IMPACT OF A TEXTILE MILL ON SOIL AND WATER QUALITY : A CASE STUDY AT RANGIA, ASSAM (INDIA)

A Thesis submitted to the
GAUHATI UNIVERSITY, GUWAHATI
For the degree of DOCTOR OF PHILOSOPHY
IN CHEMISTRY (Faculty of Science)

By
Gitimoni Deka
HEAD, DEPARTMENT OF CHEMISTRY
RANGIA COLLEGE, RANGIA.
KAMRUP, ASSAM (INDIA)
DECEMBER 2007

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To

The Academic Registrar
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This is to certify that Ms. Gitimoni Deka has completed this thesis entitled "Impact of a textile mill on soil and water quality: a case study at Rangia, Assam (India)" under my guidance and supervision, which she has now submitted for the degree of Doctor of Philosophy in Chemistry (Faculty of Science) of Gauhati University.

This thesis is the result of her own investigation carried out at the Department of Chemistry, Gauhati University. She has fulfilled all the requirements under the Ph.D. Regulations of Gauhati University. This thesis or any part of it has not been submitted by the candidate to any other university/institution for any other degree.

KGB

K G Bhattacharyya

Declaration

I hereby declare that this thesis entitled "**Impact of a textile mill on soil and water quality: a case study at Rangia, Assam (India)**" or part of this was not submitted for any other research degree to Gauhati University or any other University/institution.

Gitimoni Deka

Gitimoni Deka

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Contents

Chapter 3 Results and Discussions

3.2.17 Trace metals

3.3.18 Trace metals

3.4 Rice grains and husks

List Of Figures

List of Plates

ABSTRACT

Impact of a textile mill on soil and water quality: a case study at Rangia, Assam (India)

Soil is the natural covering of most of the earth's land surface. It is the part where plants grow, ice lands, lava flows, dune moves, rock mountain stands. Soils are used to grow most of the world's food and much of its fiber. Soil is normally considered as a three-phase system - solid, liquid and gaseous, the liquid and gaseous matter occluded in the pores. When completely dry or frozen, soil becomes a two-phase system, the liquid phase being either absent or a part of the solid phase, but the soil pores still contain some gaseous matter. The three phases of the soil system have definite roles to play. The solid phase provides mechanical support and nutrients to the plants. The liquid phase supplies water and along with it, dissolved nutrients to plant roots. The aeration need of plants is satisfied by the gaseous phase. The soil's responsibility to sustain plant growth is thus shared complementarily by its three phases.

Since soil is a very specific component of the biosphere, it is not only a geochemical sink for contaminants but also acts as a natural buffer controlling the transport of chemical elements and substances to the atmosphere, hydrosphere and biota. Soil is generally contaminated by industrial wastes and effluents, domestic and municipal wastes and also by vehicular traffic.

Synthetic dyestuffs are extensively used in textile, paper, printing industries and dye houses. The textile industry utilizes about 10,000 different dyes and pigments in the world. Dyes are an abundant class of coloured organic compounds that present an increasing environmental danger. Many dyes are difficult to decolourise due to their complex structure and synthetic origin. There are many structural varieties, such as, acidic, basic, disperse, azo, diazo, anthroquinone based and metal complex dyes. The textile industry produces large quantities of highly coloured effluents, which are generally toxic and resistant to destruction by biological treatment methods. Textile wastewater, being mostly non-biodegradable under both natural and sewage treatment plant conditions, is a potential nuisance to the environment. The runoff comprises of

substances, used as auxiliary products in textile production and treatment. These polar organic pollutants in give rise to problems non-biodegradability and persistence.

APOL (Assam Polyester Co-operative Society Limited) is Assam's only textile mill near Rangia town in the district of Kamrup, Assam, just 50 kilometers north of Guwahati (26.11W, 91.47E). The plant covering an area of 38.02 acres of agricultural land was opened in June 1988 and started commercial production of spinning yarn of 5000 kg/day from November 1988, weaving and processing from November 1991. The installed capacity of the weaving unit was 8000 m/day and that of the processing unit was 20,000 m/day. The mill is producing yarn and cloths, especially viscose, polyester and acrylic fibre. In addition to this, to meet the growing demand of the local weavers, it has started manufacturing polyester mixed cotton yarn of variety of shades, blended with 'Eri' and 'Muga' yarn. The mill has its own dyeing unit with a capacity of 1500-2000 kg/day.

The northern and southern boundaries of the Mill are covered by scattered residential accommodation while the vast western side is open agricultural land. The effluent of the mill is released through this agricultural land. There is a historical earthen dam at a distance of about 125 meters from the boundary wall of the mill along the western direction. King Baidyadev built it during the period of 1138-1145 and the dam is about 6.4 km long and 6-8 meter wide. This dam divides the area into two sides (A and B), the side A is between the Mill and the dam, and the side B from the dam and beyond. The side A experiences more effluent load in comparison to side B.

The present work was designed to evaluate the impact of the textile mill effluents and other wastes on quality of soil and water of the surrounding areas. The principal objectives were:

- To monitor the quality of soil, particularly from the area receiving the Mill effluent, with respect to important physico-chemical properties, and compare the same with that of unpolluted or 'Control' soil from no-impact zone.
- To study the quality of water that keeps the agricultural land near the textile mill in a submerged condition.

- To study the quality of water from different sources (pond, dug well, tube well) in the impact zone to find out if there is any infiltration of the textile mill effluent.
- To investigate if the rice grain and husk have accumulated a few heavy metals that is found in the Mill effluent.

This thesis, reporting the results of the investigation, is organized into four-chapter viz. (1) Introduction (2) The Study area and Methodology (3) Results and Discussion and (4) Conclusion

Chapter 1 (Introduction) starts with a brief definition of soil and its composition. It also gives the outline of some of the soil contaminants and uptake of these contaminants by the crop plants, particularly heavy metals. The impacts of industrial effluent on drinking and surface water quality in and around an industry are also described in brief. A review of the relevant literature is also given.

Chapter 2 (The Study area and Methodology) gives a general description of Rangia with reference to the study area. The Mill and its activities are also briefly described. The sampling sites for collection of soil, water (surface as well as ground) and rice grain and husk collection and the sampling frequencies are described in detail. Samples for analysis were collected in two seasons, viz. (i) pre-monsoon (April – May) and (ii) post-monsoon (October – November) during three consecutive years. In total, 175 soil samples, 35 drinking water samples, 32 surface water samples and 5 rice grain samples were collected, analysed and compared with those of "Control" samples. The physico-chemical parameters selected for monitoring and their measurement methodology were also discussed.

Chapter 3 (Results and Discussion) **present the experimental data obtained from the measurements and a parameter wise discussion for different types of samples was included along with data tables and graphs. The results were discussed with respect to the distance of the sampling site from the Mill, the values obtained for the**

'Control' samples and wherever available, with WHO and other standards, and maximum permissible limits.

