0	285.9	268.0	15.7
	S14	276.1	280.0	224.0	224.0	280.0	260.0	31.3
	S15	298.8	288.0	230.0	230.0	298.8	272.3	37.0
W	S16	252.5	263.0	215.0	215.0	263.0	243.5	25.2
	S17	257.0	239.0	186.0	186.0	257.0	227.3	36.9
	S18	266.2	254.0	78.8	78.8	266.2	199.7	104.9
	S19	251.6	272.0	152.0	152.0	272.0	225.2	64.2
	S20	263.8	285.0	200.0	200.0	285.0	249.6	44.2
SW	S21	201.4	216.0	169.0	169.0	216.0	195.5	24.1
	S22	35.3	95.0	74.0	35.3	95.0	68.1	30.3
	S23	154.3	143.0	96.0	96.0	154.3	131.1	30.9
	S24	44.7	79.0	70.0	44.7	79.0	64.6	17.8
	S25	114.5	152.0	102.0	102.0	152.0	122.8	26.0
	Min	24.7	48.0	41.5				
	Max	298.8	288.0	257.0				
	Mean	168.7	177.4	141.2				
	SD	93.9	82.0	65.2				

Table 3.17. (b). Chromium (Cr) content of the soil in Side B (mg/kg).

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	15.4	15.2	14.8	14.6	15.0	14.6	15.4	15.0	0.3
S	S26	113.0	101.3	74.0	86.3	74.2	74.0	113.0	89.8	17.1
	S27	105.6	116.2	66.8	57.2	62.1	57.2	116.2	81.6	27.2
	S28	87.6	92.3	88.7	80.1	69.0	69.0	92.3	83.5	9.3
	S29	56.3	62.3	59.0	60.0	64.0	56.3	64.0	60.3	3.0
N	S30	98.5	102.5	93.5	71.0	50.9	50.9	102.5	83.3	21.8
	S31	76.3	78.0	62.8	66.4	43.3	43.3	78.0	65.4	13.9
	S32	81.4	74.6	43.8	55.2	30.0	30.0	81.4	57.0	21.3
	S33	62.8	71.2	51.6	59.4	54.0	51.6	71.2	59.8	7.7
NW	S34	130.0	142.5	126.4	120.8	107.8	107.8	142.5	125.5	12.7
	S35	123.0	106.7	118.3	98.3	99.2	98.3	123.0	109.1	11.2
	S36	117.0	112.0	114.6	122.4	104.0	104.0	122.4	114.0	6.8
	S37	76.0	68.0	75.7	78.2	78.6	68.0	78.6	75.3	4.3
W	S38	142.6	133.7	97.4	107.3	88.6	88.6	142.6	113.9	23.3
	S39	121.5	103.8	98.5	102.0	97.0	97.0	121.5	104.6	9.8
	S40	143.0	129.1	106.2	96.4	86.8	86.8	143.0	112.3	23.3
	S41	114.6	115.6	112.0	93.7	98.6	93.7	115.6	106.9	10.1
SW	S42	116.5	110.4	115.5	102.0	96.5	96.5	116.5	108.2	8.7
	S43	114.0	110.0	114.3	93.7	95.2	93.7	114.3	105.4	10.2
	S44	113.8	116.7	96.5	98.5	94.0	94.0	116.7	103.9	10.5
	S45	102.4	109.0	105.6	101.1	86.0	86.0	109.0	100.8	8.8
	Min	56.3	62.3	43.8	55.2	30.0				
	Max	143.0	142.6	126.4	122.4	107.8				
	Mean	104.8	102.8	91.1	87.5	79.0				
	SD	24.5	22.2	24.5	20.6	22.1				

at S14 (mean value 2.64 g/kg). Almost all the soil samples in this area could be seen with a reddish brown colour when dry.

In side B, the same situation was observed like in side A. As a whole, the Fe-content of the soil samples had a decreasing trend from batch A1 to A3 with some exception. In some cases, the distance variation could be observed but it is to be noted that even the samples at locations away from the Mill have got sufficient amount of iron. The "Control" sample had also large iron content (mean value 0.71 g/kg) indicating that the soil was naturally rich in Fe-content.

Injury due to high soil iron concentration is not common under neutral or high pH soil conditions. Toxic situations occur primarily on acid soils (< pH 5.0) and where excess soluble iron salts have been applied as foliar sprays or soil amendments. The first symptoms of iron toxicity are necrotic spots on the leaves (Vitosh et al., 1994) of the plants grown in soil. Iron is an essential nutrient for all organisms, used in a variety of enzyme systems, including those for photosynthesis, respiration, and nitrogen fixation (Falkowski et. al. 1998; Morel and Prince, 2003). Iron is very insoluble under oxidizing conditions above pH 4 (Kraemer, 2004). Under poor drainage the iron becomes reduced and in the presence of organic matter is frequently mobilized

(g) Mercury (Hg)

Mercury is one of the heavy metals present in the soil of industrial area. The amounts of mercury present in the study area are depicted in Tables 3.20 (a) and 3.20 (b) for Side A and Side B respectively. The values show high content of Hg in almost all the directions from the Mill. Some samples in the third pre-monsoon batch, B2, possess Hg below detection level. From the first pre–monsoon (B0) season to the third pre–monsoon (B2) season, the values had a tendency to decrease with a few exceptions. The sample S25 did not show detectable amount of Hg at any season. The maximum value obtained was at S20 (mean value 10.020 mg/kg) and the minimum at S24 (mean value 0.007 mg/kg).
As the side B is at a larger distance from the Mill, it is likely that the soil in side B has less mercury content than the side A. The samples at maximum distance from the Mill in the south and north directions had Hg at below detection level in some of the seasons in this side. The distance variation can be seen in this side. From A1 to A3 batch, the values decreased. The

Table 3.18 (a). Cu-contents of the soil in Side A (mg/kg)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	12.5	11.5	11.0	11.0	12.5	11.7	0.8
NE	S1	325.9	352.0	380.0	325.9	380.0	352.6	27.1
	S2	389.5	401.0	378.0	378.0	401.0	389.5	11.5
	S3	302.8	365.0	308.0	302.8	365.0	325.3	34.5
	S4	115.9	183.0	210.0	115.9	210.0	169.6	48.5
	S5	142.5	200.0	185.0	142.5	200.0	175.8	29.8
N	S6	243.1	267.0	285.0	243.1	285.0	265.0	21.0
	S7	240.8	283.0	264.0	240.8	283.0	262.6	21.1
	S8	221.4	272.0	236.0	221.4	272.0	243.1	26.1
	S9	210.6	270.0	262.0	210.6	270.0	247.5	32.2
	S10	227.7	285.0	210.0	210.0	285.0	240.9	39.2
NW	S11	328.7	380.0	345.0	328.7	380.0	351.2	26.2
	S12	320.5	317.0	275.0	275.0	320.5	304.2	25.3
	S13	328.0	386.0	326.0	326.0	386.0	346.7	34.1
	S14	315.7	370.0	318.0	315.7	370.0	334.6	30.7
	S15	336.5	328.0	268.0	268.0	336.5	310.8	37.3
W	S16	131.4	152.0	85.0	85.0	152.0	122.8	34.3
	S17	80.8	110.0	76.0	76.0	110.0	88.9	18.4
	S18	96.3	92.0	46.0	46.0	96.3	78.1	27.9
	S19	75.0	101.0	68.0	68.0	101.0	81.3	17.4
	S20	98.6	104.0	72.0	72.0	104.0	91.5	17.1
SW	S21	100.3	100.0	85.0	85.0	100.3	95.1	8.8
	S22	103.5	109.0	96.0	96.0	109.0	102.8	6.5
	S23	104.0	93.0	64.0	64.0	104.0	87.0	20.7
	S24	62.6	95.0	81.0	62.6	95.0	79.5	16.2
	S25	85.4	90.0	57.0	57.0	90.0	77.5	17.9
	Min	62.6	90.0	46.0				
	Max	389.5	401.0	380.0				
	Mean	199.5	228.2	199.2				
	SD	106.7	115.4	114.9				

Table 3.18 (b). Cu-contents of the soil in Side B (mg/kg).

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	12.5	11.5	13.9	14.5	14.0	11.5	14.5	13.3	1.3
S	S26	1203.0	638.0	624.0	645.0	610.0	610.0	1203.0	744.0	256.9
	S27	715.0	500.0	328.0	380.0	317.0	317.0	715.0	448.0	166.0
	S28	523.0	132.0	118.0	128.0	123.0	118.0	523.0	204.8	178.0
	S29	216.0	116.0	125.0	116.0	102.0	102.0	216.0	135.0	46.0
N	S30	1004.0	538.0	440.0	452.0	418.0	418.0	1004.0	570.4	246.6
	S31	725.0	201.0	135.0	154.0	164.0	135.0	725.0	275.8	252.3
	S32	246.0	165.0	116.0	129.0	125.0	116.0	246.0	156.2	53.6
	S33	133.0	98.0	90.0	96.0	100.0	90.0	133.0	103.4	17.0
NW	S34	278.0	218.5	368.0	327.0	307.0	218.5	368.0	299.7	56.0
	S35	368.0	345.5	315.0	286.0	257.0	257.0	368.0	314.3	44.6
	S36	316.0	326.0	302.0	255.0	213.0	213.0	326.0	282.4	47.4
	S37	346.0	330.5	315.0	289.0	186.0	186.0	346.0	293.3	63.6
W	S38	462.0	171.5	205.0	200.0	185.0	171.5	462.0	244.7	122.2
	S39	189.0	135.0	164.0	166.0	160.0	135.0	189.0	162.8	19.2
	S40	151.0	160.0	135.0	141.0	127.0	127.0	160.0	142.8	13.0
	S41	184.0	160.0	135.0	122.0	120.0	120.0	184.0	144.2	27.4
SW	S42	454.0	436.0	482.0	438.0	375.0	375.0	482.0	437.0	39.2
	S43	372.0	368.0	360.0	374.0	385.0	360.0	385.0	371.8	9.1
	S44	280.0	254.0	252.0	260.0	210.0	210.0	280.0	251.2	25.6
	S45	105.0	110.0	125.0	86.0	80.0	80.0	125.0	101.2	18.3
	Min	105.0	98.0	90.0	86.0	80.0				
	Max	1203.0	638.0	624.0	645.0	610.0				
	Mean	413.5	270.2	256.7	252.2	228.2				
	SD	294.1	158.7	147.5	148.4	136.5				

Table 3.19 (a). Iron (Fe) content (g/kg) of the soil in Side A of the study area

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	0.71	0.72	0.7	0.7	0.72	0.71	0.01
NE	S1	20	18	13	13	20	17.0	3.6
	S2	19	20	12	12	20	17.0	4.4
	S3	11	15	10	10	15	12.0	2.6
	S4	12	10	9	9	12	10.3	1.5
	S5	10	10	6	6	10	8.7	2.3
N	S6	26	22	12	12	26	20.0	7.2
	S7	23	23	10	10	23	18.7	7.5
	S8	10	11	7	7	11	9.3	2.1
	S9	11	13	7	7	13	10.3	3.1
	S10	16	16	10	10	16	14.0	3.5
NW	S11	15	12	12	12	15	13.0	1.7
	S12	10	10	6	6	10	8.7	2.3
	S13	11	10	6	6	11	9.0	2.6
	S14	4	2	15	2	15	7.0	7.0
	S15	5	3	2	2	5	3.3	1.5
W	S16	11	7	3	3	11	7.0	4.0
	S17	5	8	4	4	8	5.7	2.1
	S18	10	10	7	7	10	9.0	1.7
	S19	8	10	7	7	10	8.3	1.5
	S20	9	10	5	5	10	8.0	2.6
SW	S21	10	10	4	4	10	8.0	3.5
	S22	8	9	5	5	9	7.3	2.1
	S23	8	9	6	6	9	7.7	1.5
	S24	8	9	5	5	9	7.3	2.1
	S25	8	9	6	6	9	7.7	1.5
	Min	4	2	2				
	Max	26	23	15				
	Mean	11.5	11.4	7.6				
	SD	10.9	10.8	7.1				

Table 3.19 (b). Iron (Fe) content (g/kg) of the soil in Side B of the study area

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	0.7	0.72	0.7	0.7	0.73	0.7	0.73	0.712	0.015
S	S26	30	15	13	15	12	12	30	17	7
	S27	20	4	5	6	9	4	20	9	7
	S28	6	4	3	3	3	3	6	4	1
	S29	4	4	3	3	2	2	4	3	1
N	S30	12	4	4	3	3	3	12	5	4
	S31	7	2	2	2	2	2	7	3	2
	S32	4	1	1	1	1	1	4	2	1
	S33	2	2	1	1	1	1	2	1	1
NW	S34	11	11	10	9	10	9	11	10	1
	S35	11	9	10	9	9	9	11	10	1
	S36	9	8	8	7	2	2	9	7	3
	S37	10	10	9	8	8	8	10	9	1
W	S38	22	15	15	11	9	9	22	14	5
	S39	13	13	10	10	10	10	13	11	2
	S40	15	9	12	9	9	9	15	11	3
	S41	17	11	10	8	8	8	17	11	4
SW	S42	18	16	16	13	11	11	18	15	3
	S43	11	10	9	9	9	9	11	10	1
	S44	10	9	9	8	8	8	10	9	1
	S45	10	10	9	9	9	9	10	9	1
	Min	1	1	1	1	1				
	Max	30	16	16	15	12				
	Mean	12	8	8	7	7				
	SD	7	5	4	4	4				

maximum value was obtained at S42 (mean value 1.087 mg/kg) in the southwest direction near the Mill and the minimum at S29 (south) and S33 (north).

(h) Manganese (Mn)

The amount of manganese present in the soil samples in different directions from the sides A and B are given in Tables 3.21 (a) and Table 3.21 (b).

In Side A, the first pre-monsoon season (B0) had Mn in the range 13.2 – 146.9 mg/kg, the second pre-monsoon (B1) 42.0 – 135.0 mg/kg and the third pre-monsoon (B2) 32.0 – 128.0 mg/kg. The control sample had 19.3, 12.6 and 12.1 mg/kg of Mn in B0, B1 and B2 batches respectively. The samples near to the Mill had more Mn content in comparison to those away from it with a few exceptions. The maximum amount of Mn was found at S16 (mean value 136.6 mg/kg) in the west direction and the minimum at S5 (mean value 29.1 mg/kg) in the northeast direction.

In Side B, the amounts of Mn are present in the following ranges:

- A1 batch 16.5- 162.7 mg/kg
- B1 batch 17.2 – 128.0 mg/kg
- A2 batch 20.0 – 135.0 mg/kg
- B2 batch 15.4 – 120.4 mg/kg
- A3 batch 16.7 – 111.5 mg/kg

The values have a decreasing trend from A1 batch to A3 batch. The distance variation was almost distinct. The maximum amount of Mn was obtained at S42 (mean value 123.5 mg/kg) in the southwest direction and the minimum at S29 (mean value 18.2 mg/kg) in the south direction. The soil samples in the south direction had less amount of Mn in comparison to north, west, northwest and southwest directions. As a whole, the soil samples had less content of Mn than the World average of 850 mg/kg.

Levels of Mn in the soil are controlled mainly by the soil's Mn reserve, pH, and the availability of electrons (e^-) (Adams, 1981; Sparrow and Uren, 1987).

(i) Nickel(Ni)

The nickel present in the soil samples in the study area is given in Tables 3.22(a) and 3.22(b). The amount of Ni present in Side A was within the range 21.5 – 101.0 mg/kg. The soil samples in this side is rich with nickel. The maximum mean value for different samples in different directions are as follows:

- 34.2 – 66.6 mg/kg in NE direction
- 55.2 – 91.6 mg/kg in N direction
- 48.5 – 65.6 mg/kg in NW direction
- 57.4 – 83.9 mg/kg in W direction
- 34.0 – 53.4 mg/kg in SW direction

From the results it can be concluded that almost all the samples are rich with high content of Ni (World average, 40 mg/kg).

In Side B, almost all the samples in all the seasons have high content of Ni like Side A. With distance away from the Mill, the amount of Ni present in soil decreased. The "Control" has a very low range of values (2.1 – 2.7 mg/kg). The maximum mean value obtained was at S34 (68.4 mg/kg), which was very near to the earthen dam in the NW direction from the Mill and the minimum at S33 (41.1 mg/kg) at the distant sample in N direction from the Mill.

Ni concentration in anthropogenically-polluted soils can reach 200 – 2600 mg/kg. The primary sources of nickel pollution are the burning of coal and oil, emission of smelters and metal works, municipal wastes, sewage, phosphate fertilizers and pesticides (Izosimova et al., 2005). In the present work, the Mill has a direct influence on soil quality with respect to Ni content

Table 3.20 (a) Mercury (Hg) content (mg/kg) of soil samples in the study area (Side A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	BDL	BDL	BDL	BDL	BDL	BDL	BDL
NE	S1	3.6	2.7	0.6	0.6	3.6	2.30	1.54
	S2	2.1	1.05	1.024	1.024	2.1	1.39	0.61
	S3	2.8	1.3	BDL	BDL	2.8	2.05	1.06
	S4	4.6	0.36	0.028	0.028	4.6	1.66	2.55
	S5	1.8	0.08	BDL	BDL	1.8	0.94	1.22
N	S6	0.2	1.34	0.4	0.2	1.34	0.65	0.61
	S7	1.5	0.56	0.03	0.03	1.5	0.70	0.74
	S8	7.6	3.71	BDL	BDL	7.6	5.66	2.75
	S9	5.8	2.8	1.05	1.05	5.8	3.22	2.40
	S10	1.5	0.63	0.04	0.04	1.5	0.72	0.73
NW	S11	10.4	5.8	1.46	1.46	10.4	5.89	4.47
	S12	7.6	3.2	2.73	2.73	7.6	4.51	2.69
	S13	2.2	0.9	0.1	0.1	2.2	1.07	1.06
	S14	3.6	1.05	BDL	BDL	3.6	2.33	1.80
	S15	8.6	9.14	3.3	3.3	9.14	7.01	3.23
W	S16	6.6	2.1	0.8	0.8	6.6	3.17	3.04
	S17	20.6	9.5	2.4	2.4	20.6	10.83	9.17
	S18	13.7	5.34	6.04	5.34	13.7	8.36	4.64
	S19	10.2	9.7	4.5	4.5	10.2	8.13	3.16
	S20	14	9.85	6.2	6.2	14	10.02	3.90
SW	S21	2.7	2.04	1.5	1.5	2.7	2.08	0.60
	S22	0.9	0.54	0.02	0.02	0.9	0.49	0.44
	S23	1.2	2.3	BDL	1.2	2.3	1.75	0.78
	S24	BDL	0.02	BDL	BDL	0.02	0.007	BDL
	S25	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	Min	BDL	BDL	BDL				
	Max	20.60	9.85	6.20				
	Mean	5.82	3.17	1.79				
	SD	5.18	3.28	2.02				

Table 3.20 (b) Mercury (Hg) content (mg/mg) of soil samples in the study area (Side B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
S	S26	0.008	0.006	0.008	0.005	0.002	0.002	0.008	0.006	0.002
	S27	0.005	0.014	0.007	0.005	0.001	0.001	0.014	0.006	0.005
	S28	0.002	0.006	0.005	0.006	0.003	0.002	0.006	0.004	0.002
	S29	BDL	0.001	BDL	BDL	BDL	0.001	0.001	0.001	0.000
N	S30	0.018	0.02	0.016	0.025	0.022	0.016	0.025	0.020	0.003
	S31	0.082	0.051	0.05	0.008	0.0012	0.001	0.082	0.038	0.034
	S32	0.006	0.005	0.002	0.001	0.001	0.001	0.006	0.003	0.002
	S33	BDL 1	0.002	BDL	0.001	BDL	0.001	0.002	0.002	0.001
NW	S34	2.73	0.065	0.055	0.05	0.004	0.004	2.730	0.581	1.202
	S35	0.012	0.008	0.001	0.001	BDL	0.001	0.012	0.006	0.005
	S36	0.01	0.009	0.006	BDL 1	0.001	0.001	0.010	0.007	0.004
	S37	0.008	0.008	0.005	0.005	0.001	0.001	0.008	0.005	0.003
W	S38	1.15	0.56	0.52	0.091	0.002	0.002	1.150	0.465	0.457
	S39	0.952	1.04	0.83	0.5	0.075	0.075	1.040	0.679	0.395
	S40	0.93	0.858	0.526	0.15	0.1	0.100	0.930	0.513	0.386
	S41	0.73	0.7	0.42	0.07	0.025	0.025	0.730	0.389	0.335
SW	S42	2.02	1.35	1.11	0.95	0.003	0.003	2.020	1.087	0.730
	S43	1.25	0.975	0.554	0.076	0.002	0.002	1.250	0.571	0.546
	S44	0.008	0.005	0.005	BDL	BDL	0.005	0.008	0.006	0.002
	S45	0.0073	0.001	0.001	BDL	BDL	0.001	0.007	0.003	0.004
	Min	BDL	0.001	BDL	BDL	BDL				
	Max	2.73	1.35	1.11	0.95	0.1				
	Mean	0.552	0.284	0.229	0.122	0.016				
	SD	0.814	0.446	0.344	0.253	0.030				

Table 3.21 (a) Manganese content (mg/kg) of the soil in Side A of the study area

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	19.3	12.6	12.1	12.1	19.3	14.7	4.0
NE	S1	132.7	102.0	110.0	102.0	132.7	114.9	15.9
	S2	58.3	69.0	61.0	58.3	69.0	62.8	5.6
	S3	26.9	54.0	55.0	26.9	55.0	45.3	15.9
	S4	25.4	50.0	53.0	25.4	53.0	42.8	15.1
	S5	13.2	42.0	32.0	13.2	42.0	29.1	14.6
N	S6	101.5	117.0	98.0	98.0	117.0	105.5	10.1
	S7	72.8	89.0	75.0	72.8	89.0	78.9	8.8
	S8	71.6	80.0	62.0	62.0	80.0	71.2	9.0
	S9	62.2	72.0	68.0	62.2	72.0	67.4	4.9
	S10	64.7	75.0	60.0	60.0	75.0	66.6	7.7
NW	S11	76.1	68.0	62.0	62.0	76.1	68.7	7.1
	S12	70.2	74.0	70.0	70.0	74.0	71.4	2.3
	S13	74.3	55.0	52.0	52.0	74.3	60.4	12.1
	S14	50.3	68.0	66.0	50.3	68.0	61.4	9.7
	S15	52.5	60.0	62.0	52.5	62.0	58.2	5.0
W	S16	146.9	135.0	128.0	128.0	146.9	136.6	9.6
	S17	116.0	130.0	126.0	116.0	130.0	124.0	7.2
	S18	108.1	116.0	98.0	98.0	116.0	107.4	9.0
	S19	63.3	75.0	70.0	63.3	75.0	69.4	5.9
	S20	44.7	59.0	43.0	43.0	59.0	48.9	8.8
SW	S21	98.4	103.0	97.0	97.0	103.0	99.5	3.1
	S22	86.5	92.0	68.0	68.0	92.0	82.2	12.6
	S23	87.4	90.0	73.0	73.0	90.0	83.5	9.2
	S24	64.3	73.0	70.0	64.3	73.0	69.1	4.4
	S25	62.8	60.0	63.0	60.0	63.0	61.9	1.7
	Min	13.2	42.0	32.0				
	Max	146.9	135.0	128.0				
	Mean	73.2	80.3	72.9				
	SD	31.9	25.0	23.9				

Table 3.21 (b) Manganese content (mg/kg) of the soil in Side B of the study area

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	19.3	12.6	13.5	12.9	12.6	12.6	19.3	14.2	2.9
S	S26	162.7	111.0	132.2	86.0	75.0	75.0	162.7	113.4	35.4
	S27	129.6	50.6	62.6	78.0	56.3	50.6	129.6	75.4	32.0
	S28	56.3	77.0	76.0	64.0	70.0	56.3	77.0	68.7	8.7
	S29	16.5	17.2	20.0	19.4	18.0	16.5	20.0	18.2	1.5
N	S30	128.6	128.0	135.0	66.0	59.7	59.7	135.0	103.5	37.2
	S31	142.0	67.5	74.4	68.0	50.0	50.0	142.0	80.4	35.6
	S32	76.5	63.0	70.0	66.0	62.0	62.0	76.5	67.5	5.9
	S33	37.8	23.2	32.2	27.6	30.2	23.2	37.8	30.2	5.4
NW	S34	60.8	52.7	54.7	41.5	28.5	28.5	60.8	47.6	12.8
	S35	48.1	40.1	50.5	52.0	48.8	40.1	52.0	47.9	4.6
	S36	40.0	34.6	32.2	36.7	47.8	32.2	47.8	38.3	6.1
	S37	21.2	23.9	24.8	22.0	24.3	21.2	24.8	23.2	1.6
W	S38	135.6	120.0	117.0	97.0	83.5	83.5	135.6	110.6	20.5
	S39	129.0	76.5	86.0	89.0	63.0	63.0	129.0	88.7	24.7
	S40	86.7	67.0	58.0	62.0	60.0	58.0	86.7	66.7	11.6
	S41	21.8	20.3	24.4	15.4	16.7	15.4	24.4	19.7	3.7
SW	S42	136.9	122.9	125.6	120.4	111.5	111.5	136.9	123.5	9.2
	S43	72.6	60.7	54.3	53.8	40.2	40.2	72.6	56.3	11.8
	S44	55.0	45.8	48.5	44.3	45.0	44.3	55.0	47.7	4.4
	S45	24.0	22.9	26.0	25.0	31.0	22.9	31.0	25.8	3.1
	Min	16.5	17.2	20.0	15.4	16.7				
	Max	162.7	128.0	135.0	120.4	111.5				
	Mean	79.1	61.2	65.2	56.7	51.1				
	SD	48.3	35.7	37.1	28.5	23.6				

Table 3.22 (a) Nickel content (mg/kg) of the soil in Side A of the study area

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	2.7	2.5	2.6	2.5	2.7	2.6	0.1
NE	S1	64.8	73.0	62.0	62.0	73.0	66.6	5.7
	S2	45.5	66.0	58.0	45.5	66.0	56.5	10.4
	S3	34.7	54.0	50.0	34.7	54.0	46.2	10.2
	S4	35.3	47.0	40.0	35.3	47.0	40.8	5.9
	S5	32.6	40.0	30.1	30.1	40.0	34.2	5.2
N	S6	80.8	93.0	101.0	80.8	101.0	91.6	10.2
	S7	66.0	71.0	65.0	65.0	71.0	67.3	3.2
	S8	69.5	70.0	63.0	63.0	70.0	67.5	3.9
	S9	61.6	58.0	46.0	46.0	61.6	55.2	8.2
	S10	60.0	61.0	53.0	53.0	61.0	58.0	4.4
NW	S11	58.7	70.0	68.0	58.7	70.0	65.6	6.0
	S12	62.8	67.0	60.0	60.0	67.0	63.3	3.5
	S13	44.6	58.0	43.0	43.0	58.0	48.5	8.2
	S14	56.4	50.0	40.0	40.0	56.4	48.8	8.2
	S15	62.4	55.0	39.0	39.0	62.4	52.1	12.0
W	S16	90.6	84.0	77.0	77.0	90.6	83.9	6.8
	S17	83.7	86.0	75.0	75.0	86.0	81.6	5.8
	S18	59.3	65.0	63.0	59.3	65.0	62.4	2.9
	S19	75.1	70.0	57.0	57.0	75.1	67.4	9.3
	S20	61.3	63.0	48.0	48.0	63.0	57.4	8.2
SW	S21	58.3	60.0	42.0	42.0	60.0	53.4	9.9
	S22	21.5	49.0	36.0	21.5	49.0	35.5	13.8
	S23	33.0	41.0	28.0	28.0	41.0	34.0	6.6
	S24	47.5	46.0	41.0	41.0	47.5	44.8	3.4
	S25	51.4	49.0	27.0	27.0	51.4	42.5	13.4
	Min	21.5	40.0	27.0				
	Max	90.6	93.0	101.0				
	Mean	56.7	61.8	52.5				
	SD	17.0	13.7	17.3				

Table 3.22 (b) Nickel content (mg/kg) of the soil in Side B of the study area

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	2.7	2.5	2.1	2.6	2.5	2.1	2.7	2.5	0.2
S	S26	55.0	56.0	51.0	47.6	46.0	46.0	56.0	51.1	4.4
	S27	53.8	50.0	52.0	50.0	46.0	46.0	53.8	50.4	2.9
	S28	48.0	52.0	51.5	48.0	49.0	48.0	52.0	49.7	1.9
	S29	50.0	51.6	50.2	46.8	47.0	46.8	51.6	49.1	2.1
N	S30	55.6	53.0	54.3	50.0	41.0	41.0	55.6	50.8	5.8
	S31	53.0	48.0	45.0	45.1	46.0	45.0	53.0	47.4	3.3
	S32	58.2	54.0	48.0	42.0	38.0	38.0	58.2	48.0	8.3
	S33	37.9	44.6	44.0	39.0	40.0	37.9	44.6	41.1	3.0
NW	S34	78.4	74.4	68.5	61.5	59.3	59.3	78.4	68.4	8.2
	S35	60.8	57.0	58.0	52.0	47.0	47.0	60.8	55.0	5.5
	S36	53.0	50.2	50.5	48.0	41.8	41.8	53.0	48.7	4.2
	S37	58.0	53.0	51.0	52.8	48.0	48.0	58.0	52.6	3.6
W	S38	62.7	66.8	58.1	60.0	57.9	57.9	66.8	61.1	3.7
	S39	60.1	56.7	46.8	46.0	37.9	37.9	60.1	49.5	8.9
	S40	54.0	49.2	42.8	44.0	37.6	37.6	54.0	45.5	6.3
	S41	58.0	60.0	52.5	48.0	42.0	42.0	60.0	52.1	7.4
SW	S42	68.2	68.0	58.0	48.7	50.2	48.7	68.2	58.6	9.3
	S43	57.0	53.0	54.0	50.0	49.7	49.7	57.0	52.7	3.0
	S44	56.6	55.0	54.0	47.0	46.0	46.0	56.6	51.7	4.9
	S45	64.5	57.0	56.0	53.0	43.8	43.8	64.5	54.9	7.5
	Min	37.9	44.6	42.8	39.0	37.6				
	Max	78.4	74.4	68.5	61.5	59.3				
	Mean	57.1	55.5	52.3	49.0	45.7				
	SD	8.1	7.2	5.9	5.3	5.9				

(j) Lead (Pb)

In the present study, the amounts of lead measured in the soil are presented in Table 3.23 (a) and Table 3.23 (b). It is found that substantial amounts of lead are available in all the soil (World average, 10 mg/kg) samples in all the directions.

In side A, the lead content was in the ranges of B0: 27.0 – 53.0 mg/kg, B1: 37.0 – 71.0 mg/kg and B2: 12.0 – 67.0 mg/kg, whereas the " Control" had 4.0, 5.0, and 4.0 mg/kg in B0, B1 and B2 batches respectively. The variations of the values for the sites in different distances are not uniform. The values were higher in the second pre-monsoon season (B1).

In Side B also, the soil had large amounts of lead indicating that the effluent of the Mill had carried sufficient amount of lead salts with it and spread the same over large distances. The distant samples in every direction had got less value than the near ones of the Mill. The Pb-content of the soil in the study area is more than the World average content of 10.0 mg/kg. The maximum mean value was measured at S42 (61.6 mg/kg) in the SW direction and the minimum at S29 (26.3 mg/kg) in the S direction. The values had a decreasing trend from A1 batch to A3 batch.

Presence of toxic heavy metals like Pb and Hg reduces soil fertility and agricultural output (Lokhande, and Kelkar, 1999). Pb has not been known to have any beneficial function for plants or animals (Greenland and Hayes, 1981), but the health problems created by high levels of Pb are well documented (Singh and Steinnes, 1994).

(k) Zinc (Zn)

The amounts of Zn present in the study area soil are presented in Table 3.24 (a) and Table 3.24 (b) with the minimum, the maximum, the mean and the standard deviations of the values.

The values are very high in every direction and for all the samples. The variation of values along each direction does not show any uniform trend. The maximum mean value was obtained at S16 (675.1 mg/kg) in the west direction and the minimum at S25 (201.9 mg/kg) in the southwest direction. The maximum mean value was obtained for B1 batch and similar observations have been recorded also in case of Pb, Ni and Mn in Side A.

Table 3.23 (a). Lead content (mg/kg) of the soil samples in study area of Side (A).

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	4	5	4	4	5	4	0
NE	S1	53	62	67	53	67	61	7
	S2	51	71	41	41	71	54	15
	S3	48	60	61	48	61	56	7
	S4	33	45	42	33	45	40	6
	S5	40	48	40	40	48	43	5
N	S6	50	39	34	34	50	41	8
	S7	48	47	41	41	48	45	4
	S8	27	42	43	27	43	37	9
	S9	39	40	35	35	40	38	3
	S10	49	55	49	49	55	51	3
NW	S11	52	50	39	39	52	47	7
	S12	49	57	56	49	57	54	4
	S13	40	53	47	40	53	47	7
	S14	41	50	40	40	50	44	6
	S15	33	47	40	33	47	40	7
W	S16	39	43	44	39	44	42	3
	S17	50	56	49	49	56	52	4
	S18	43	60	55	43	60	53	9
	S19	45	62	60	45	62	56	9
	S20	48	60	56	48	60	55	6
SW	S21	42	60	43	42	60	48	10
	S22	36	47	45	36	47	43	6
	S23	31	49	42	31	49	41	9
	S24	34	40	26	26	40	33	7
	S25	30	37	12	12	37	26	13
	Min	27	37	12				
	Max	53	71	67				
	Mean	42	51	44				
	SD	8	9	12				

Table 3.23 (b). Lead content (mg/kg) of the soil in Side B of the study area

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	4.0	4.5	4.4	4.4	4.3	4.0	4.5	4.3	0.2
S	S26	53.0	40.0	37.0	31.0	28.0	28.0	53.0	37.8	9.7
	S27	52.0	57.0	28.0	30.0	35.0	28.0	57.0	40.4	13.2
	S28	34.0	23.0	22.0	26.0	33.0	22.0	34.0	27.6	5.6
	S29	28.7	23.4	20.0	27.0	32.5	20.0	32.5	26.3	4.8
N	S30	49.0	26.0	24.0	26.0	31.0	24.0	49.0	31.2	10.3
	S31	43.0	26.0	27.0	23.0	21.0	21.0	43.0	28.0	8.7
	S32	43.5	33.0	30.0	32.0	36.0	30.0	43.5	34.9	5.3
	S33	32.6	32.9	25.0	29.0	32.0	25.0	32.9	30.3	3.3
NW	S34	60.0	63.0	56.7	58.0	56.0	56.0	63.0	58.7	2.8
	S35	62.0	59.0	62.0	58.0	60.0	58.0	62.0	60.2	1.8
	S36	61.0	64.0	59.0	60.0	62.0	59.0	64.0	61.2	1.9
	S37	58.0	56.0	43.0	58.0	55.5	43.0	58.0	54.1	6.3
W	S38	62.0	47.0	51.0	56.0	41.0	41.0	62.0	51.4	8.1
	S39	57.8	42.0	48.0	52.0	59.0	42.0	59.0	51.8	7.0
	S40	40.5	29.0	32.0	20.0	36.0	20.0	40.5	31.5	7.7
	S41	38.6	29.2	27.0	21.0	30.0	21.0	38.6	29.2	6.3
SW	S42	70.6	68.5	71.4	65.3	32.0	32.0	71.4	61.6	16.7
	S43	52.6	48.7	26.5	25.0	25.0	25.0	52.6	35.6	13.9
	S44	30.5	26.4	27.5	26.0	27.5	26.0	30.5	27.6	1.8
	S45	28.0	27.8	29.2	30.0	25.5	25.5	30.0	28.1	1.7
	Min	28.0	23.0	20.0	20.0	21.0				
	Max	70.6	68.5	71.4	65.3	62.0				
	Mean	47.9	41.1	37.3	37.7	37.9				
	SD	12.9	15.5	15.3	15.9	13.0				

In Side B, the soil samples in the western direction had sufficient amounts of Zn (range 0.92 – 1.87 g/kg) in comparison to other directions. The study reveals that there is a decreasing trend of values from A1 batch to A3 batch. Again, as the distance increased from the Mill, the values had a decreasing trend.

Excessive Zn in soil may cause damage to plants and at lower pH the yield is reduced (Leeper, 1978).

General discussion of the trace metal concentrations

The high concentration of metal ions in the effluent amended soils is due to the stagnation of precipitated insoluble metal salts, which deposit on the surface of the soil particles. The soluble metallic species percolate through soil bed and move towards the water table of the area (Nemade and Shrivastava, 1996, 1998; Shrivastava et al. 1989; Shrivastava and Chaudhury, 2000). These facts are clearly evident from the concentration of metals in soil and ground water samples.

The present study should be regarded as an indication of detail investigation on heavy metals (such as solid phase speciation, mobility, adsorption and desorption studies) of terrestrial ecosystems in the vicinity of an industry.

The soil is as a whole very rich in Al which is a natural constituent of the soil, but a large amount is also contributed by the Textile Mill wastes. In any particular direction from the Mill, the general pattern of variation is a decrease away from the Mill. This is illustrated in Figs. 3.15 for the Side A and the Side B with respect to the minimum, the maximum and the mean values at each site.