Important changes were observed with respect to the soil pH, which was from 2.5 – 7.0 for the study area. 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. The soil samples in the study area were very rich in ionic content and more so in Side A. The EC values range from 0.02 – 3.51 mS/cm. The bulk density values were from 0.72 – 1.59 g/cm^3 and the soil samples in north, northwest and west directions were found to have gathered more organic matter compared to the soil in the other directions. The samples in Side B, away from the Mill, had less organic load in comparison to Side A, but the values exhibited the same trends as in Side A with distance. The water holding capacity of the soil samples was in the range of 51.1 – 81.0 %, and the mean values for all the batches were very similar. It was observed that the values obtained were lower during the post-monsoon season than the pre-monsoon values. The soil, which remained soaked with runoff during the rainy season, had been found to lose some capacity to retain water. The hydraulic conductivity values were from 0.19- 0.46 cm/min. 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. 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 had improved.

The soil texture reflects sand 54- 74.7 %, silt 9.8 – 26.6 % and clay 10.6 – 26.3 %. The organic matter was present 0.61-4.96 % with high accumulation of organic matter in some samples of side A indicating release of organic matter from the Mill along with the effluent. As distance increased from the mill, the organic matter in the soil decreased showing that the Mill had a certain area of influence beyond which the organic matter content was not dependent on the contributions from the Mill. The soil did not contain much oil and grease although in some cases, the values may be quite high, e.g. 100 mg/kg. The total nitrogen was 0.02- 0.262% and the soil samples in north, northwest and west directions of Side A have comparatively more nitrogen than the other two directions (northeast and southwest). The nitrogen content was comparatively less in the Side B than in the side A. The available phosphorus was found from 0.09 – 3.4 mg/kg in Side A and B. In all the directions, soil samples away from the Mill had lower phosphorous content with a few exceptions. Among the common metals, calcium was present from 7.2 -86.1 meq/kg, which were likely to have influenced the study area soil composition. In side B, all the soil samples had much lower values of calcium in comparison to Side A. The soil had magnesium from 0.2 – 34.4 meq/kg and no distinct variation of the values could be seen in a particular direction and season. Sodium and potassium were found in the study area soil within the range of 0.24 – 6.36 meq/100 g and 0.05 – 0.82 meq/100 g respectively. In both the cases, the samples from Side B have more contents than the Side A samples. With respect to the trace metals, As and Hg could not be detected in samples mostly from the Side B and the overall ranges were As: BDL – 21.78 μg/kg Hg: BDL–20.6 mg/kg. Both Al and Fe were present in large amounts, the ranges being Al: l 6- 89 g/kg and Fe: 1- 30 g/kg. Substantial amounts of Cd (range 0.9 – 26.3 mg/kg), Cr (range 24.7 – 298.8 mg/kg) and Cu (range 46 – 1203 mg/kg) were observed in all the soil samples. Though Cd was obtained more in Side B, all the three metals had a decreasing trend away from the Mill. Mn content (range 13.2 – 162.7 mg/kg) was lower than the world average, but large amounts of Ni (range 21.5 – 101.0 mg/kg), Pb (range 12 – 71.4 mg/kg) and Zn (range 156 – 1872 mg/kg) were observed in all the soil samples.

The results of analysis of the drinking water samples from the study area were compared with the WHO guideline values. pH was within the range of 6.1 – 8.4. The electrical conductivity was from 0.13 – 0.64 cm/mS, which indicated entry of considerable load of dissolved salts into water. Total alkalinity was from 61 – 603 mg/L, and some samples recorded alkalinity values almost in the higher range of the 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.

In case of total solids (range 202 – 1464 mg/L), distinct seasonal variation was observed. Total dissolve solids was within the range of 168- 984 mg/L. The total hardness (range 60- 195 mg/L) values were comparatively higher in the water samples collected during the post-monsoon season. Phenol was below detection level in most of the samples but a few samples had phenol in the range of 0.08 – 0.61 mg/L, which were much above the EPA permissible limit.

Chloride (range 20.7– 85.2 mg/L), sulphate (range BDL – 48 mg/L) and nitrate (range BDL – 5.9 mg/L) were within the WHO permissible limits for drinking water. The values for fluoride were in the range of 0.8 - 1.67 mg/L and some of the sources had fluoride in excess of the WHO guideline value for drinking water quality. Most of the water samples had phosphate (range BDL – 0.7 mg/L) more than the USPHS limit (0.1 mg/L). Calcium (range 10.4 – 43.9 mg/L), magnesium (8.74 – 25.38 mg/L), sodium (range 5.8 – 60.8 mg/L) and potassium (range 2.2 – 12.8 mg/L) were found in the drinking water samples within the desirable limits. Among the metals, Al (range 1.85 – 9.60 mg/L), Cd (range 0.20 – 0.53 mg/L), Cr (range 0.21– 2.70 mg/L), Fe (range 0.36 – 7.36 mg/L), Ni (range BDL – 0.5 mg/L) and Pb (range BDL – 0.72 mg/L) were measured in different ranges some of which were quite high. As (BDL – 0.008 μg/mg), Cu (0.001– 0.962 mg/L), Hg (BDL – 0.004 mg/L), Mn (0.07 – 0.96 mg/L) and Zn (0.08 – 1.32 mg/L) were within the permissible limits.

For the surface water samples, pH was from 3.4 – 8.0. EC (range 0.12- 3.01 cm/mS) and total alkalinity (range 61 – 1250 mg/L) contents were high in the surface water. Total hardness was within the range of 60.0 – 221.0 mg/L whereas substantial amounts of total solids (range 530 – 8340 mg/L) and total dissolved solids (range 260 – 3380 mg/L) were available in the surface water. Chloride (range 17.8 – 326.6 mg/L) , fluoride (range 0.2 – 6.9 mg/L), sulphate (range 18.0 – 203.0 mg/L) and phosphate (range BDL – 1.6 mg/L) were also found to be high in the study. Substantial amounts of phenol (range BDL – 1.8 mg/L) and oil and grease (range BDL – 333.89 mg/L) in the surface water of the area gave a clear indication of the industrial effluent having definite impact on the surface water quality.

The presence of nitrate (range BDL – 9.0 mg/L), Ca (range 12.0 – 72.0 mg/L), Mg (range 3.0 – 29.0 mg/L) and K (range 2.0 – 24.4 mg/L) was not considerably high. Na content was within the range of 10.7 – 288.5 mg/L. The ranges of values for other metals present in the surface water were Al: 4.7 – 71.4 mg/L, As: BDL – 0.0018 μg/mg, Cd: 0.01 – 0.32 mg/L, Cr: 0.02 – 1.98 mg/L, Cu: 0.021 – 2.13 mg/L, Fe: 0.5 – 13.5 mg/L, Hg:

BDL – 0.045 mg/L, Mn: 0.05 – 9.07 mg/L, Ni: BDL – 3.9 mg/L, Pb: BDL – 0.23 mg/L, Zn: 0.1 – 4.21 mg/L.

In the rice grains, no As and Hg could be detected. However, the grains contained other metals in the ranges of Al: 30.23 – 110.5 mg/kg, Cd: 0.67 – 1.66 mg/kg, Cr: 1.4 – 2.4 mg/kg, Cu: 4.3 – 10.2 mg/kg, Fe: 36.0 – 59.0 mg/kg, Mn: 38.1 – 60.0 mg/kg, Ni: 0.93 – 3.1 mg/kg, Pb: 1.6 – 8.82 mg/kg, Zn: 18.77 – 61.6 mg/kg. The rice husks were found to contain more of the different metals than the rice grains from the study area a few exceptions.