Table 3.24 (a) Zinc (Zn) content of soil samples (mg/kg) in the study area of Side (A)

Direction	Season	B0	B1	B2	Min	Max	Mean	SD
	Control	12.36	12.40	12.50	12.36	12.50	12.42	0.07
NE	S1	448.20	408.00	410.00	408.00	448.20	422.07	22.65
	S2	436.10	447.00	407.00	407.00	447.00	430.03	20.68
	S3	452.70	483.00	478.00	452.70	483.00	471.23	16.24
	S4	460.70	482.00	476.00	460.70	482.00	472.90	10.98
	S5	402.00	436.00	411.00	402.00	436.00	416.33	17.62
N	S6	441.80	409.00	387.00	387.00	441.80	412.60	27.58
	S7	468.50	473.00	436.00	436.00	473.00	459.17	20.19
	S8	414.50	438.00	440.00	414.50	440.00	430.83	14.18
	S9	530.10	602.00	460.00	460.00	602.00	530.70	71.00
	S10	725.50	660.00	582.00	582.00	725.50	655.83	71.84
NW	S11	509.36	551.00	528.00	509.36	551.00	529.45	20.86
	S12	511.42	505.00	511.00	505.00	511.42	509.14	3.59
	S13	501.70	526.00	483.00	483.00	526.00	503.57	21.56
	S14	480.40	525.00	475.00	475.00	525.00	493.47	27.44
	S15	455.90	480.00	368.00	368.00	480.00	434.63	58.95
W	S16	730.20	695.00	600.00	600.00	730.20	675.07	67.35
	S17	663.50	682.00	614.00	614.00	682.00	653.17	35.16
	S18	695.20	735.00	682.00	682.00	735.00	704.07	27.59
	S19	667.50	710.00	645.00	645.00	710.00	674.17	33.01
	S20	612.70	647.00	615.00	612.70	647.00	624.90	19.17
SW	S21	434.80	495.00	426.00	426.00	495.00	451.93	37.56
	S22	430.10	466.00	414.00	414.00	466.00	436.70	26.62
	S23	335.62	400.00	328.00	328.00	400.00	354.54	39.55
	S24	271.30	302.00	317.00	271.30	317.00	296.77	23.30
	S25	156.80	248.00	201.00	156.80	248.00	201.93	45.61
	Min	156.80	248.00	201.00				
	Max	730.20	735.00	682.00				
	Mean	489.46	512.20	467.76				
	SD	136.66	124.40	112.45				

Table 3.24 (b) Zinc (Zn) content of soil samples (mg/kg) in the study area of Side (B)

Direction	Season	A1	B1	A2	B2	A3	Min	Max	Mean	SD
	Control	12.4	12.4	12.1	12.5	12.0	12.0	12.9	12.4	0.4
S	S26	447.0	423.0	436.0	440.0	372.0	372.0	447.0	423.6	30.1
	S27	431.0	418.0	470.0	426.0	380.0	380.0	470.0	425.0	32.2
	S28	452.0	417.0	423.0	408.0	376.0	376.0	452.0	415.2	27.4
	S29	337.2	305.0	328.0	316.0	295.0	295.0	337.2	316.2	17.0
N	S30	503.0	518.0	528.0	382.0	326.0	326.0	528.0	451.4	91.5
	S31	328.8	360.0	372.0	316.0	304.0	304.0	372.0	336.2	28.9
	S32	238.2	265.0	248.0	228.0	218.0	218.0	265.0	239.4	18.2
	S33	210.0	198.0	206.0	187.0	160.0	160.0	210.0	192.2	20.0
NW	S34	640.0	541.0	506.0	427.0	316.0	316.0	640.0	486.0	122.0
	S35	263.7	287.0	236.0	240.0	204.0	204.0	287.0	246.1	31.2
	S36	383.5	314.0	306.0	297.0	263.0	263.0	383.5	312.7	44.1
	S37	349.0	368.0	351.0	330.0	342.0	330.0	368.0	348.0	13.9
W	S38	1573.0	1564.0	1872.0	1052.0	985.0	985.0	1872.0	1409.2	378.3
	S39	1583.0	1119.0	1043.0	1148.0	1073.0	1043.0	1583.0	1193.2	221.6
	S40	1445.0	1012.0	1192.0	1052.0	995.0	995.0	1445.0	1139.2	187.7
	S41	1474.0	1053.0	1204.0	1009.0	915.0	915.0	1474.0	1131.0	218.3
SW	S42	346.4	318.0	328.0	326.5	315.0	315.0	346.4	326.8	12.3
	S43	511.0	527.0	506.0	478.0	440.0	440.0	527.0	492.4	34.2
	S44	346.0	402.0	378.0	365.0	348.0	346.0	402.0	367.8	23.2
	S45	294.0	314.0	307.0	476.0	440.0	294.0	476.0	366.2	85.1
	Min	210.0	198.0	206.0	187.0	160.0				
	Max	1583.0	1564.0	1872.0	1148.0	1073.0				
	Mean	607.8	536.2	562.0	495.2	453.4				
	SD	478.7	359.7	428.8	303.6	286.2				

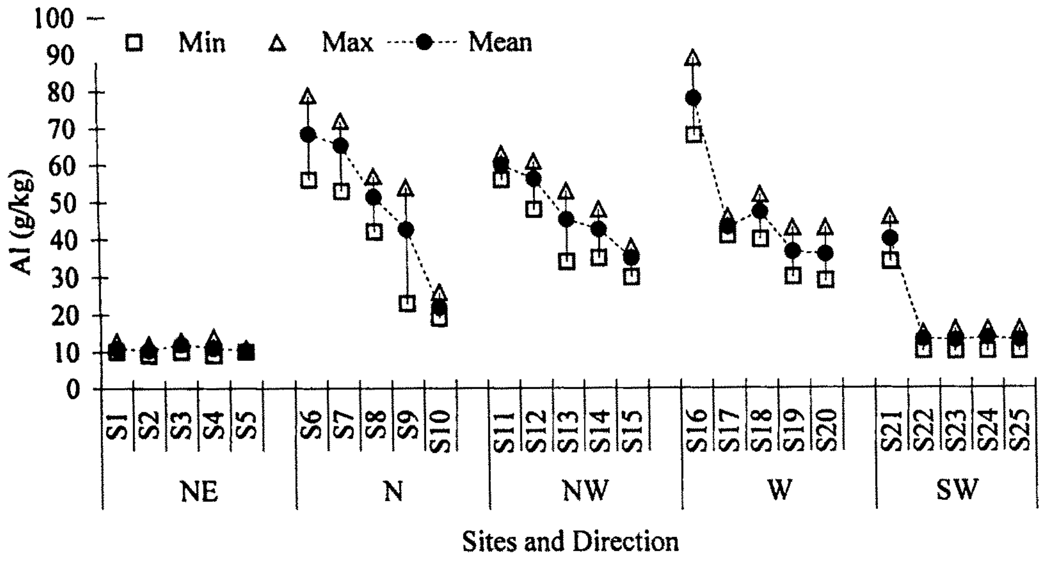
Although not much, the soil is also contaminated with the toxic As. No distinction was made between As(III) and As(V) in the measurements, and the values presented are total As-content of the soil. Despite being present in very small amounts, the values still exhibit some amount of enrichment near the Mill. Similar conclusion may be made with respect to Cd – the only difference being its increased enrichment in Side B compared to Side A. A plot of the mean values of Cd at each sampling site for both the sides (Fig 3.16) shows the trends in Cd-contents of the soil.

In estimating Cr, again only the total Cr was determined without distinguishing between Cr(III) and Cr(VI). The soil is considerably rich in this toxic metal. The Side A is conspicuous by the presence of high Cr-content compared to the Side B. The seasonal trends for each site are shown separately for the Sides, A and B, in Fig. 3.17(a) and Fig. 3.16(b) respectively.

Cu-enrichment of the soil is again more in Side B than in Side A and the reason for the same may be similar to that of Cd. The variation trends with distance and direction from the Mill are shown in Fig 3.18 with respect to the minimum, the maximum and the mean values at each site for the two sides respectively.

Considering the amounts present, Fe cannot be regarded as trace metal. It is present in large quantities in the soil and the results are in conformity with the generally iron-rich quality of Assam soil. Because of very large amounts of Fe being present in the distant soil samples, no definite conclusion can be made about any contribution from the activities from the Textile Mill. This can also be seen from Fig. 3.19 for variation of the minimum, the maximum and the mean contents of iron in the soil for Side A and Side B respectively with distance.

The trace metal, Hg, is present in many sites in the study area with appreciable concentration. It is to be noted that the soil close to the Mill showed presence of more Hg than the soil away from it, and therefore, whatever Hg was found in the soil, was likely to have its origin in the activities of the Mill.



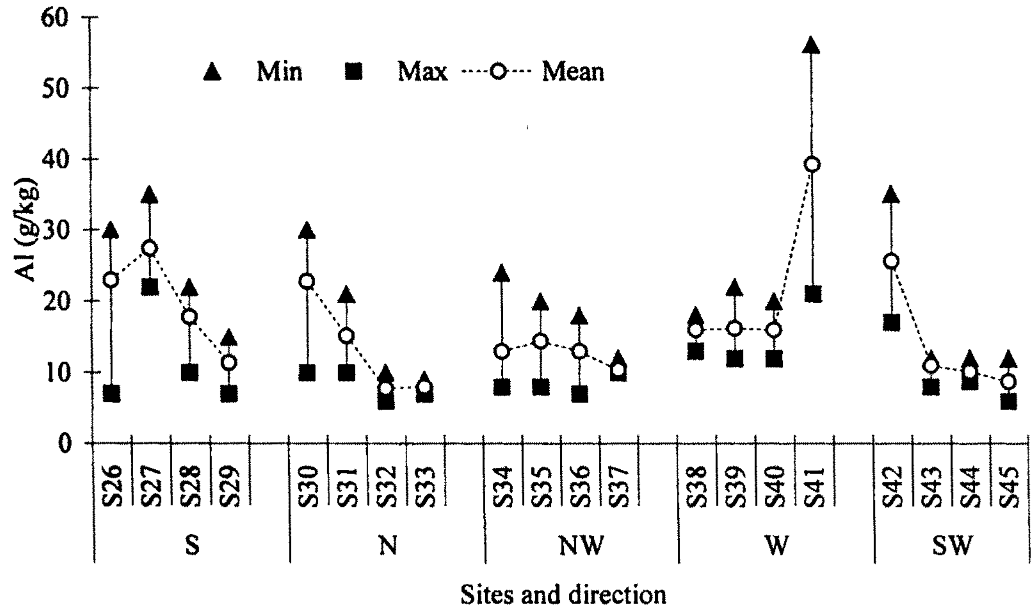


Fig. 3.15. Variation pattern of minimum, maximum and mean Al-content in the soil of the study area for Side A (top) and Side B (bottom) with respect to the sampling sites and sampling direction.

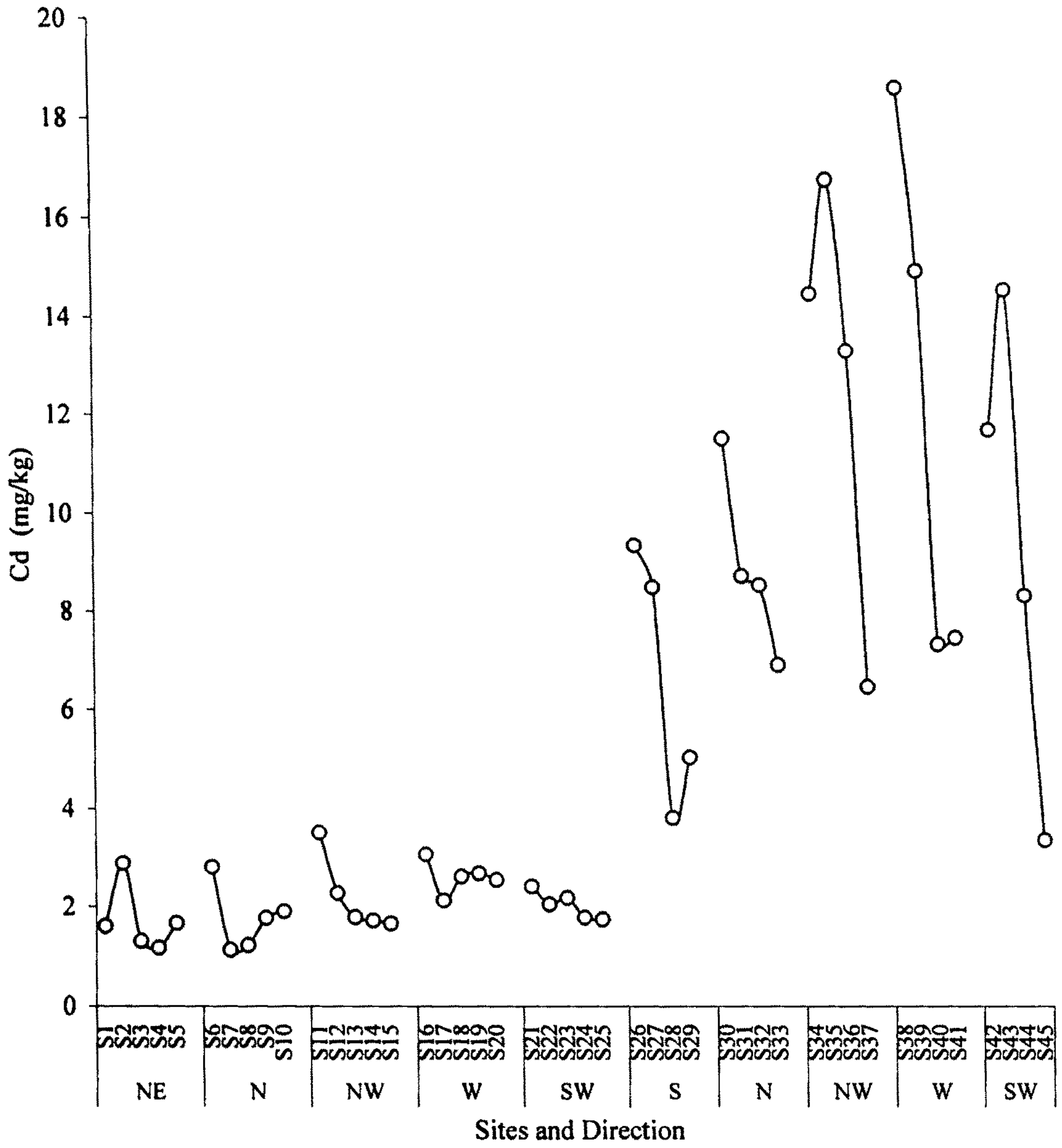


Fig. 3.16. Variation pattern of mean Cd-content in the soil of the study area for Side A (S1 to S25) and Side B (S26 to S45) with respect to the sampling sites and directions.

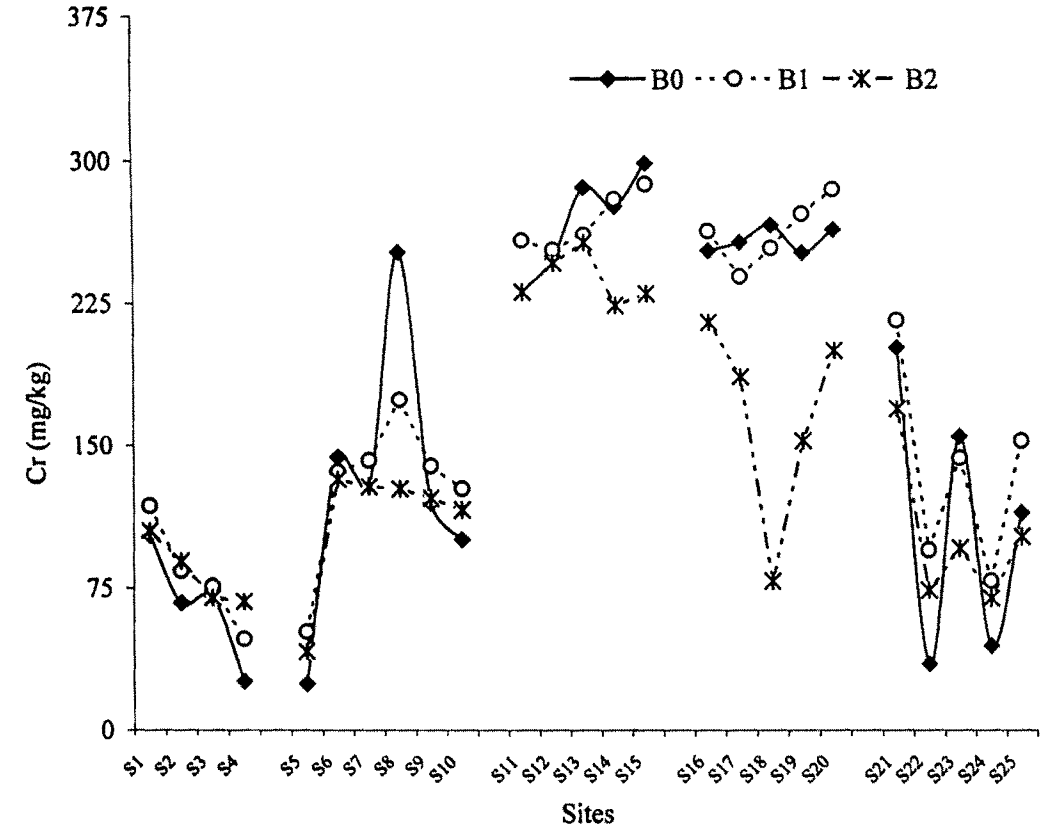


Fig. 3.17 (a). Variation pattern of total Cr-content in Side A with respect to the sampling seasons and sampling sites.

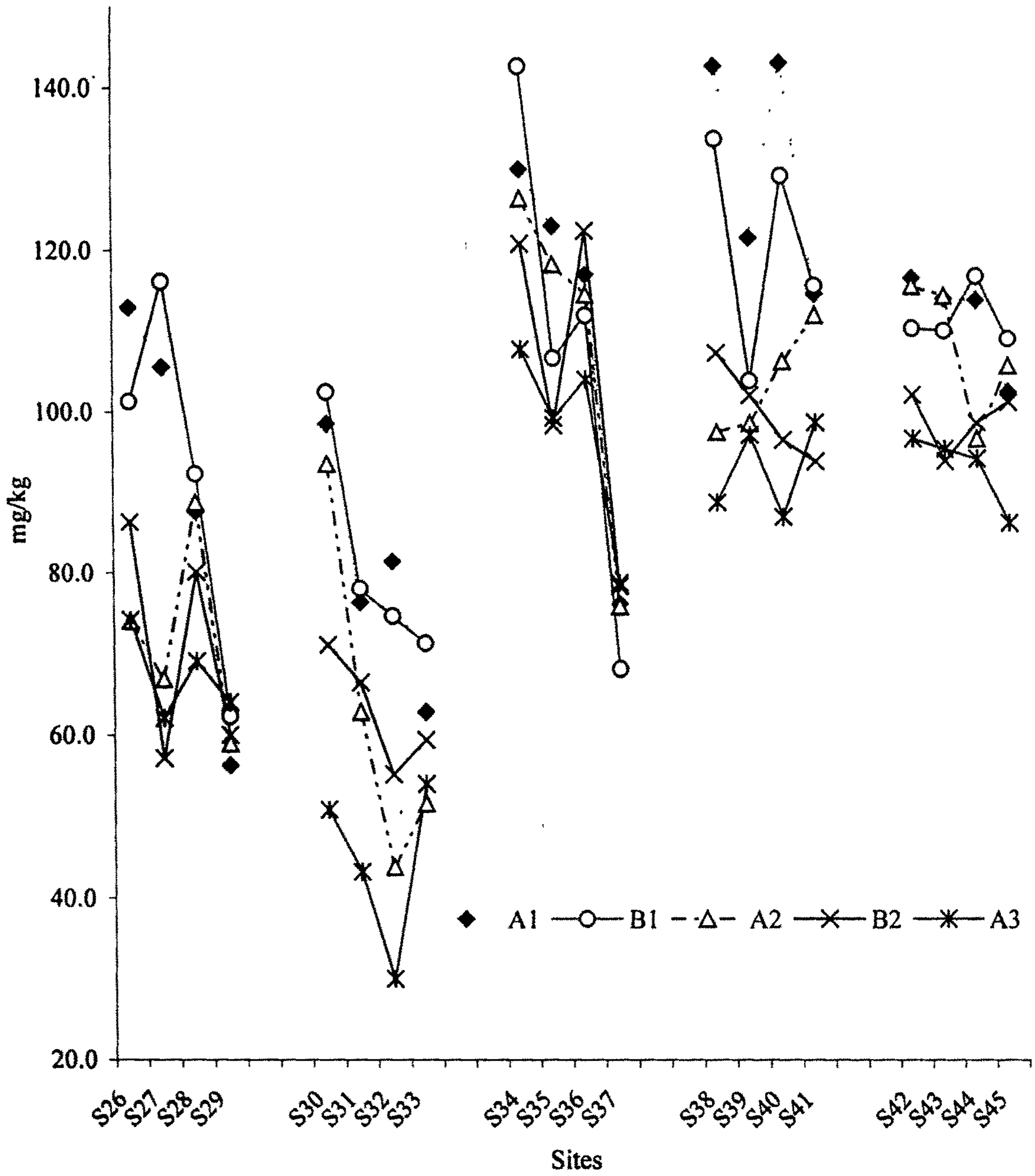
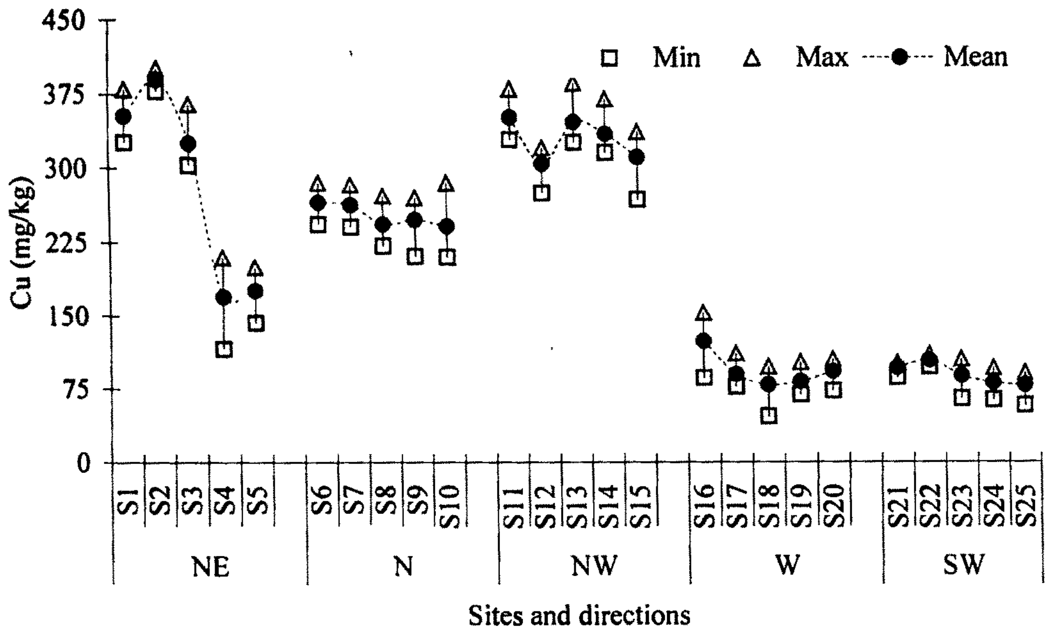


Fig. 3.17 (b). Variation pattern of total Cr-content in Side B with respect to the sampling seasons and sampling sites.