The results have been discussed with reference to similar works of other workers and the variation as well as the distribution patterns for various parameters was presented in details.

Chapter 4 (Conclusion) gives a summary of the results and the conclusions drawn on the basis of the investigation about the impacts of the Textile Mill on the quality of soil and water in the study area. Suggestions for further work have also been formulated.

The thesis concludes with a complete list of References consulted during the present work for discussing the results.

CHAPTER 1

INTRODUCTION

1.1 Soil: its definition

As early as 5000 B.C., the Vedas and the Upanishads as well as other ancient Indian scriptures mentioned soil as synonymous with land – the Mother- supporting and nourishing all life on earth. Soil is the natural covering of most of the earth's land surface. It is the part where plants grow, ice lands, lava flows, dune moves, rock mountain stands. Soils are used to grow most of the world's food and much of its fiber. To the farmer, soil is that portion of the earth's surface which he can plough and grow crops on to provide him with food and fiber for his own needs and that of his animals. A poor man uses soil for his mud house and a rich man uses it for making bricks, which is used as a building material. Everybody uses soil as his/her source of 'Energy'-physical and mental – in this world.

As soil is a complex heterogeneous system, it is very difficult to define it. It is probably worthwhile therefore to quote the definition of soil given by Joffe (1949) who stated:

"The soil is a natural body of mineral and organic constituents, differentiated into horizons of variable depth, which differs from the material below in morphology, physical makeup, chemical properties and composition and biological characteristics".

The limitations of this definition lie in the fact that in many cases soil horizons may be absent and the material below may be hard to find.

1.2 Soil composition

Soil is composed of partly weathered, unweathered and transformed products of rocks and rock minerals, and organic matter. The soil particles are present partly as individual and partly as aggregates or pads. The organic matter is often firmly combined with mineral particles forming aggregates, which are of various sizes and shapes just as the pores.

Soil is normally considered as a three-phase system - solid, liquid and gaseous, the liquid and gaseous matter occluded in the pores. When completely dry or frozen, soil becomes a two-phase system, the liquid phase being either absent or a part of the solid phase, but the soil pores will still contain some gaseous matter.

The solid phase is composed of (a) inorganic and (b) organic constituents. Soils having more than 20% of organic constituents are arbitrarily designated as organic soils. When inorganic constituents dominate, they are called mineral soils.

The Inorganic Fraction

The inorganic constituents, forming the bulk of the solid phase of soil, consist of silicates both of primary and secondary origin having a definite chemical composition and a well-defined crystalline structure. Soil may also contain a certain proportion of carbonates, soluble salts and free oxides of iron, aluminium and silicon in addition to some amorphous silicates.

Primary minerals found in rocks are the original source of all primary minerals found in soils. The most abundant minerals are quartz and feldspars with relatively small proportions of pyroxenes, amphiboles, olivines, micas, etc. The primary minerals in soil are mostly concentrated in the coarse fraction.

Under conditions of weathering, the primary minerals are broken down to small fragments and even to molecular species such as silica, alumina, iron oxide, etc., the latter are capable of being synthesized into structurally different silicates, which are called the secondary minerals. Soil clay fraction with particle size 0.002 mm is called the clay fraction, which possesses colloidal properties. Secondary minerals are dominant in the majority of soil clay, which are aluminosilicates in chemical composition and have crystalline structure.

The Organic Fraction

Only a small fraction of the solid phase is of organic origin. The sources of organic constituents are plants and animals. Billions of organisms, macro and micro in nature, thrive on the debris of animals and plants and other organic residues of soil and themselves add to the soil organic matter when these organisms die. Chains of biological activity start in which new organisms take over the work from old ones. In the process of microbial decomposition of organic materials, most of them are fully decomposed but a small part is transformed into new products, which get thoroughly mixed up with the soil, and becomes an ingredient of it called soil humus. The humus and humus like fractions of the solid phase constitute the soil organic matter.

The Soil Pores

Almost half of the bulk volume of soil is generally occupied by voids or soil pores. These pores may be completely or partially filled with water. Some of the water gets adsorbed and stored in the pores and the rest returns to the atmosphere by evaporation or by transpiration through plants.

The air filled pores constitutes the gaseous phase of the soil system. The volume of the gaseous phase is thus dependent on that of the liquid phase. The sum of the volumes of the liquid and gaseous phases remains constant for a particular soil. The gaseous phase supplies oxygen for root respiration, which finally liberates carbon dioxide. This phase exchange between soil air and atmospheric air ensures fresh supply of oxygen and thereby prevents carbon dioxide toxicity.

The three phases of the soil system have definite roles to play. The solid phase provides mechanical support and nutrients to the plants. The liquid phase supplies water and along with it, dissolved nutrients to plant roots. The aeration need of plants is satisfied by the gaseous phase. The soil's responsibility to sustain plant growth is thus shared complementarily by its three phases.

1.3 Soil Contamination

Since soil is a very specific component of the biosphere, it is not only a geochemical sink for contaminants but also acts as a natural buffer controlling the transport of chemical elements and substances to the atmosphere, hydrosphere and biota. 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). Their continuous use on agricultural land may results in metal accumulation in surface soil (Gupta *et al.*, 1986). Some heavy metals are essential in 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 ecosystems may lead to an excessive accumulation of metals, becoming toxic to plants and possible danger to human health problem.

Trace elements originating from various sources may finally reach the surface soil and their fate depends on soil chemical and physical properties. Metals accumulated in soils are depleted slowly by leaching, plant uptake, erosion or deflation. Soil is generally contaminated by industrial wastes and effluents, domestic and municipal wastes and also by vehicular traffic. Long distance aerial transport of volatile compounds (e.g. As, Hg, Se, Sb, etc.) may pollute soil. In this case it is very difficult to estimate the background values for some trace elements in soils. Fertilizers, pesticides and sewage material add to the pool of soil contaminant. Effects of sewage sludge application and free application of effluents on soil are especially of great environmental concern and have been the subject of many studies and much legislation.

1.4 Water

Water is the liquid of life. It is now well established that life first came into existence in an aquatic environment. The role of water in the origin of life is projected from its importance in organic world where water is an essential medium and an ingredient of biological reaction. The chemistry of water is influenced by the inputs of minerals, their solubility and the chemical equilibrium prevailing in the aqueous solution. Thus, in spite of abundant availability of water resources, high standards of life together with poor maintenance and improper drainage system have affected water quality, which has direct impact on human health, particularly due to the toxic and harmful contaminants present in water. Water quality can also have a great influence on the ability of aquatic plants and animals in a stream, pond or lake to sustain growth (Swaranlatha,N and Narsing Rao, 1997). The geology of a particular area has a great influence on the occurrence and quality of water and its movement. Many a times, ground water carries a higher mineral content than the surface water when there is slow circulation and longer period of contact. Changes in the ground water quality with the passage of time have hydrologic significances. The quality also varies due to a change in chemical composition of soil formulations over which the water flows (Rajmohan et al., 2003).

An adequate supply of wholesome water is the foundation of the health of any community. The quality of water resources usually depends on its physical, chemical and biological characteristics. The normal ranges of these characteristics serve as the benchmark for good water quality and determine suitability or otherwise for its use in drinking and all kinds of domestic activities (Sharma, 2001).