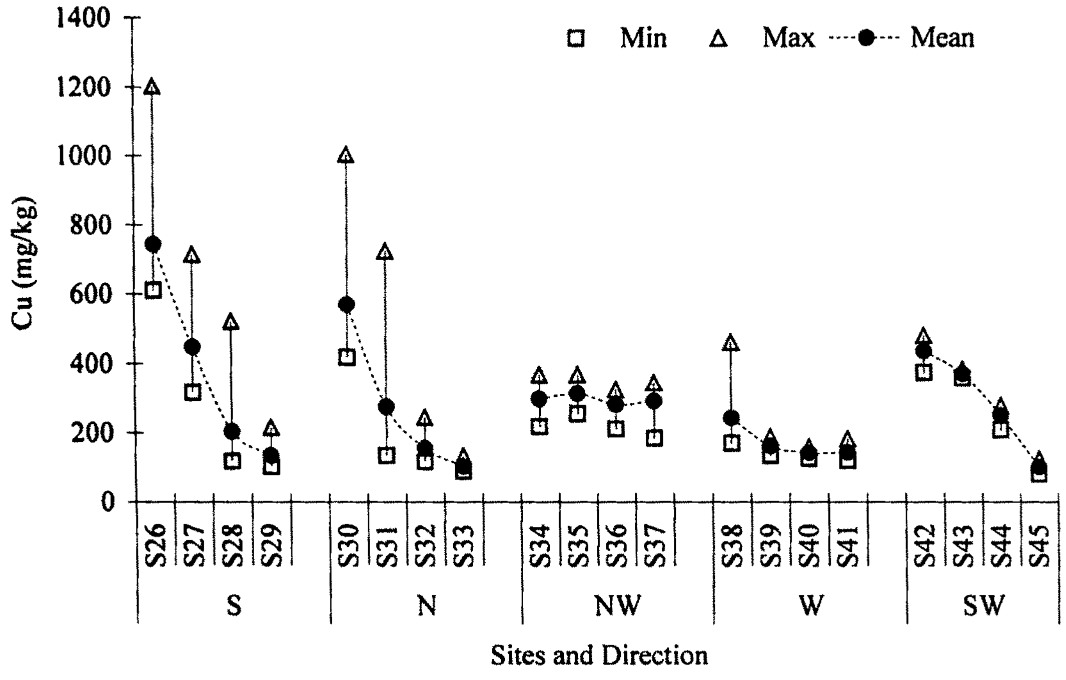
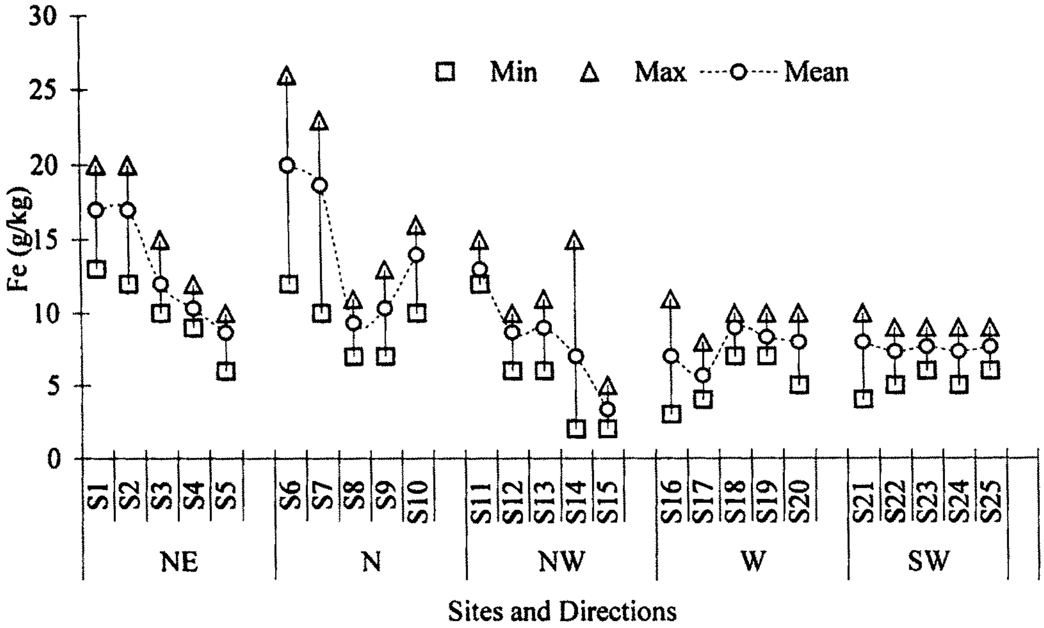


Fig. 3.18. Variation pattern of minimum, maximum and mean Cu-content in the soil for Side A (top) and Side B (bottom) with respect to the sampling sites and sampling direction.



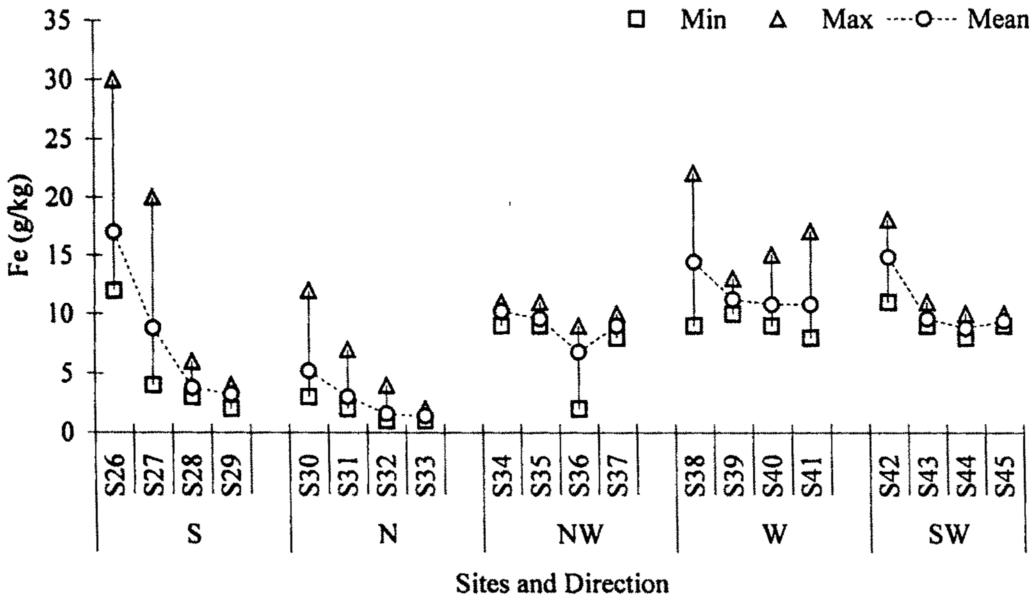


Fig. 3.19. Variation pattern of minimum, maximum and mean Fe-content in the soil for Side A (top) and Side B (bottom) with respect to the sampling sites and sampling direction.

Although the soil was found to have considerable amount of Mn in all the sites in all directions from the Mill, yet the values are less than the world average for Mn-content of soil. The average contents of Mn in the soil are shown in a bar graph (Fig. 3.20) for both the sides. The soil is also appreciably rich in Ni-content and the variation of the average values with distance is presented in Fig. 3.21.

The soil near the Textile Mill has been receiving a significant contribution of Pb from the Mill wastes and this can be seen from the considerable Pb-content of the soil – which are more than the world average. The variation of the Pb-content with distance from the Mill in different directions and in different seasons is shown in Fig. 3.22. The largest values are generally observed close to the Mill indicating definite input from the Mill activities. It is also to be noted that Pb-content had very similar but large values at the first few sites on both Side A and Side B – a clear indication that Pb accumulates close to the Mill as well as close to the earthen bandh away from the Mill. Topography of the area might have led to such preferential accumulation as was also observed in case of Cd and Cu.

The trends in variation of the Zn content of the soil in Side A and Side B are shown in Fig. 3.23. It is seen that with one or two exceptions, the Zn-content decreased away from the Mill. As is found in case of a few other trace metals, Zn also shows much more enrichment in Side B than in Side A.

All the results of trace metal estimation can be summarized by the general trend of enrichment of the soil either in Side A or in Side B, indicating a substantial input from the Mill effluent and other wastes being dumped into the area. Several metals can be found in much more amount in Side B than in Side A which may be attributed to soil conditions, topography, flow of the effluent, etc.

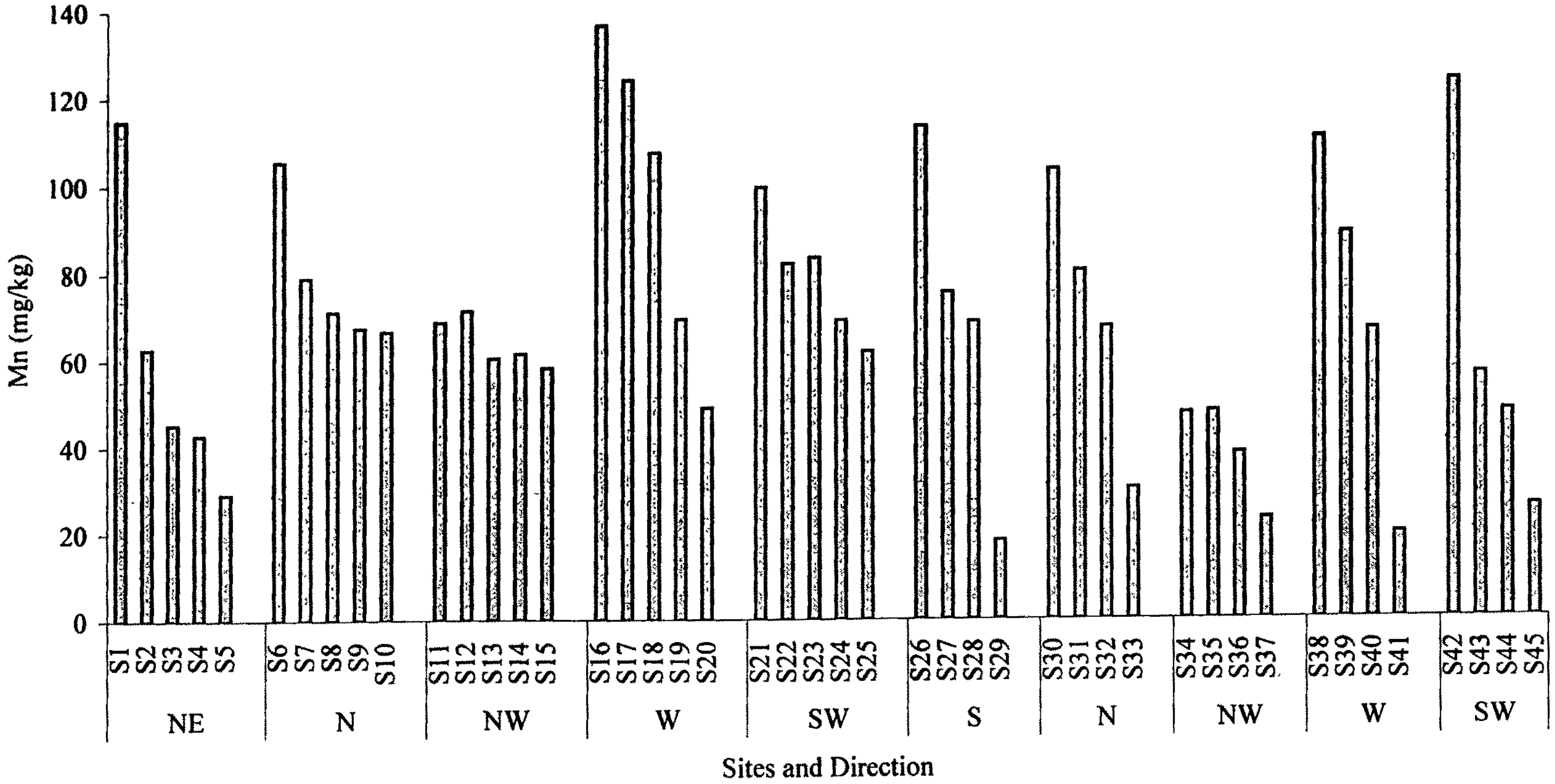


Fig. 3.20 Variation pattern of mean Mn-content in the soil of the study area for Side A (S1 to S25) and Side B (S26 to S45) with respect to the sampling sites and directions.

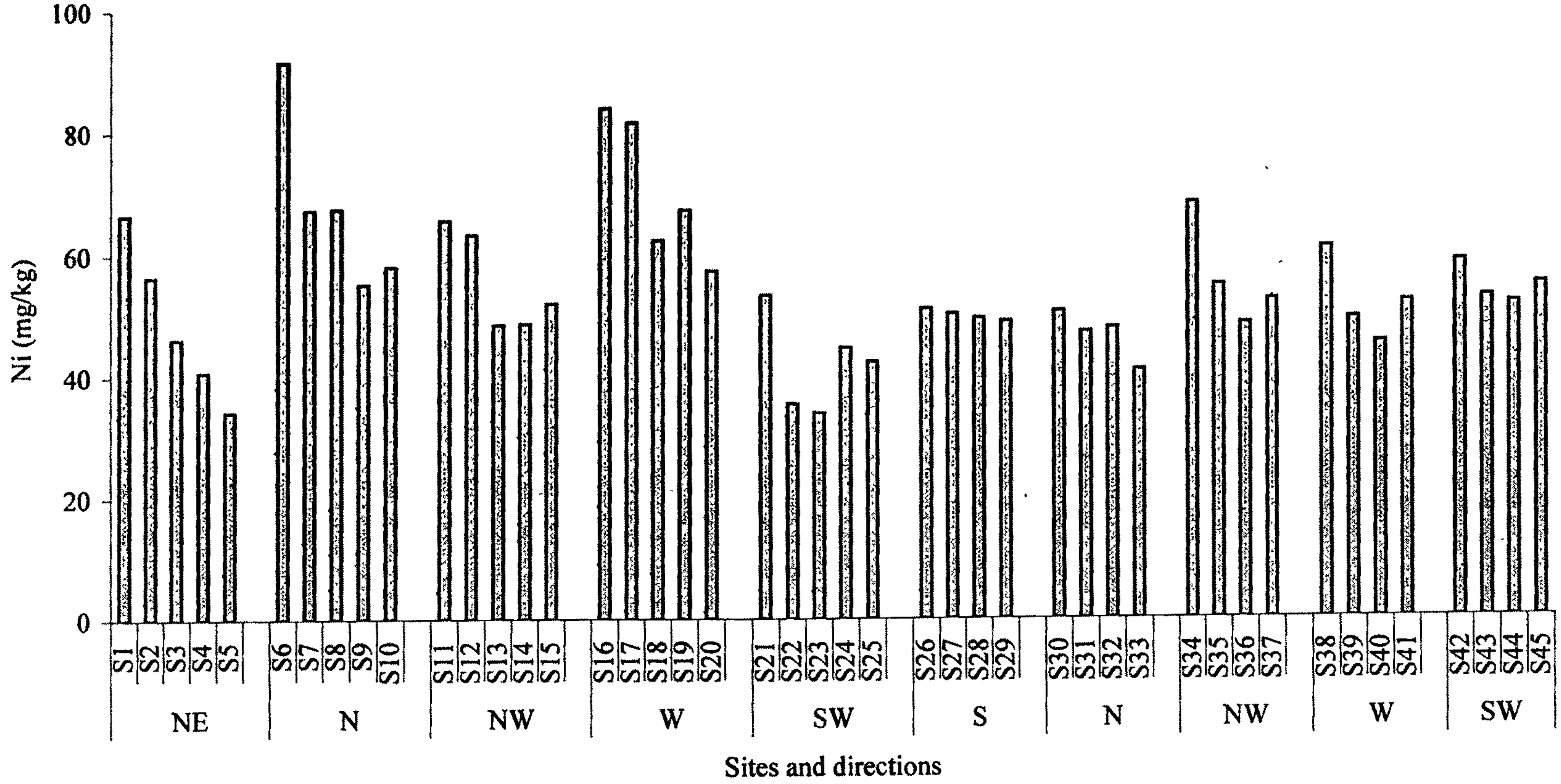


Fig. 3.21. Variation pattern of mean Ni-content in the soil of the study area for Side A (S1 to S25) and Side B (S26 to S45) with respect to the sampling sites and directions.