Globally, ground water constitutes one third of the drinking water and it is important that it remains free from all kinds of pollutants. Although the surface water on land is the most easily accessible source of water for human needs including aquaculture, agriculture, and industries (Khabade and Mule, 2003), it is also the most polluted one. On the other hand, ground water has historically been considered as reliable and safe source of water protected from surface contamination by geological filters of soil layers that remove pollutants as water percolates through the same (Prasad and Bhagan, 2004). This is why ground water has been used for drinking purpose for a long time and its purity has made it a well-known source of potable water.

Still ground water is not absolutely free from the pollutants. The indifferent attitudes of the industries that discharge the effluents without any treatment have created the scarcity of good quality ground water. Various organic and inorganic pollutants have now been routinely measured in ground water (Moore and Moore 1976; Thayer, 1995; Dikshith, 1996).

The pollutants present in liquid effluents or solid wastes generated by human and industrial activities discharged either on land or in small watercourses leach out into the ground and then, enter ground water aquifers affecting their quality. A large amount of works (Sharma et al., 1999; Sharma et al., 2001; Hussain et al., 2001) have come to the conclusion that the ground water of an industrial area and its surroundings have poor quality due to impact of the industrial wastewater discharged on land either untreated or after improper treatment.

1.5 Contaminant uptake by Plants

Environmental pollution by metals has become extensive as mining and industrial activities increased in the late 19th and early 20th century. These pollutants, ultimately derived from a growing number of diverse anthropogenic sources (industrial effluents and wastes, urban runoff, sewage treatment plants, boating activities, agricultural fungicide runoff, domestic garbage dumps, and mining operations), have progressively affected more and more different ecosystems (Macfarlane and Burchett, 2001). Metal toxicity and tolerance in plants is a subject that has been broadly reviewed on several occasions over the last several years (Brown and Jones, 1975; Foy et al., 1978; Ernst et al., 1992; Das et al., 1997; Sanitá di Toppi and Gabrielli, 1999; Hall, 2002; Clemens et al., 2002).

Fifty-three of the ninety naturally occurring elements are heavy metals (Weast, 1984). Among these metals, Fe, Mo and Mn are important as micronutrients, while Zn, Ni, Cu, Co, V and Cr are toxic elements, with high or low importance as trace elements. Ag, As, Hg, Cd, Pb and Sb have no known function as nutrients and seem to be more or less toxic to plants and microorganisms (Niess, 1999). The presence of both essential and non-essential heavy metals in the atmosphere, soil and water, in excessive amounts, can cause serious problems to all organisms. Knowledge of metal-plant interactions is not only important for the safety of the environment, but is also necessary for reducing the risks associated with the introduction of trace metals into the food chain.

Heavy metals are found ubiquitously in both polluted and unpolluted soils Although these heavy metals occur naturally in the Earth's crust, they tend to be concentrated in agricultural soil because of irrational application of commercial fertilizers, manures and sewage sludge containing heavy metals and also due to contamination caused by mining and industry (Gimeno-García et al., 1996; Grant et al., 1998; McLaughlin et al., 1999). The current worldwide production of Cu, Cd, Pb, and Hg is considerable (Pinto et al., 2004). All heavy metals are toxic at higher concentrations (Marschner, 1995; McLaughlin et al., 1999) and thus, it has been a subject of extensive research in recent years (Archer et al., 2004) especially in the light of their accumulation and movement in soil and plants (Pueye et al., 2003; Kidd et al., 2004; McBride et al., 2004). Heavy metals are toxic to higher plants by causing oxidative stress, displacing other essential metals in plant pigments or enzymes, leading to disruption of function of these molecules and of many metabolic processes, and finally reducing growth and yield (Rulkens et al., 1998; Seregin and Ivanov, 2001; Verma and Dubey, 2001; Zhang et al., 2002; Wang et al., 2003). Moreover, toxic heavy metals enter the food chain due to uptake and accumulation by crops, posing a potential threat to human health (Jackson and Alloway, 1992; Brzóska and Moniuszko-Jakoniuk, 2001; Sponza and Karaoğlu, 2002). Among these metals, cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb) are commonly considered as toxic to both plants and humans. For instance, in Japan, Cd contamination of rice led to renal impairment and bone disease in an exposed population. It is necessary to decrease toxic heavy metal accumulation in cereals for food production, particularly in rice, which is one of the most frequently, consumed cereals worldwide.

Heavy metal accumulation in crops is a function of complex interaction among soil, plant and environmental factors. It has been well documented that the contents of these metals in crop plants are closely associated with their levels in soil. Moreover, the uptake and accumulation of heavy metals by plants are largely dependent on the 'available' rather than 'total level' of a metal in soil (Dudka et al., 1996; Garrett et al., 1998; Norvell et al., 2000; Moral et al., 2002). The uptake of some heavy metals varies greatly among plant species (Sarić, 1983). In rice, a wide difference exists among genotypes in their ability to accumulate Cd in grains (Morishita et al., 1987; Arao and Ae, 2003; Liu et al., 2003), indicating the potential possibility of reducing grain Cd accumulation by means of genetic improvement. Breeding for low Cd accumulating cultivars has been undertaken in sunflower and durum wheat (Penner et al., 1995; Li et al., 1997). Meanwhile, environmental factors which may alter the availability of heavy metals in soil and the metabolic pattern of crop plants, are also the cause of variation of heavy metal accumulation in crops (Garrett et al., 1998; Norvell et al., 2000; Moral et al., 2002; Nan et al., 2002; Wu et al., 2002).Thus in moderately contaminated soils, heavy metal accumulation in crops could be reduced by using alternative cultivars with lower accumulation or by improving agronomic practices, such as water and fertilizer management, which lower the availability of heavy metals in the rhizosphere (McLaughlin et al., 1999; Melamed et al., 2003). These practices will depend on understanding genetic and environmental variation in heavy metal concentrations of crops.

However, little is known about genotypic and environmental variation in toxic heavy metals, including Cd, Cr, Ni, Pb and As. The sensitivity of plants to heavy metals depends on an interrelated network of physiological and molecular mechanisms that includes uptake and accumulation of metals through binding to extracellular exudates and cell wall, complexation of ions inside the cell by various substances, for example, organic acids, amino acids, ferritins, phytochelatins, and metallothioneins; general biochemical stress defense responses such as the induction of *antioxidative enzymes and* activation or modification of plant metabolism to allow adequate functioning of metabolic pathways and rapid repair of damaged cell structures (Verkleij and Schat, 1990; Prasad, 1999; Sanita di Toppi and Gabrielli, 1999; Hall, 2002; Cho et al., 2003).

1.6 Heavy metal toxicity

The toxicity produced by heavy metals generally involves neurotoxicity, hepatotoxicity and nephrotoxicity . Differences in solubility, absorbability, transport and chemical reactivity in these metals will lead to specific differences in toxicity within the body (Stohs and Bagchi, 1995). The chemical form of heavy metals in soil solution is dependant on the metal concerned, pH and the presence of other ions (Das et al., 1997). The toxicity symptoms observed in plants in the presence of excessive amounts of heavy metals may be due to a range of interactions at the cellular level (Hall, 2002). Toxicity may result from the binding of metals to sulphydryl groups in proteins, leading to an inhibition of activity or disruption of structure (Van Assche and Clijters, 1990).

Enzymes are one of the main targets of heavy metal ions and prolonged exposure of soils to heavy metals results in marked decreases in soil enzyme activity (Tyler et al., 1989). Metal interaction with ligand groups of enzymes largely defines their toxicity, and the inhibition of enzymes may be due to masking of catalytically active groups or protein denaturation (Das et al., 1997). In addition, excess heavy metal concentration may stimulate the formation of free radicals and reactive oxygen species (Gallego et al., 1996; Dietz et al., 1999; Groppa et al., 2001; Sandalio et al., 2001; Fornazier et al., 2002). In order to cope with highly toxic metals, or to maintain the level of essential metals within physiological ranges, plants have evolved *complex* mechanisms that serve to control the uptake, accumulation and detoxification of metals.

1.7 Textile Industry and the environmental issues

The colored drawings on the walls on the Altamira cave in Spain are dated at 15,000–9000 before Christ. The drawings were performed with inorganic pigments, which can last a very long time. Dyed clothes have been produced in all cultures since a very long time ago but the durability of these products is limited. Thus, very old samples of dyed textiles are rare, e.g., dyed textile material from Egypt could be dated to 3200 BC, and in India dyed textiles were dated at 2000 BC.

Depending on the climate, various plants serve as sources for natural dyes, e.g., indigo plant, madder, barberry etc. (Schweppe, 1992). Up to the end of the nineteenth century natural dyes were the main colorants available for textile dyeing procedures. The development of synthetic dyes at the beginning of the twentieth century has led to improvement in quality and more reproducible techniques of application. As a result, a distinct lowering in the dyestuff costs per kg of dyed goods has been achieved (Taylor, 1986). The predominance of synthetic dyes has hindered a continuous development and adaptation of natural dyeing to the changing requirements of modern dye houses. As a result, a considerable gap now exists, separating the knowledge about natural dyes from the demands of commercial dyeing processes.

Dyes are an abundant class of coloured organic compounds that present an increasing environmental danger. Many dyes are difficult to decolourise due to their complex structure and synthetic origin. There are many structural varieties, such as, acidic, basic, disperse, azo, diazo, anthroquinone based and metal complex dyes.

Synthetic dyestuffs are extensively used in textile, paper, printing industries and dye houses. The textile industry utilizes about 10,000 different dyes and pigments in the world (Spadaro et al., 1994) The chemical reagents used are very diverse in chemical composition, ranging from inorganic compounds to polymers and organic products (Mishra and Tripathy, 1993; Banat et al., 1996; Juang et al., 1996). Colored effluents have been produced, most certainly, since the dyeing technique was invented. Through hundreds of years, obviously, the scale of production and the nature of dyes changed drastically, consequently having a more and more negative impact in nature (Waters, 1995). Recent estimates indicate that, approximately 12% of synthetic textile dyes used each year are lost during manufacture and processing operations and that 20% of these lost dyes enter the environment through effluents that result from the treatment of residual industrial waters (Weber and Stickney, 1993).

It is therefore necessary for dye-containing effluents to be treated in an effective manner before being discharged into natural waterways. Although the dyes may have been effectively removed, industries still face the problem of the disposal of this concentrated sludge (Robinson et al., 2001). Due to increasing awareness of dyestuffs contamination to the soils, the dye manufacturing and textile processing industries have been forced to change their working culture in effluent discharge and disposal of waste by (a) reduction of the volume and toxicity of discharges, (b) adoption of alternative processing methods and chemicals and (c) recycling and reuse of water, chemicals and colourants (Lomass, 1983).

The most pressing environmental problem facing the textile industry is related to reactive dyes (Lin and Lin, 1993; Zissi and Lyberatos, 1996; Beydilliet et al., 1998). Reactive dyes are, commercially, a very important class of textile dyes, whose losses through processing are particularly significant and difficult to treat. Thus, in the case of cellulose fibers dyed with these dyes, nearly 50% may be lost to the effluent (Easton, 1995). These dyes, that didn't react with the fiber and are in a hydrolysed state (Cooper, 1993), encounter themselves in a different and irretrievable form in the resulting effluent.

The textile industry produces large quantities of highly coloured effluents, which are generally toxic and resistant to destruction by biological treatment methods. Textile wastewater, being mostly non-biodegradable under both natural and sewage treatment plant conditions, is a potential nuisance to the environment. Textile wastewaters contain a wide range of non-polar and polar compounds, but polar ones are predominant. They comprise substances, which are used as auxiliary products in textile production and treatment and are washed out of the textiles having run off with the wastewater. These polar organic pollutants in textile wastewater may give rise to problems due to the fact that they are non-biodegradable and their elimination is incomplete. Moreover, some of the contaminants have a toxic effect on the bacteria applied for wastewater purification.

In the case of textile industry, the more complex environmental problems associated with the effluents are due to extensive use of carcinogenic or mutagenic azo dyes which are resistant to microbial degradation (Chao and Lee, 1994). Most dyes have a low toxicity (Chung, 1983) but their components and breakdown products can be more toxic. Dyes discharged from textile dyeing and finishing processes are a priority pollutant for the Regulating Authorities and Water Utilities because of their visibility at low concentrations (Easton, 1995). Ineffective colour removal is obvious and causes complaints (Brown et.al.1998). Direct discharge of these effluents causes formation of toxic carcinogenic aromatic amines under anaerobic/anoxic conditions in receiving media (Weber and Adams, 1995).

Inefficient dyeing of textiles has resulted in large amounts of the dyestuff being lost directly into wastewater and consequently having a detrimental effect on flora and fauna. The presence of low concentrations of dyes in effluent is highly visible and undesirable, reducing light penetration and potentially inhibiting photosynthesis (Mishra and Tripathy, 1993; McMullan et al., 2001). In the past, municipal treatment systems were used for the purification of textile dye effluent, but due to the xenobiotic and recalcitrant nature of many dyes, the treatment was found to be ineffective. The same is true when dyes are released into aquatic systems—anaerobic bacteria in the sediment are unable to mineralize dyes completely resulting in the formation of toxic amines (Banat et al., 1996; Nigam et al., 2000). Wastewater is the principal route by which dyestuffs also enter the soil environment (Elliot, 1996).

Textile industries, particularly those involved in finishing processes are major water consumers and the source of considerable pollution. The environmental challenge for the textile industry is associated with liquid waste, which tends to dominate over air-emissions and solid wastes in terms of the severity of environmental impacts. A typical textile unit generates various types of wastewater differing in magnitude and quality. Typically, textile wastewaters consist of a variety of waste streams from different operations. The wastewater from printing and dyeing units in a textile plant are often rich in color, containing residual of reactive dyes and chemicals, and needs proper treatment before releasing into the environment. Since synthetic dyestuffs are resistant to biological degradation, colour removal by bioprocessing is difficult.