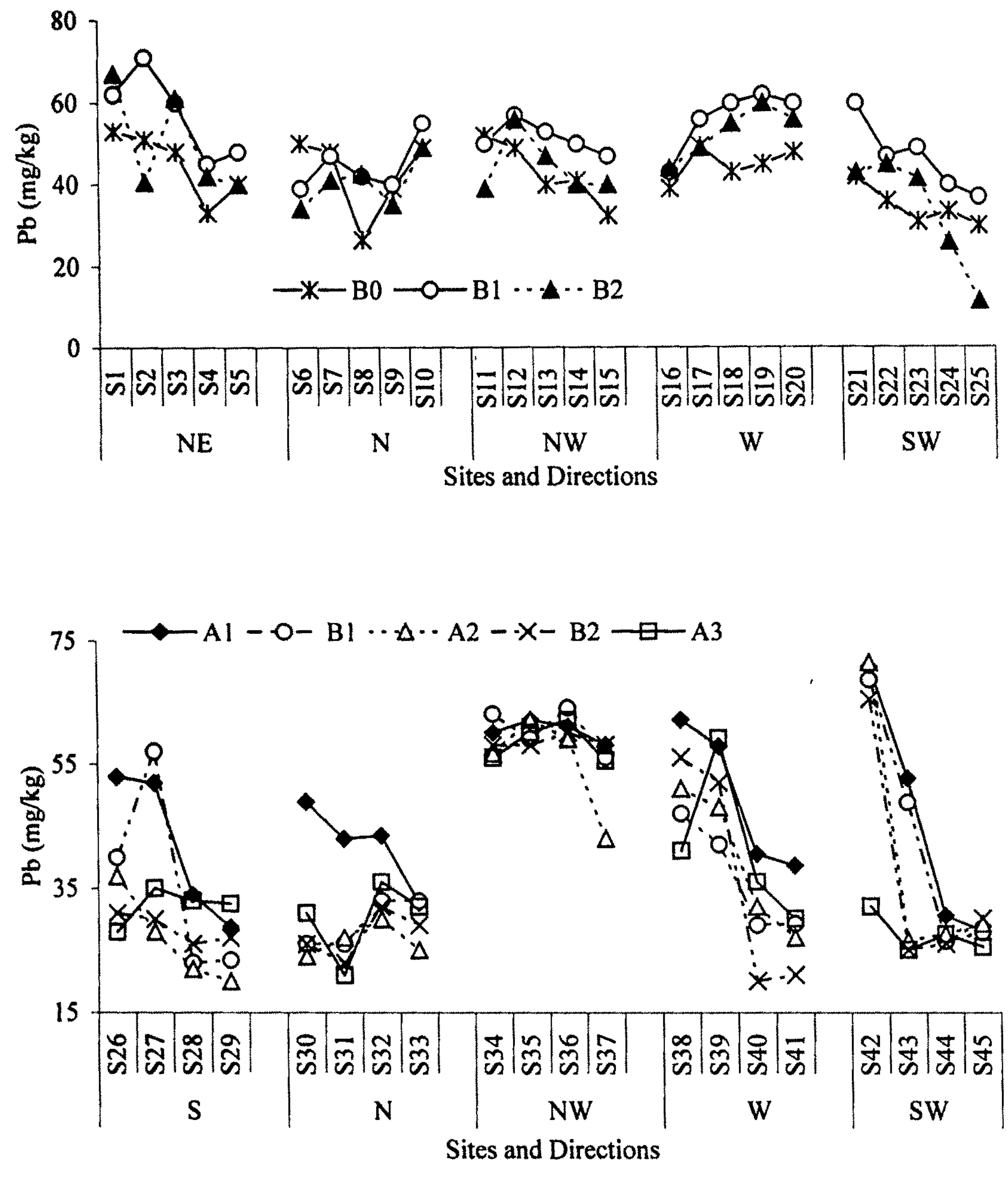
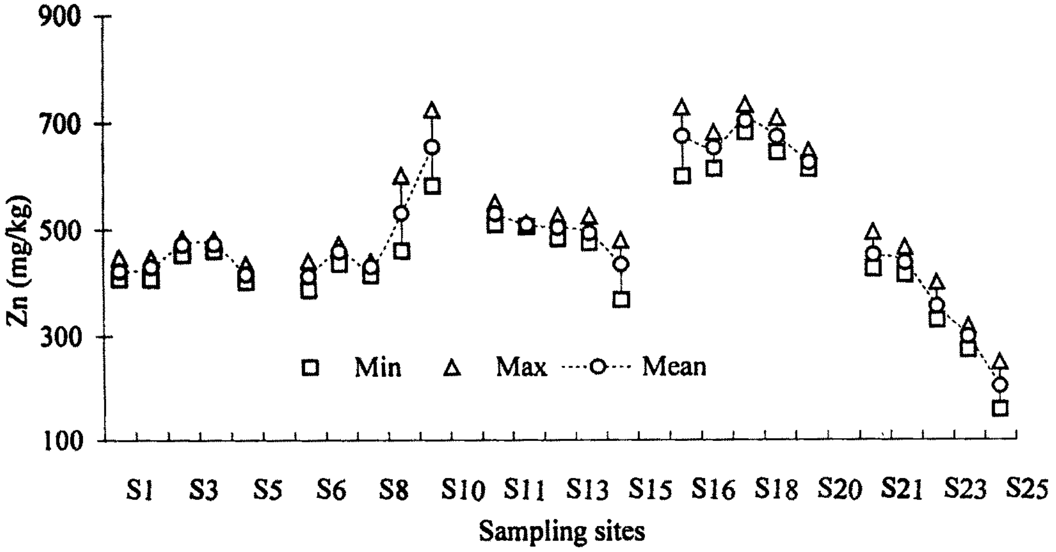


Fig. 3.22. Pb-content of the soil in Side A (top) and Side B (bottom) with respect to sampling sites and sampling seasons.



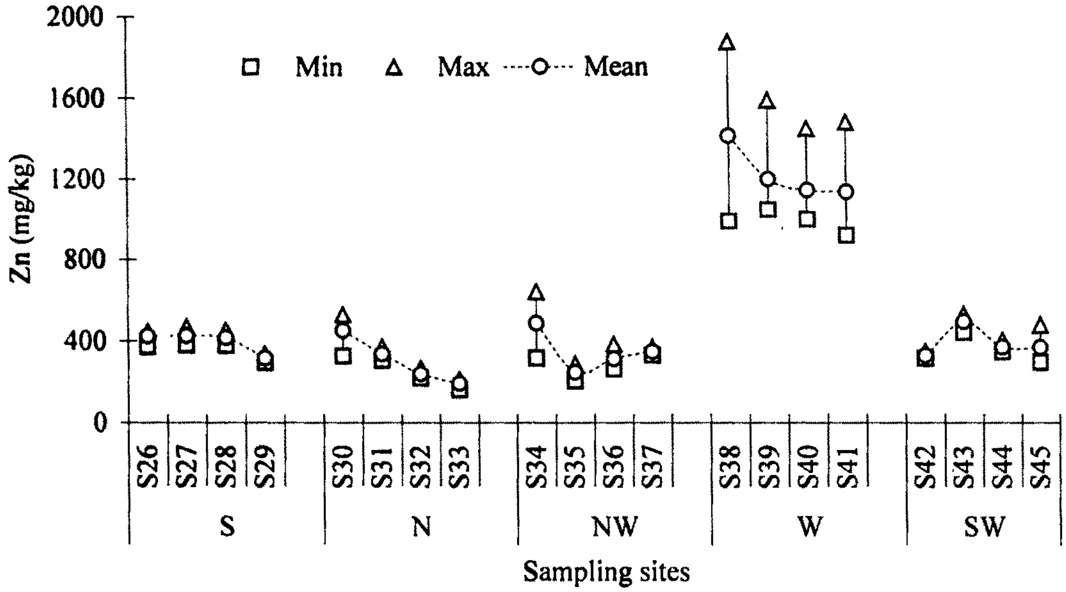


Fig. 3.23. Zn-content of the soil in Side A (top) and Side B (bottom) with respect to sampling sites and sampling seasons.

3.2 Drinking water quality

Altogether 7 drinking water samples from various sources around the textile mill were analyzed in this work for various water quality paramteters. For comparison, the same parameters were determined with respect to a Control water sample collected from an unimpacted zone. Water samples were collected in five seasons over three years 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
5	A3	2004 Post- monsoon

A parameter-wise discussion of the results is given below:

3.2.1 pH

The pH values of the drinking water samples are shown in Table 3.25. The values are in the following ranges:

- 6.1 to 7.9 for A1,
- 6.4 to 8.2 for B1,
- 6.6 to 8.2 for A2,
- 8.1 to 8.4 for B2, and
- 6.8 to 7.9 for A3.

It is seen that all the values are within the WHO permissible limits for drinking water. The pH had a tendency to increase during the summer, which is likely to be due to entry of runoff from the surrounding areas. In general, the water is neutral to slightly alkaline which is suitable for drinking purposes (Sikdar et.al. 1994). It is evident from the present study that pH values have not exceeded permissible limit according to (WHO) standards but depending only upon the pH value the quality of water cannot be judged (Garg, et al., 1990).

Table 3.25 also shows the minimum, the maximum and the mean values of pH for each of the sampling seasons and each of the water sources including a 'Control' sample collected from a no-impact zone. The corresponding standard deviations were also calculated and shown in the table with respect to both. How the minimum, the maximum and the mean values of pH change from one source to another is shown in Fig. 3.24. It is clear that the 'Control' sample had the lowest spread of pH (6.7 – 7.6) while the sample DW3 had the largest spread (6.1 – 8.4). It can be inferred that all the sources of drinking water had some influence from the Mill operations as far as pH was concerned. Excepting DW1 and DW6, all the other samples had mean pH more than that of the 'Control' sample. It further means that the effluents of the mill and other activities in the surroundings had a tendency to raise the pH of the drinking water samples.

3.2.2 Electrical Conductivity (EC)

The electrical conductivity values (Table 3.26) for all the samples were in the range of 0.13 – 0.64 mS/cm. When these values are compared to those of the 'Control' sample, it is seen that the conductivity of the water in the impact zone of the Mill was much more with one or two exceptions (Fig. 3.25). The results indicate entry of considerable load of dissolved salts into water. The values varied from season to season, and it was observed that the values were generally high during the season A2 and low during the season, B1. In general, most of the samples were found to have more electrical conductivity during the post-monsoon than in the pre-monsoon. The samples collected from the location, DW3, were found to be very rich in dissolved ionic matter.

3.2.3 Total Alkalinity

The total alkalinity values for all the seasons and for all the water samples are given in Table 3.27 along with those of the 'Control' one. The maximum alkalinity was recorded

Table 3.25. pH of the drinking water samples of the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	6.7	7.6	6.7	7.4	6.9	6.7	7.6	7.0	0.4
DW1	6.3	6.4	6.6	8.2	7.0	6.3	8.2	6.9	0.8
DW2	7.1	7.1	7.1	8.1	6.8	6.8	8.1	7.2	0.5
DW3	6.1	8.0	7.2	8.4	7.9	6.1	8.4	7.5	0.9
DW4	6.5	8.2	6.6	8.3	7.9	6.5	8.3	7.5	0.9
DW5	6.7	8.1	6.8	8.4	7.6	6.7	8.4	7.5	0.7
DW6	6.4	7.1	6.6	8.1	6.9	6.4	8.1	7.0	0.6
DW7	7.9	8.2	8.2	8.3	6.8	6.8	8.3	7.9	0.6
Min	6.1	6.4	6.6	8.1	6.8				
Max	7.9	8.2	8.2	8.4	7.9				
Mean	6.7	7.6	6.9	8.2	7.3				
SD	0.6	0.7	0.5	0.3	0.5				

Table 3.26. Electrical conductivities (mS/cm) of the water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	0.21	0.21	0.19	0.16	0.20	0.16	0.21	0.19	0.02
DW1	0.38	0.29	0.33	0.32	0.33	0.29	0.38	0.33	0.03
DW2	0.38	0.24	0.16	0.17	0.24	0.16	0.38	0.24	0.09
DW3	0.64	0.34	0.42	0.37	0.24	0.24	0.64	0.40	0.15
DW4	0.51	0.49	0.40	0.22	0.19	0.19	0.51	0.36	0.15
DW5	0.50	0.49	0.33	0.29	0.19	0.19	0.50	0.36	0.13
DW6	0.25	0.26	0.21	0.27	0.27	0.21	0.27	0.25	0.02
DW7	0.27	0.13	0.26	0.19	0.21	0.13	0.27	0.21	0.06
Min	0.25	0.13	0.16	0.17	0.19				
Max	0.64	0.49	0.42	0.37	0.33				
Mean	0.42	0.32	0.30	0.26	0. 24				
SD	0.15	0.13	0.10	0.08	0.05				

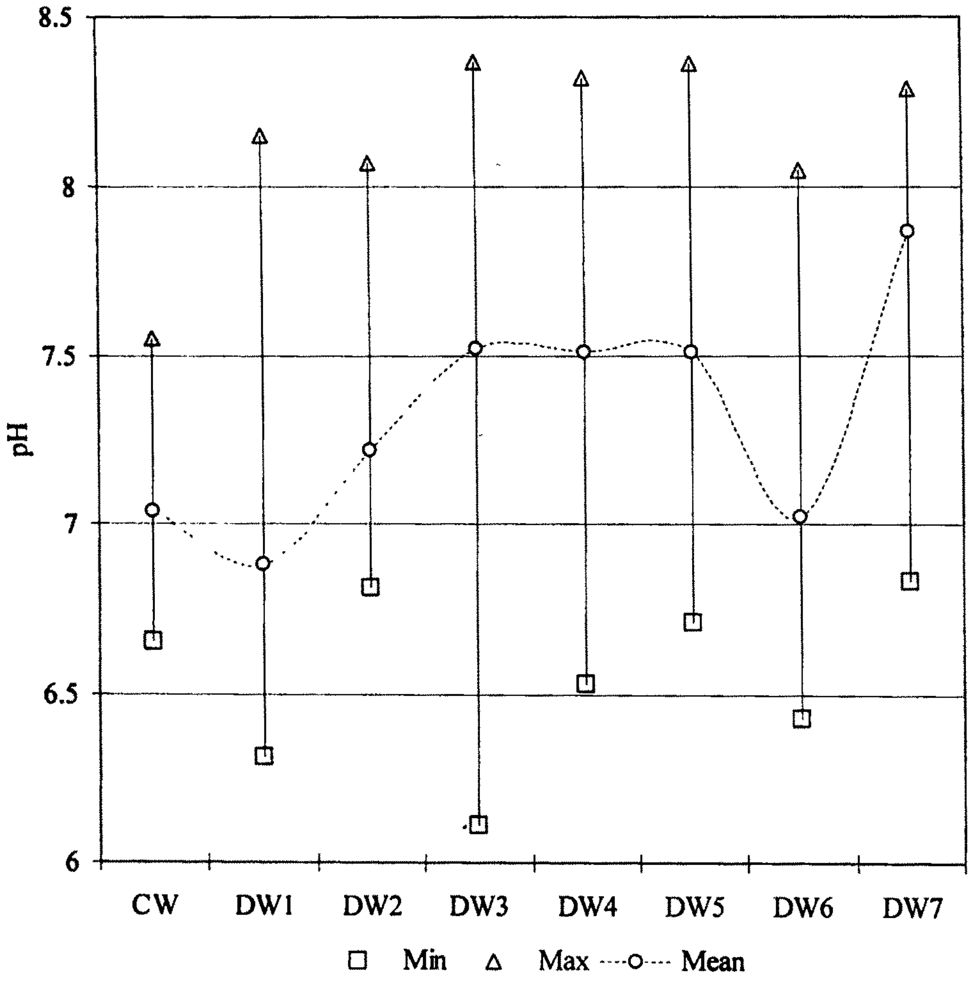


Fig. 3.24. Nature of variation of pH with respect to the minimum, maximum and mean values of the seven drinking water samples from the study area as compared to that of the 'Control' sample (CW)

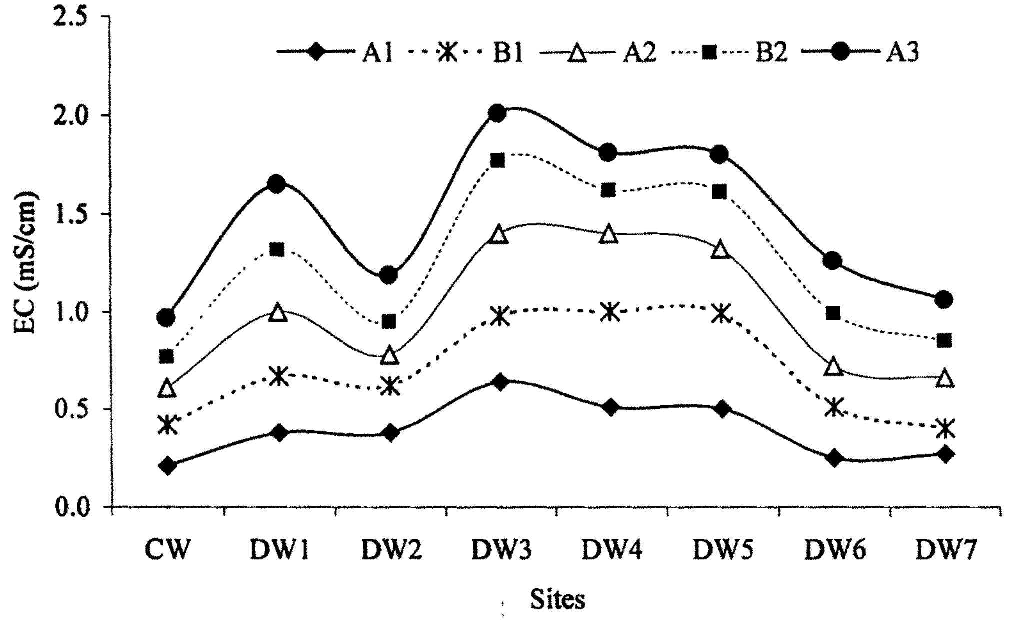


Fig. 3.25. Seasonal variation of mean Electrical conductivity for the seven drinking water samples from the study area as compared to that of the 'Control' sample (CW)

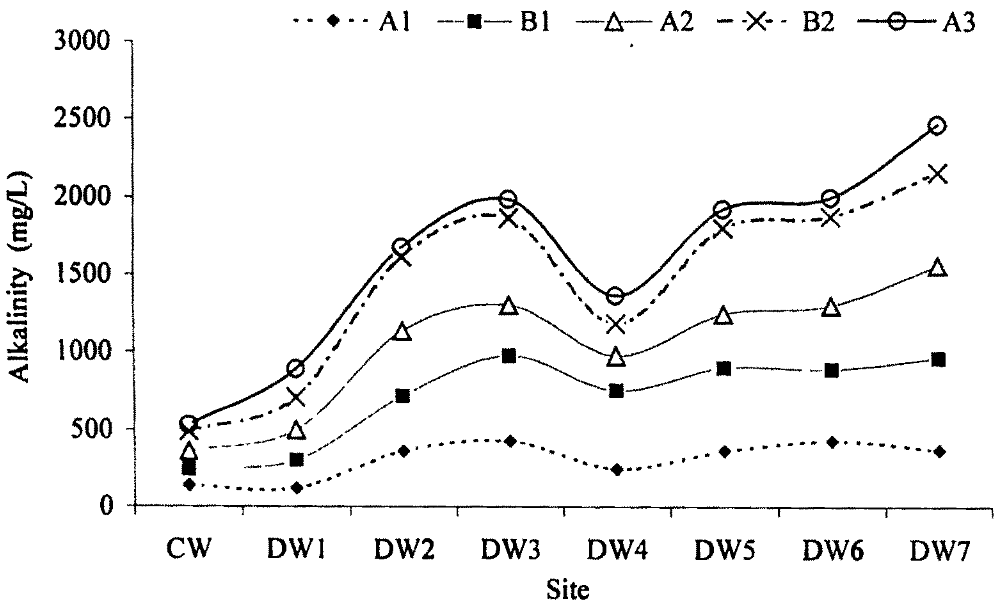


Fig. 3.26. Seasonal variation of mean Total Alkalinity for the seven drinking water samples from the study area as compared to that of the 'Control' sample (CW)

Table 3.27. Total Alkalinity (mg $CaCO_3$/L) of the drinking water samples

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	140	105	115	130	43	43	140	107	38
DW1	120	183	197	209	183	120	209	178	34
DW2	362	358	412	482	61	61	482	335	161
DW3	427	549	326	563	122	122	563	397	182
DW4	246	509	222	203	183	183	509	273	134
DW5	362	538	342	560	122	122	560	385	177
DW6	427	465	405	580	122	122	580	400	169
DW7	370	594	593	603	305	305	603	493	144
Min	120	183	197	203	61				
Max	427	594	593	603	305				
Mean	300	408	340	414	151				
SD	123	181	150	199	82				

Table 3.28. Total Dissolved Solids (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	154	178	142	150	163	142	178	157	14
DW1	168	179	176	289	376	168	376	238	92
DW2	365	416	386	641	495	365	641	461	112
DW3	789	848	402	542	438	402	848	604	204
DW4	845	920	236	465	258	236	920	545	322
DW5	368	432	189	378	408	189	432	355	96
DW6	196	984	150	468	370	150	984	434	334
DW7	452	902	638	714	525	452	902	646	175
Min	168	179	638	714	495				
Max	845	984	150	289	258				
Mean	455	669	311	500	410				
SD	269	342	173	184	120				

at DW7 (603 mg/L) in the season, B2 and minimum at DW2 (61 mg/L) in the season, A3 (Fig. 3.26). In most of the cases, the values increase from the first post-monsoon to the pre-monsoon season and then decreases. For all the sites, the minimum values are recorded in the season, A3, which indicates that the ground water samples are affected by surface water, which percolates into it. For each season, the "Control" value is less than the values observed for the study area. Some samples have recorded alkalinity values almost in the higher range of permissible limit. This shows that continuous discharge of effluents by the mill may raise the total alkalinity of the water in the area above the permissible limit. Higher amount of alkalinity imparts bitter taste to drinking water although the same may not be harmful to human beings (Trivedy and Goel, 1986; Singh et.al., 1999).