Effluent from textile industry when discharged on open land affects the soil and water quality in many ways. Colour removal from effluents of textile dyeing and finishing industry is becoming important because of aesthetic as well as environmental concerns (Balcioglu and Arslan, 2001). The efficient removal of dyes from textile industry effluents is still a major environmental challenge. Some dyestuffs are highly structured polymers and are very difficult to decompose. Currently, various chemical, physical and biological treatment methods are used to remove color. Because of the high cost and disposal problems, many of these methods for treating dye wastewater have not been widely applied in the textile industries. A literature survey shows that research has been and continues to be conducted in the areas of chemical and combined chemical–biological treatments in order to improve the biodegradation of dyestuffs and minimize the sludge production. Many of the dyes are carcinogenic, mutagenic and detrimental to the environment. As toxicity standards become more stringent, the development of new techniques for minimizing the concentration of dyes and their breakdown products in the wastewater also becomes necessary. Although some existing technologies may have certain efficiency in the removal of reactive dyes, their initial and operational costs are so great, that they constitute an inhibition to dyeing and finishing industries. On the other hand, low cost technologies don't allow a wishful color removal or have certain disadvantages, needing to be integrated into a more complex and complete treatment plan, such as a combination of biological, chemical and physical procedures (Yeh et al., 1993). Hence, research has been directed to other non-conventional materials and procedures of color removal that will combine effectiveness with cheapness (Laszlo, 1994).

In the absence of any specific government regulations on the eventual disposal of these dyes, the problem remains as the main environmental problem related to textile activities. Since some regulations have been introduced to control the disposal of dyestuffs, mainly because of their high polluting potential, the development of alternative treatment methods will become important (Nasr et al., 1997). There is no universally useful method available for treatment of dye wastes, probably because of the complex and very varied chemical structures of these compounds (Peralta-Zamora et al., 1998). Protection of human health and the environment is now perceived as more important than the profitability and efficiency of a business.

1.8 Objectives of the present work

The present work was designed to evaluate the impact of a textile mill at Rangia (District Kamrup, Assam) on quality of soil and water in the surrounding areas. The principal objectives were:

(i) To monitor the quality of soil, particularly from the area receiving the Mill effluent, with respect to important physico-chemical properties, and compare the same with that of unpolluted or 'Control' soil from no-impact zone.

(ii) To study the quality of water that keeps the agricultural land near the textile mill in a submerged condition.

(iii) To study the quality of water from different sources (pond, dug well, tube well) in the impact zone to find out if there is any infiltration of the textile mill effluent.

(iv) To investigate if the rice grain and husk have accumulated a few heavy metals that is found in the Mill effluent.

CHAPTER 2

THE STUDY AREA AND METHODOLOGY

Rapid growth of population has multiplied human needs several fold resulting in a fast pace of industrialization and urbanization. To fulfill human requirements, new technologies have been evolved to increase production. In the process of human civilization, the use of cloth itself was a definite stage. With the passage of time cloth became a basic need. In ancient times, this need was fulfilled by cottage industry but with the growth of population and advancement in technology, hand woven cloth gave way to the machine-made cloth in the large number of textile mills. Consumer demand for textile products is ever increasing in domestic as well as in international market resulting in setting up of more and more textile processing industries. Not going far back in the history of textile industry in India, the East India Company started its business by cotton industry (Hussain et al., 2004). Textile industry is one of the largest and oldest organized sectors in India and is also at the same time extremely complex (Dutta, 1994). Usually, 6-7 liters of water are used for producing one meter of cloth (ISI, 1980) and consequently, a very large volume of effluent consisting of a large amount of dyes, pigments and other chemicals is discharged to the environment.

The present work was aimed at evaluating the impact of a textile mill at Rangia (District Kamrup, Assam) on quality of soil and water in the surrounding areas. The textile unit is operating for the last eighteen years. However, no study has been reported on the impact of the continuous operation of the mill on the quality of soil and water of the area.

2.1 Rangia town: Important features

Rangia town (26^0 28′ 11″N, $91^0$37′ 47″E) is the nerve center of the Rangia Civil Sub-Division, the only Sub-Division in the Kamrup (rural) district, situated at a distance of about 60 km from Guwahati ($26^0$11' N, $91^0$47' E). The river Borolia flows through the town. The geographical location of Rangia is shown in Figs. 2.1 and 2.2.

The total population of the town is 26,674 (as of March, 2007; Source-Rangia Municipal Board) distributed in ten municipal wards. The demographic profile of the town reflects a mixed pattern of population, including Hindus and Muslims in almost equal percentage, together with a sizeable Bodo population.

The National Highway No. 31 runs through the town and Rangia is an important Railway junction of the N. F. Railway. These have contributed in a big way towards the overall development of the township in general and communication network in particular. The International Route to Bhutan runs through the town, which is better known as the Rangia-Darranga Road.

In the academic scenario, there are five colleges, three Higher Secondary schools, ten High Schools and nine Lower Primary Schools operating within the town towards fulfilling the academic needs of the student community.

The industrial activity within the town is not very noticeable. There are nine SSI units within the town, which manufacture steel trunks and 'kerahi'. Three stone crusher units are also operating at the outskirts of the township. Two big rice mills are there. In both sides of the Rangia-Darranga road, adjacent to the town, seven brick industries produce large quantities of bricks. Just on the side of the Rangia-Darranga Road, is situated the APOL Mill at a distance of 8 km from Rangia town. In recent times, one industrial park has been established by the state government at a distance of about 6 km from the town on Rangia-Guwahati road (NH 31) and it is expected that this will help in expansion of industrial activities in Rangia. Another contributing factor in this direction is the 'Gram Swaraj Parishad, Rangia'. In close cooperation with Khadi and Village Industries Department, Government of India, this institution has contributed a lot towards generation of employment and motivation for self-employment amongst the enterprising new generation in and around Rangia.

In Rangia town, Government water supply scheme is yet to build up (either by Municipal Board or the State Public Health Engineering department). But in some of the surrounding villages, Public Health Engineering department has installed water supply scheme through deep tube wells but the covering area is very small. The most common source of drinking water for the residents in and around Rangia town is tube-well water. In some public institutions like temples, deep dug-well is also seen as source of drinking water. People find it easier to collect water from such a dug well as only a bucket and a 50-60 feet rope are required and usually no maintenance is called for.