3.2.4 Total Dissolved Solids (TDS)

The TDS of water is probably the most used criterion of its quality (Rani et al. 2006). In the study area, almost all the samples have TDS content (Range 150– 984 mg/L) within permissible limit (WHO 1000 mg/L). In terms of dissolved solids, DW1 had the least content for all the seasons (Table 3.28). The TDS content was more in the first pre-monsoon (B1) season than the previous post-monsoon season (Fig. 3.27). The mean value was also found to be the maximum in the first pre-monsoon season (B1) and minimum in the next season. The sample DW2 (tube well) showed lower variations compared to other sources.

The TDS contributes to the content of the ionic matter present in water and its impact on human health depends on its exact chemical composition. Several of the constituents of the dissolved solids may have properties requiring special attention. A few of the important constituents of TDS, which need special attention, include alkalinity, hardness, fluoride, metals, organics and nutrients (Peavy et. al., 1987).

3.2.5 Total Solids (TS)

The values of total solids for all the samples with maximum, minimum, mean and standard deviation with respect to all the seasons are given in Table 3.29. In the present study, substantial amounts of solids were found for DW3 (Range 584 – 1218 mg/L) and

DW4 (Range 339 – 1388 mg/L), but the highest value was obtained at DW6 (1464 mg/L) in the season, B1 amongst all the samples. In case of TS, distinct seasonal variation was observed. The pre-monsoon values are more than those of the previous post-monsoon season. Subsequently in the next post-monsoon season, the TS is less than those for the pre-monsoon season. This is because of the pre-monsoon shower bringing in more solids of different forms enhancing the total solid content of water. The Control samples have less total solids than the water samples of the study area for all the seasons.

Water with high solids (TS, TDS and TSS) contents were of inferior palatability and may induce an unfavourable physiological reaction in the transient consumer (Sahu and Behra, 1995)

The total suspended solids (TSS) can be obtained by simply subtracting the TDS values from the corresponding TS values. The relationship between TDS, TSS and TS with respect to their mean values is shown in Fig. 3.28. This shows that the drinking water samples from the study area have different solid loads.

3.2.6. Total Hardness

The results of total hardness for all the seasons and for all the samples are given in Table 3.30. The results indicate that all the drinking water samples could not be considered as 'hard'. The range of values is 30 – 190 mg/L that is above the standard limit of 100 mg/L(WHO,1984). The values were comparatively higher in the water samples collected during the post-monsoon season. Because there is no rainfall at this time, and the water volume decreases, the conditions lead to accumulation of the contaminants. The hardness has no known adverse effects on human health but Keller (1979) observed a correlation between hardness of water and its role in heart and kidney problem. Similar observations have also been made by Park and Park (1986).

3.2.7. Phenol

Phenol is used as a slimicide (a chemical that kills bacteria and fungi found in watery slimes), as a disinfectant, and in medical products. The presence of phenol in water can cause serious problems because mutagens may be formed during disinfection by chlorination (Onodera et. al. 1998). The US Environmental Protection Agency (US EPA) has decided that water (lakes, streams) should not contain more than 0.3 mg

Table 3.29. Total Solids (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	176	214	162	170	195	162	214	183	21
DW1	202	219	214	374	512	202	512	304	136
DW2	533	689	558	951	749	533	951	696	168
DW3	1150	1218	584	758	618	584	1218	866	299
DW4	1263	1388	339	640	355	339	1388	797	499
DW5	522	662	273	490	624	273	662	514	152
DW6	258	1464	199	632	522	199	1464	615	508
DW7	737	1320	963	1094	817	737	1320	986	231
Min	202	219	214	374	817	202	817	365	262
Max	1263	1464	963	1094	355				
Mean	666	994	447	706	600				
SD	419	517	274	300	203				

Table 3.30. Total Hardness (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	20	20	30	30	60	20	60	32	16
DW1	50	30	50	30	104	30	104	53	30
DW2	90	70	80	50	100	50	100	78	19
DW3	190	100	172	60	60	60	190	116	62
DW4	50	40	36	30	128	30	128	57	40
DW5	100	70	80	40	64	40	100	71	22
DW6	40	30	32	20	52	20	52	35	12
DW7	90	80	84	30	80	30	90	73	24
Min	40	30	32	30	52				
Max	190	100	172	60	128				
Mean	87	60	76	37	84				
SD	53	29	47	13	27				

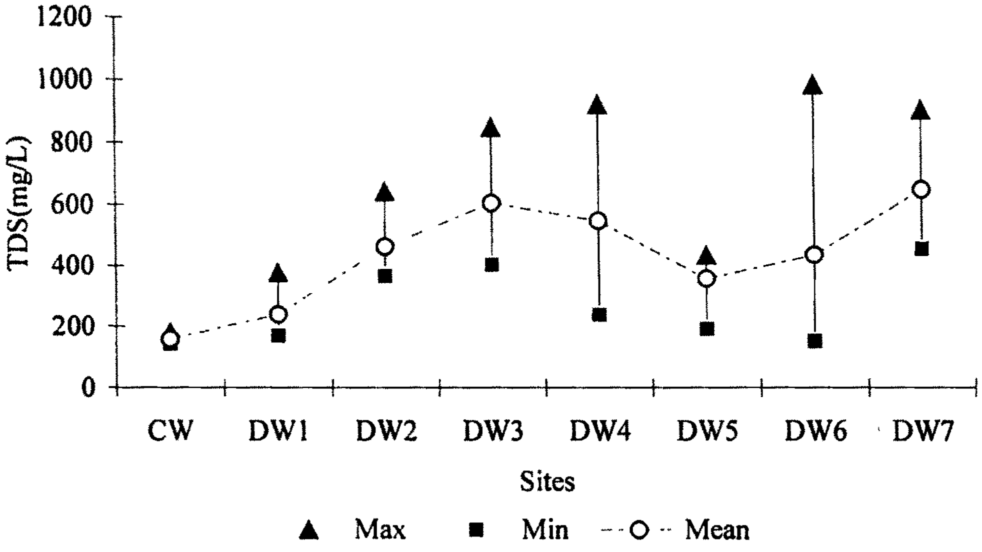


Fig. 3.27. Variation of the minimum, the maximum and the mean values of TDS in the drinking water samples of the study area.

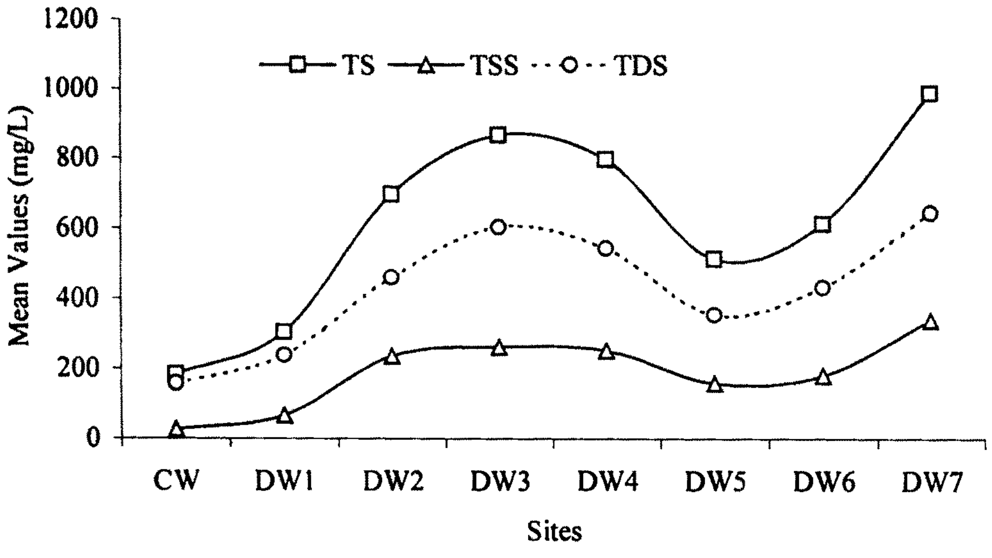


Fig. 3.28. Variation of the mean values of TDS, TSS and TS in the drinking water samples of the study area.

phenol per liter to protect human health from the possible harmful effects of exposure to phenol (Source: Toxicological Profile, 1989). In the present study, some of the drinking water samples did contain phenol as shown in Table 3.31. Among the seven drinking water samples, three samples (DW5, DW6 and DW7) did not have detectable amount of phenol in all the seasons. The "Control" sample was also free from phenol. The other four samples had phenol in the range of 0.08 – 0.61 mg/L, which are much above the EPA permissible limit. The people have used these water sources for a long time. It is likely that the use of various disinfectants by the local people and also the use of aromatic phenolic compounds in the Mill might be responsible for enhancing the presence of phenol in the four drinking water sources.

The variation of the phenol content with season for the four water samples, whose water was contaminated with phenol, is shown in Fig. 3.29. The sample, DW1, had high phenol in all the seasons, but the other samples showed some variations.

3.2.8 Chloride (Cl^-)

The chloride content of the drinking water samples is given in Table 3.32. The values range from 14.2 to 85.2 mg/L. In the present investigation, the chloride content of water samples was within the ISI standard value of 250 mg/L (Rani et al., 2006). The maximum value was obtained at DW3 in first post-monsoon (A1) season and the minimum for DW4 in second pre-monsoon season (B2). Seasonal variation was not observed. Low Cl^- content indicates that the drinking water sources are not contaminated by domestic sewage and human and animal excreta. When Cl^- is present at concentration above 250 mg/L, it imparts an unpalatable taste to waters although no adverse effects have been observed on human beings regularly consuming water with much higher concentration of chloride (Vermani and Narula, 1995).

The seasonal variation of the chloride content of the drinking water sources is shown in Fig. 3.30.

Table 3.31 Phenol (mg/L) in the drinking water samples of 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	0.61	0.60	0.57	0.60	0.53	0.53	0.61	0.58	0.03
DW2	0.37	0.30	0.24	0.15	0.08	0.08	0.37	0.23	0.12
DW3	0.38	0.32	0.26	0.30	0.30	0.26	0.38	0.31	0.04
DW4	0.38	0.31	0.26	0.20	0.17	0.17	0.38	0.26	0.08
DW5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DW6	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
DW7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Min	0.37	0.30	0.24	0.20	0.08				
Max	0.61	0.60	0.57	0.60	0.53				
Mean	0.44	0.38	0.33	0.30	0.27				
SD	0.12	0.15	0.16	0.20	0.20				

Table 3.32 Cl (mg/L) of the drinking water from the study area

Site	Sampling season					Min	Max	Mean	SD
	A1	B1	A2	B2	A3				
CW	13.9	5.2	14.2	3.5	14.2	3.5	14.2	10.2	5.4
DW1	30.2	26.5	28.4	17.8	24.6	17.8	30.2	25.5	4.8
DW2	42.9	42.6	24.9	21.5	21.5	21.5	42.9	30.7	11.1
DW3	86.4	85.2	40.5	21.3	35.5	21.3	86.4	53.8	30.1
DW4	56.2	56.8	36.6	14.2	20.7	14.2	56.8	36.9	19.7
DW5	43.4	42.6	37.2	24.9	29.7	24.9	43.4	35.6	8.1
DW6	69.1	63.9	42.6	35.8	35.8	35.8	69.1	49.4	15.9
DW7	80.2	78.1	41.2	21.3	23.9	21.3	80.2	48.9	28.6
Min	30.2	26.5	24.8	14.2	20.7				
Max	80.2	85.2	42.6	35.8	35.8				
Mean	58.3	56.5	36.0	22.4	27.4				
SD	25.0	26.6	9.9	9.2	7.5				

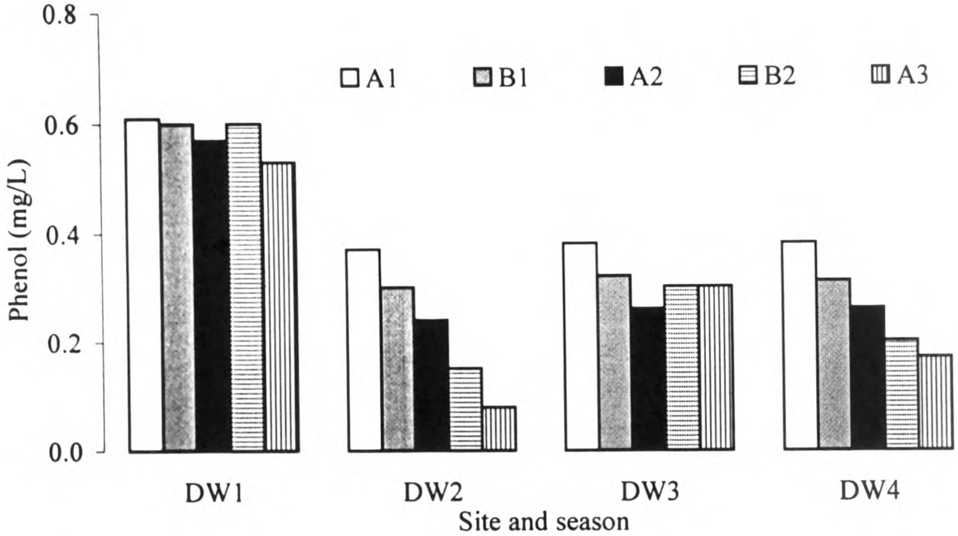


Fig. 3.29. Variation of the mean phenol content for the four drinking water sources with season.

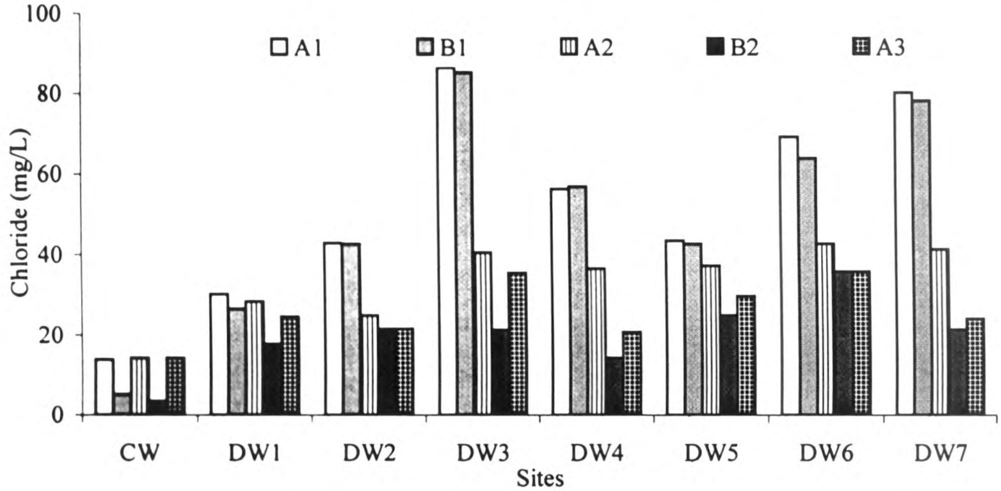


Fig. 3.30. Variation of the mean chloride content of the drinking water sources with season.

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				

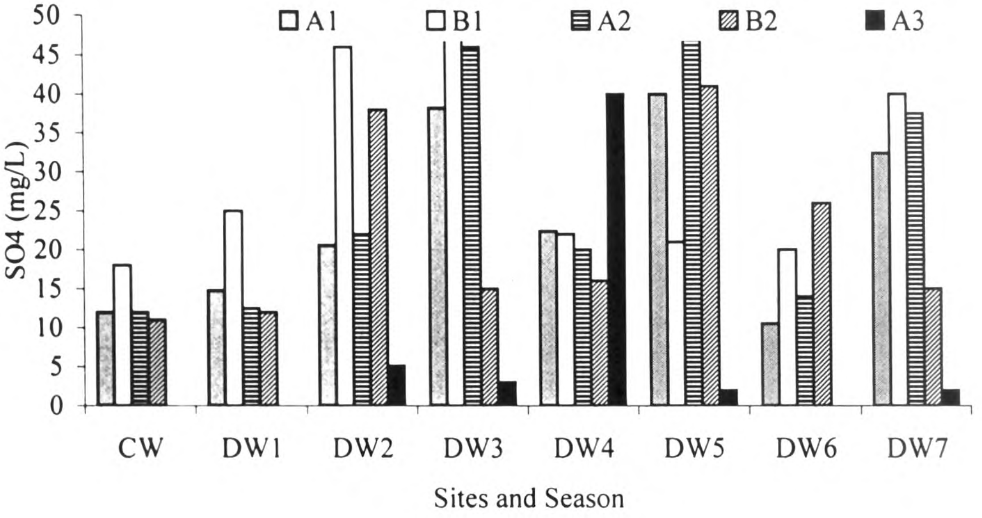


Fig. 3.31. Variation of the mean sulphate content of the drinking water sources with season.

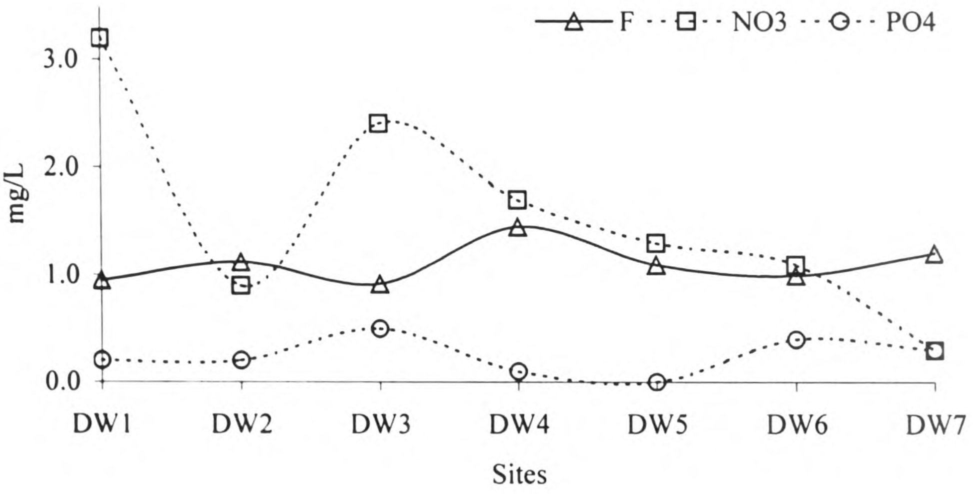


Fig. 3.32. Variation of the mean fluoride, nitrate-N and phosphate contents of the drinking water sources.

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				

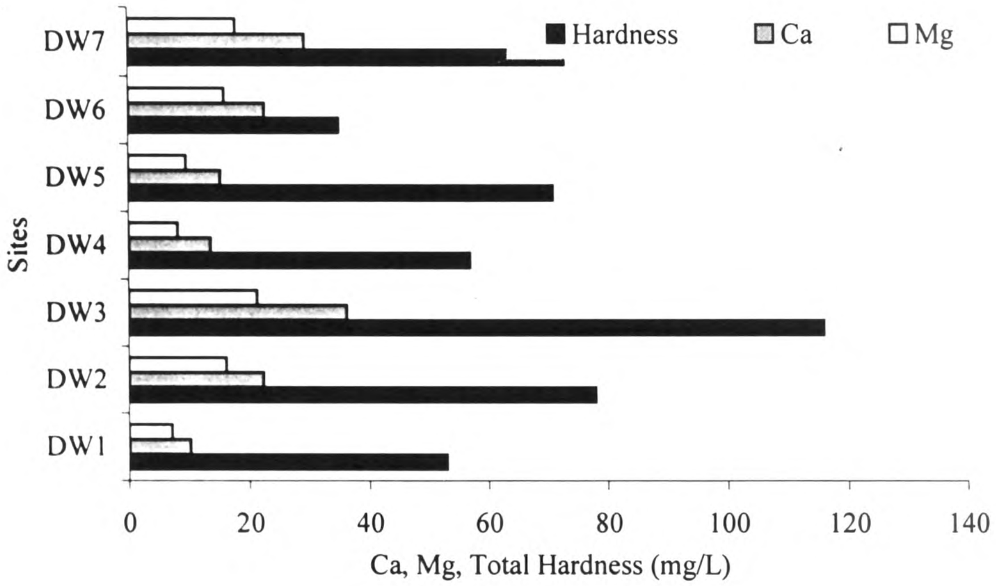


Fig. 3.33. Variation of mean values of calcium, magnesium and total hardness for the drinking water sources.

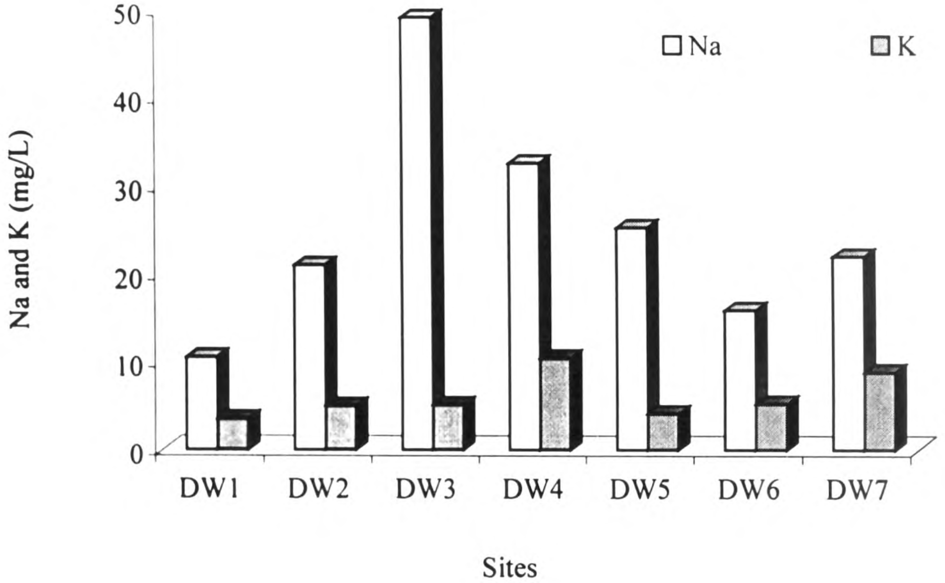


Fig. 3.34. Variation of all season mean values of sodium and potassium for the drinking water sources.

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.

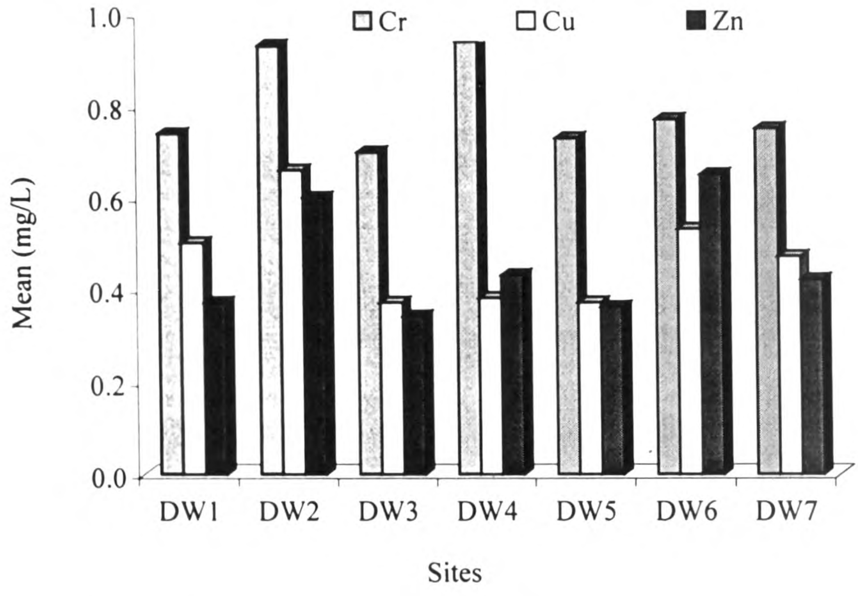


Fig. 3.35. Variation of all season mean values of chromium, copper and zinc for the drinking water sources.

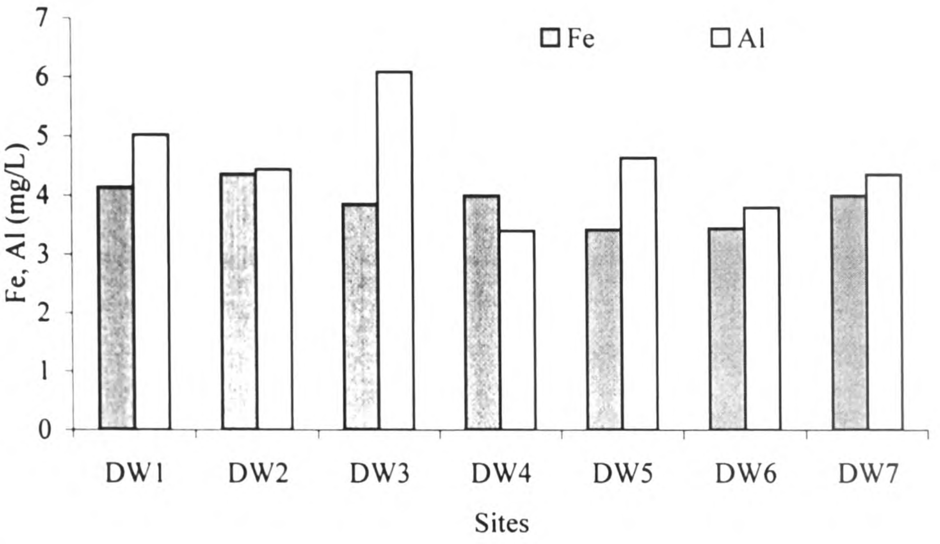


Fig. 3.36. Variation of all season mean values of aluminium and iron for the drinking water sources.

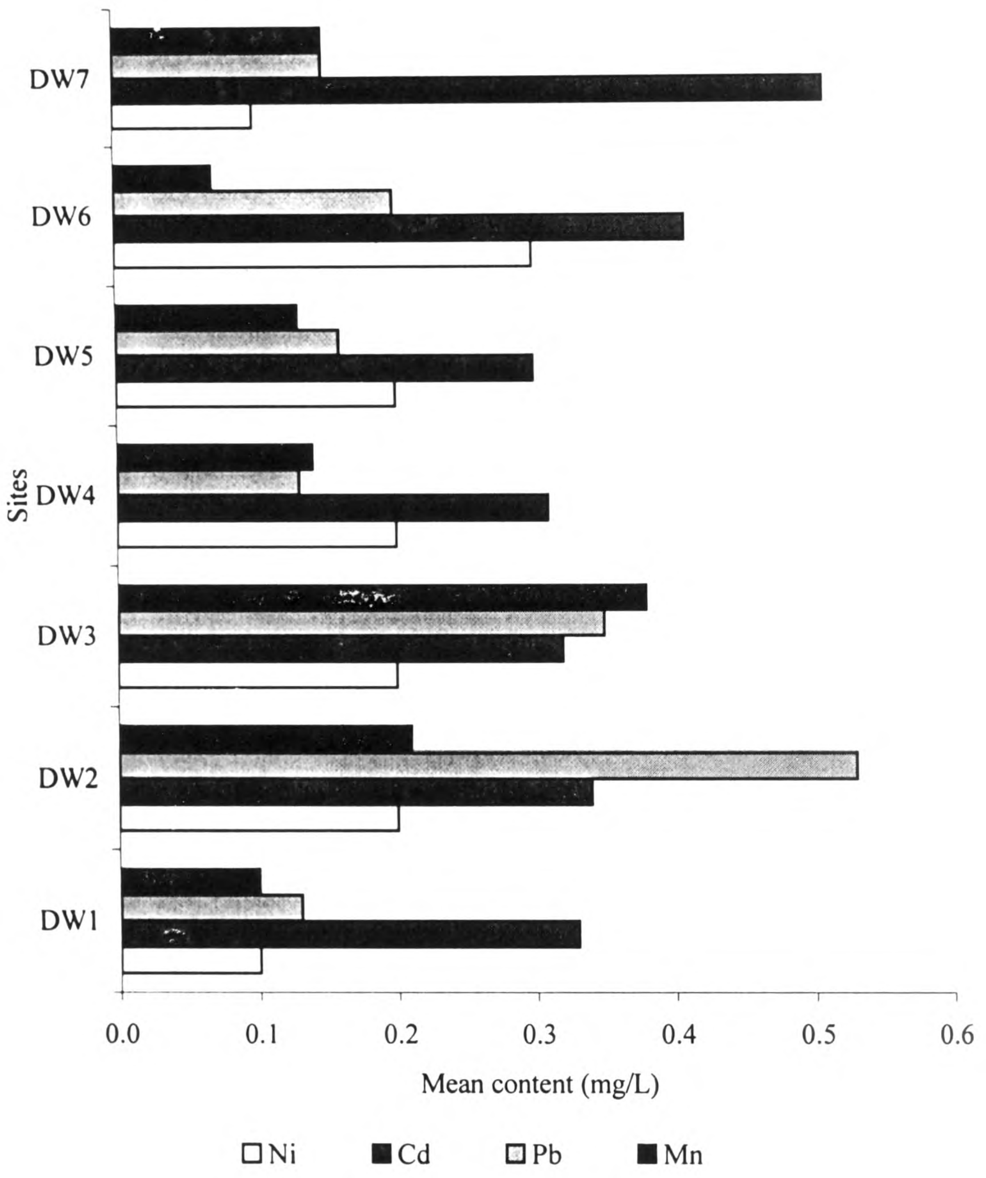


Fig. 3.37. Variation of all season mean values of nickel, cadmium, lead and manganese contents for the drinking water sources.

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.

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.

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				

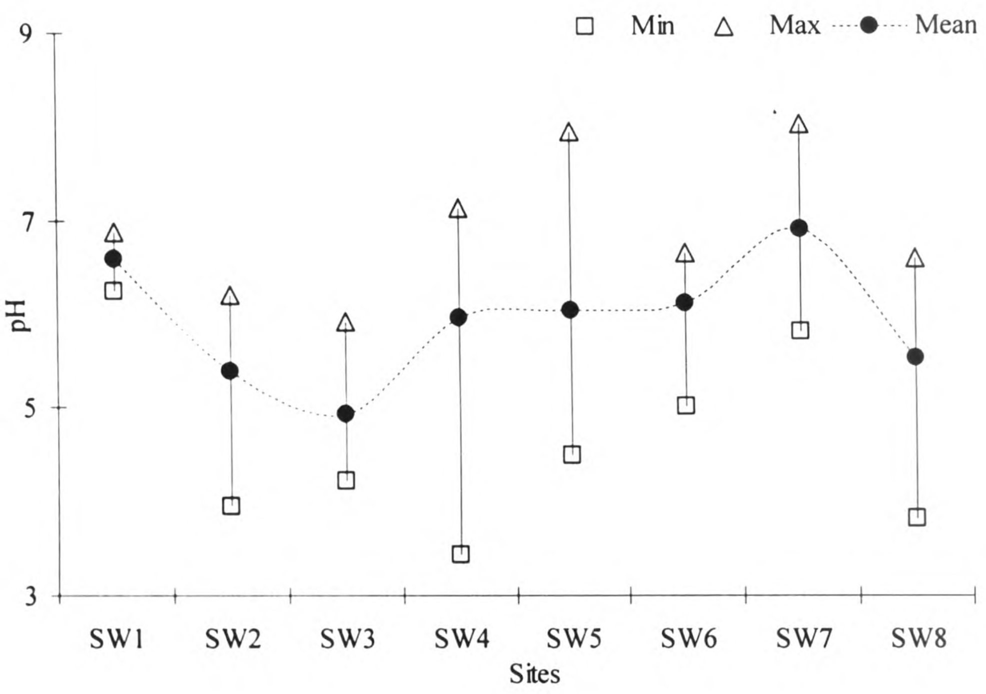


Fig. 3.38. pH ranges of the water in the eight surface water sites

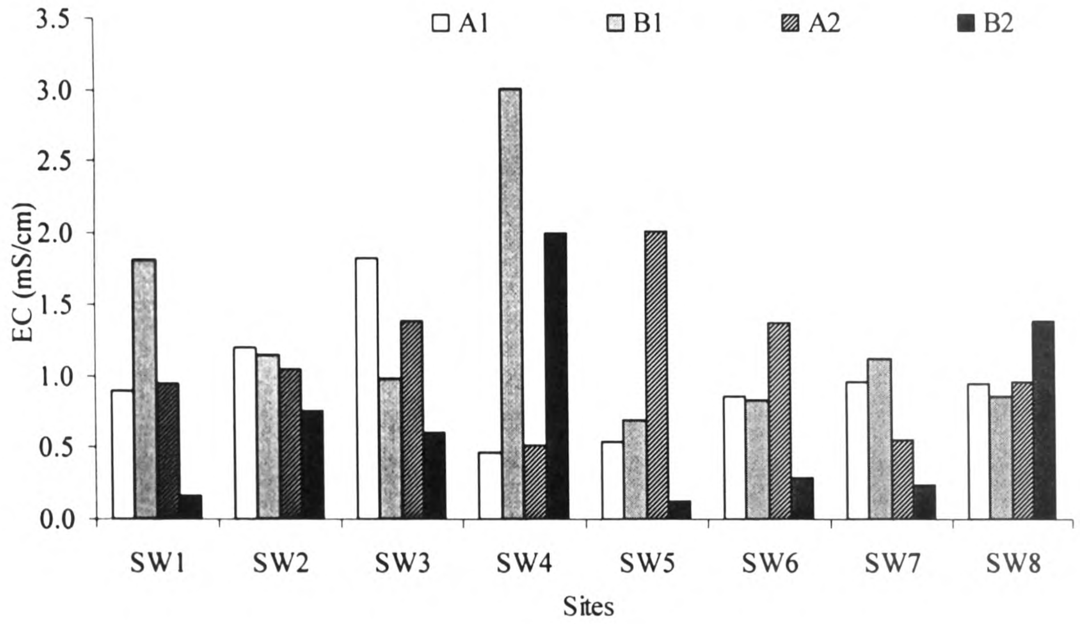


Fig. 3.39. Seasonal variation of electrical conductivities of the surface water samples for the different sites.