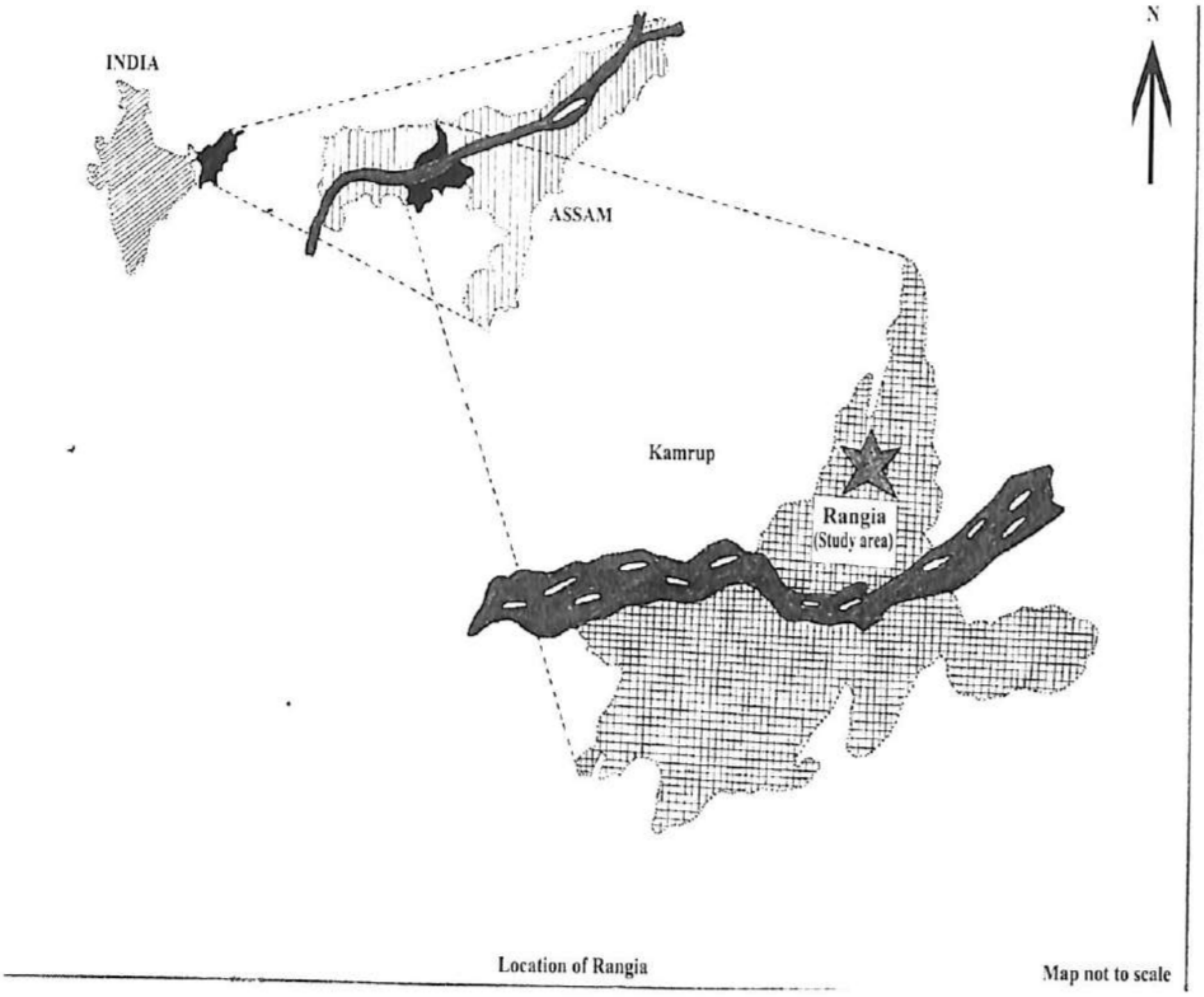


Fig. 2.1. Geographical location of Rangia vis-à-vis its position in the map of India

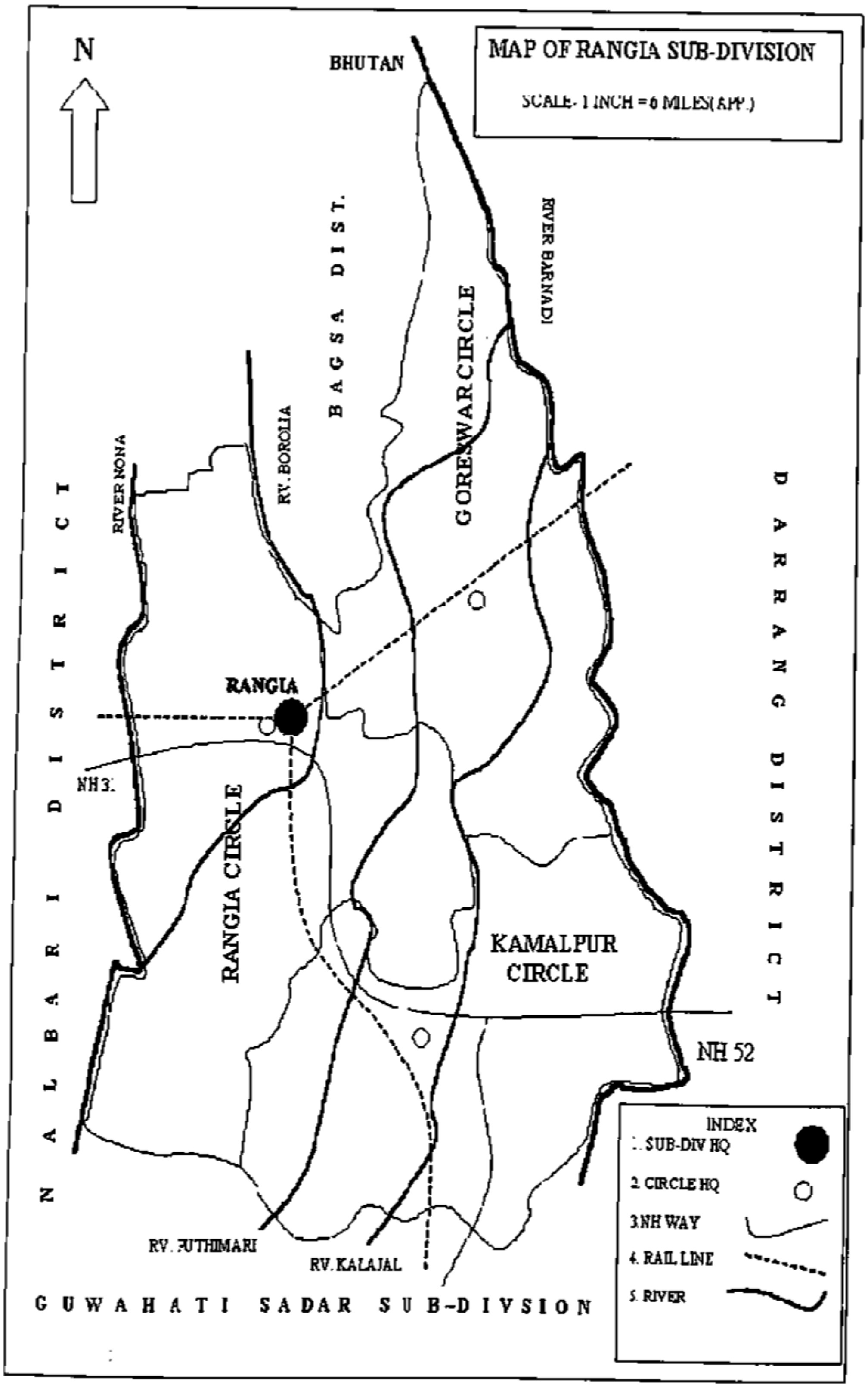


Fig. 2.2. Location of the study area (Rangia) along with the physical features.

Normally the ground water level for domestic tube wells is found at a depth of 20 to 30 m. Irrespective of the sources, the quality of water for the purpose of ordinary domestic use is not good. On storing for an hour or so, the water gets reddish because of the presence of high iron content which is considered by the people as the main problem. Moreover, the high iron content gives a bad taste. The people use water filters made of sand-stone-charcoal to get rid of excessive iron. High iron content gives a visible tinge to water of open tanks.