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				

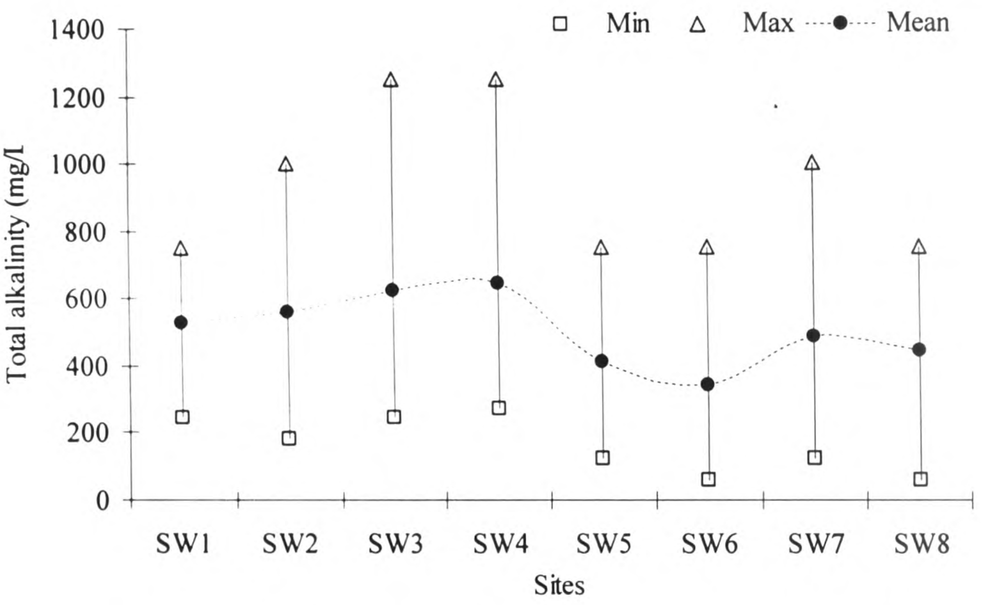


Fig. 3.40. The ranges of values of total alkalinity for the different surface water sites

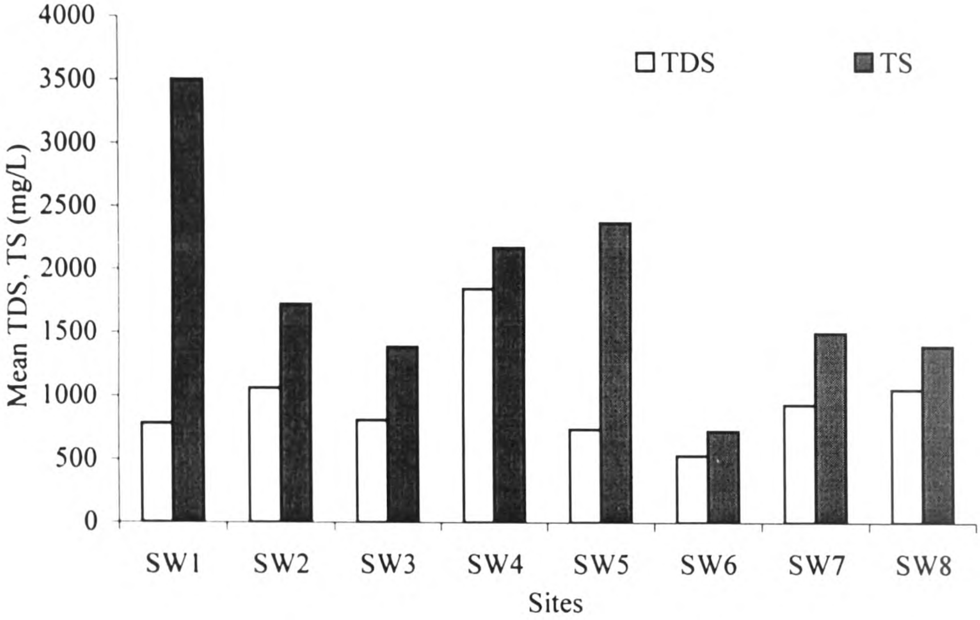


Fig 3.41. The variation of the mean total dissolved solids and total solids for the different surface water sites

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				

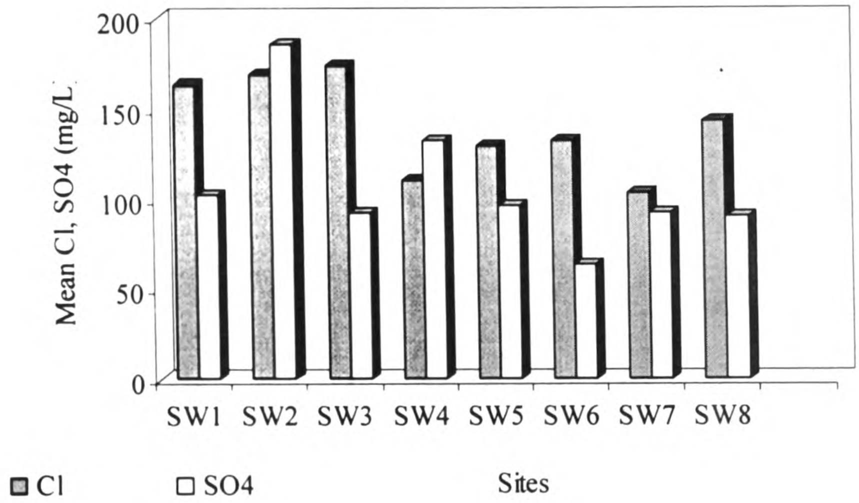


Fig. 3.42. Variation of mean chloride and sulphate contents of the surface water for the different sites.

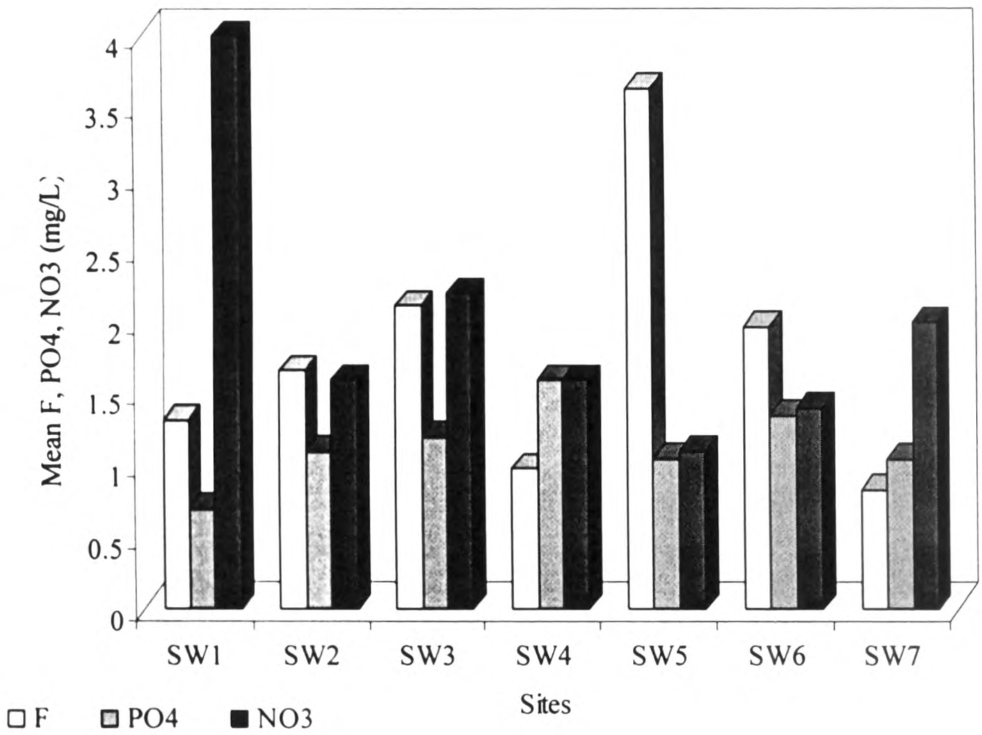


Fig. 3.43. Variation of mean fluoride, phosphate and nitrate contents of the surface water for the different sites.

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				

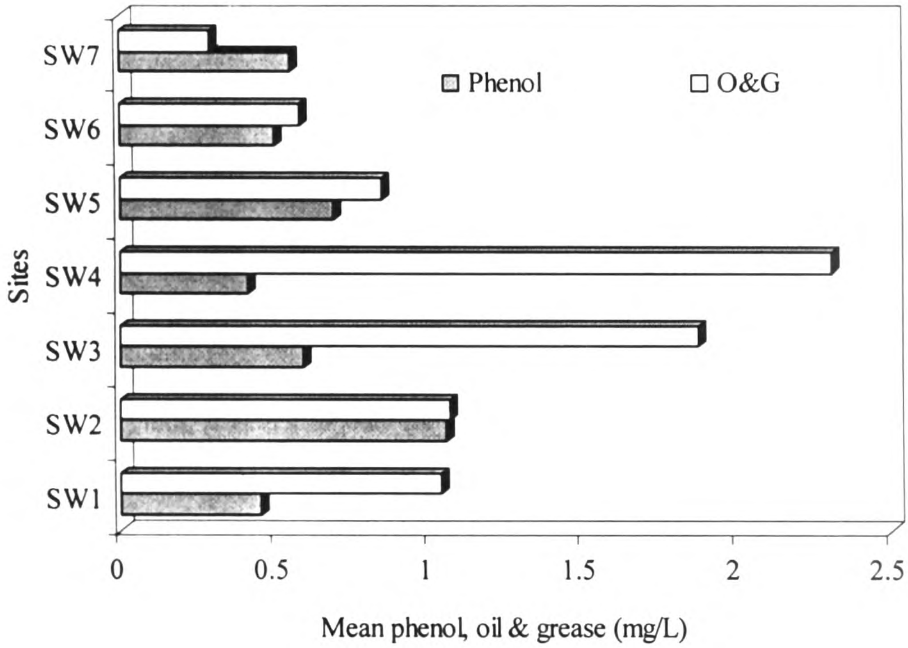


Fig. 3.44. Relative proportion of phenol and oil & grease in the surface water samples.

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				

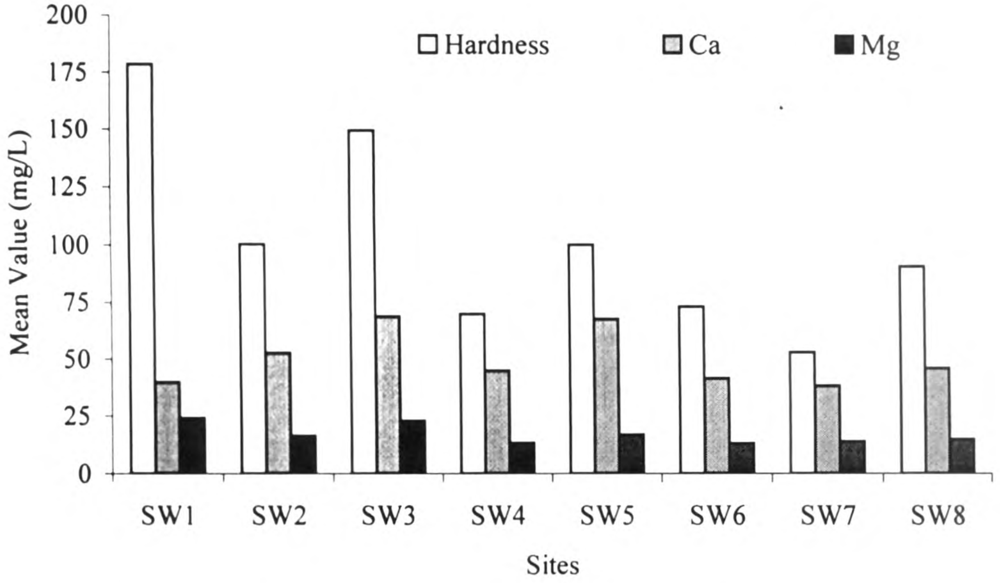


Fig. 3.45. Variation of the mean values of total hardness, calcium and magnesium contents of surface water for the different sites.

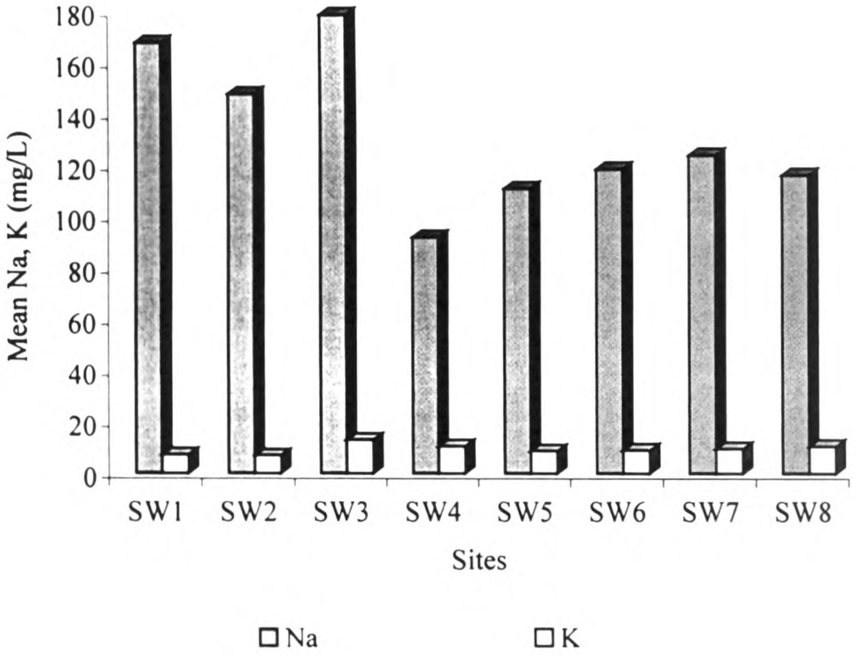


Fig. 3.46. Variation of the mean values of sodium and potassium contents of surface water for the different sites.

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

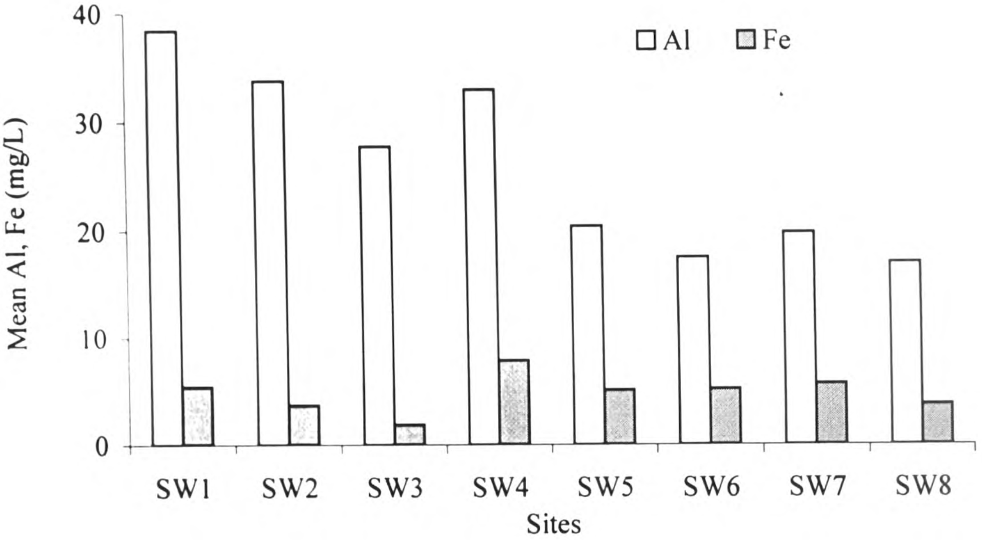
All the surface water samples had very high Al-content followed by Fe-content. This is shown for the mean values of the two constituents in Fig. 3.47. Mn and Zn contents were also high, but not as high as Al and Fe. The two metals, Mn and Zn, did not show a consistent pattern of presence relative to 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				



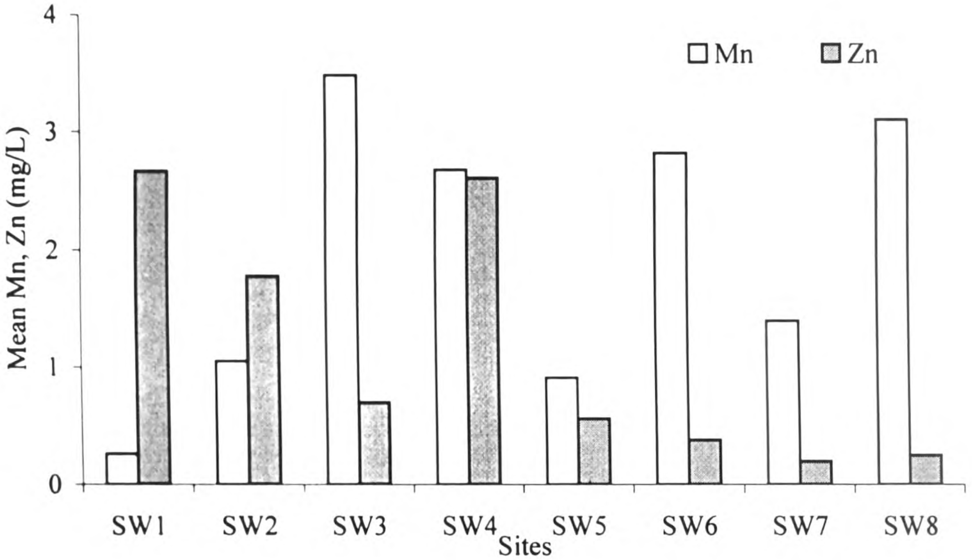


Fig. 3.47. Variation of the mean values of Al and Fe (top), and Mn and Zn (bottom) in the surface water of the sampling sites.

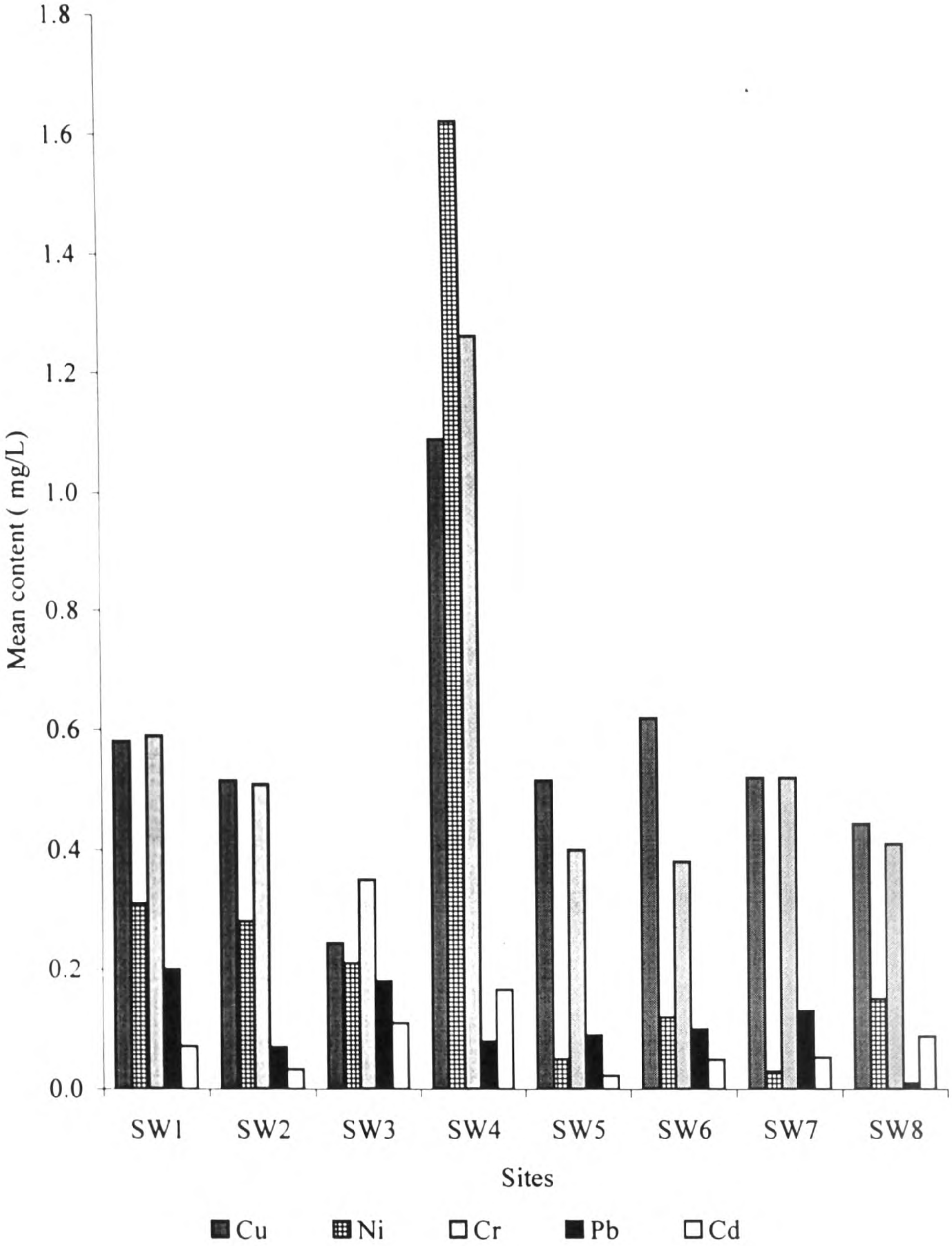


Fig. 3.48. Variation of the mean values of Cd, Cr, Cu, Ni and Pb in the surface water of the sampling sites.

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.