As far as water-borne diseases are concerned, according to Sub-Divisional Medical and Health office, Rangia, no specific outbreaks have been recorded as yet. But common health problems that occur due to use of unsafe water are quite prevalent like any other place of the state. Such problems are more numerous during the summer season as people require more water intake during these days.

2.2 The Textile Mill

APOL (Assam Polyester Co-operative Society Limited) is Assam's only textile mill near Rangia town in the district of Kamrup, Assam, just 50 kilometers north of Guwahati (26.11W, 91.47E). This unit was officially opened in June 1988 and started commercial production of spinning yarn of 5000 kg/day from November 1988 and weaving and processing from November 1991. The installed capacity of weaving unit was 8000 m/day and that of the processing unit was 20,000 m/day. The mill is producing yarn and cloths, especially viscose, polyester and acrylic fibre. In addition to this, to meet the growing demand of the local weavers, it has started manufacturing polyester mixed cotton yarn of variety of shades, blended with 'Eri' and 'Muga' yarn. The mill has its own dyeing unit with a capacity of 1500-2000 kg/day.

The raw materials required for the mill are bought from different parts of the country. The mill is using three types of fibers for spinning and weaving purpose. These are polyester, viscose and acrylic. Depending upon the types of fabric, the fibers are mixed in different proportions. The Bongaigaon Refinery and Petrochemical Limited (BRPL) supplies polyester whereas the other fibers- viscose and acrylic are taken from Nagda of Madhya Pradesh and Kolkata respectively.

The entire unit is covering an area 38.02 acres (125 bigha) of agricultural land. The Rangia-Bhutan road just passes through the eastern side of the mill. The northern and southern boundaries are covered by scattered residential accommodation while the vast western side is open agricultural land. The effluent of the mill is released through this agricultural land. There is a historical earthen dam at a distance of about 125 meters from the boundary wall of the mill along the western direction. The King Baidyadev built it during the period of 1138-1145 and the dam is about 6.4 km long and 6-8 meter wide. This dam divides that area into two sides (A and B), the side A is between the Mill and the dam, and the side B from the dam and beyond. The side A experiences more effluent load in comparison to side B. Again from the boundary wall of the mill the whole area is sloping downwards towards the western side and a drain across the dam is connecting the vast area (B) to area (A). In the last few years, as reported by the local people, this vast area has gradually lost productivity for all types of crops. The people in the area complain of pigmented water entering their agricultural land. The grazing cattle also refuse to drink this water.

The Mill and its suburbs are shown in Plate 2.1.

2.3 Collection of samples

2.3.1 Sampling frequency

The soil and water samples were collected twice a year in the months of (i) April (pre-monsoon period, before the onset of the monsoon) and (ii) November (post-monsoon period, after all rains stop) for a three-year period.

2.3.2 Soil samples

The locations of the soil sampling sites are shown in Fig. 2.3. During the three-year period, 175 samples of soil were collected from the study area for analysis. The frequency of collection is shown in details in Table 2.1 (a and b).

During the post-monsoon season, soil samples could not be collected from the area between the mill and the earthen dam as the area was occupied by the brick kiln industry. 'Control' soil samples were collected from a place where the effluent from the mill is not likely to have any influence.

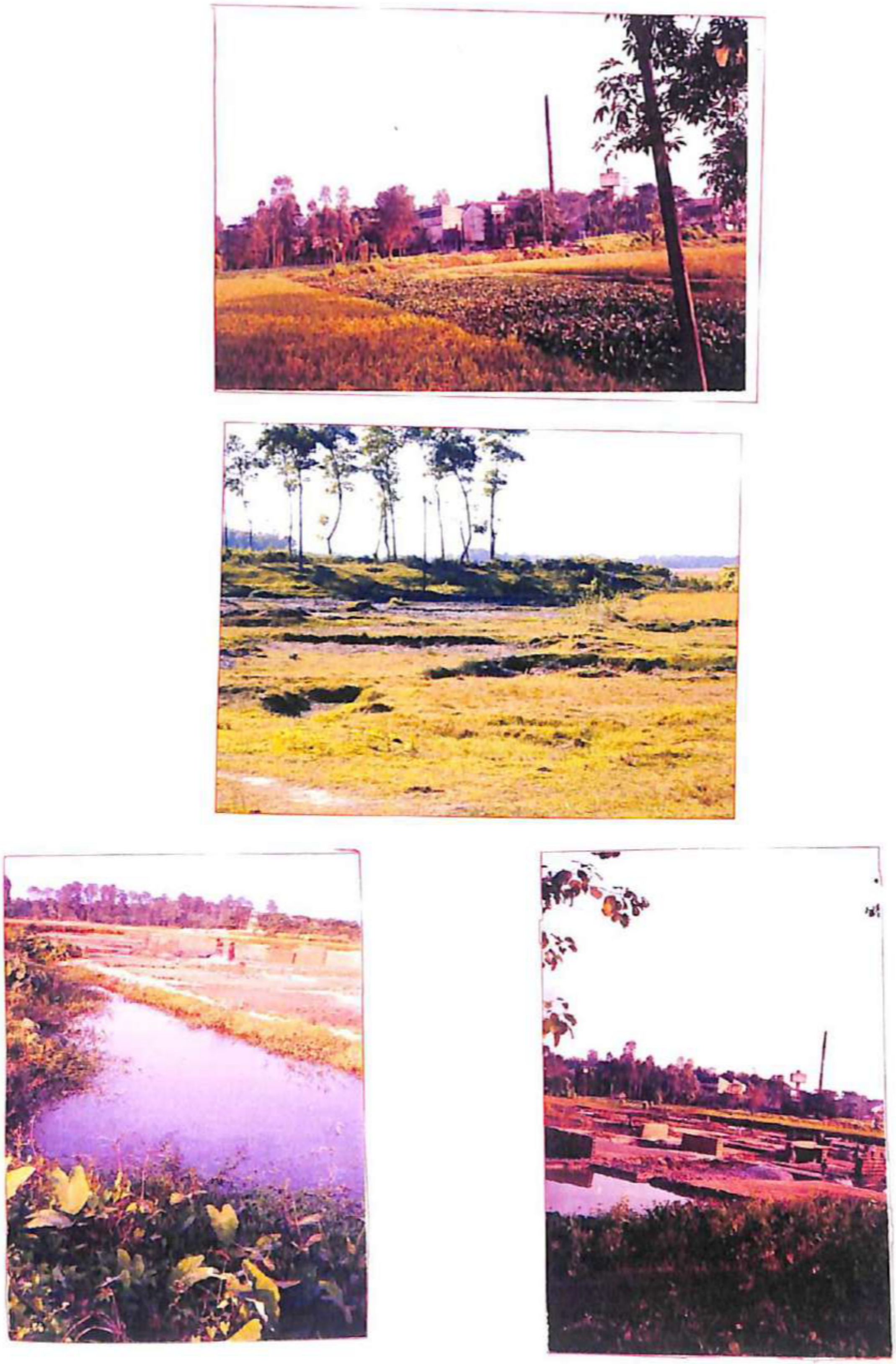


Plate 2.1. The Textile Mill and its surroundings – (i) the Mill from its rear (top), (ii) the earthen dam with the side A in front (middle), (iii) Brick manufacturing behind the Mill along with accumulated surface water (bottom, left and right).

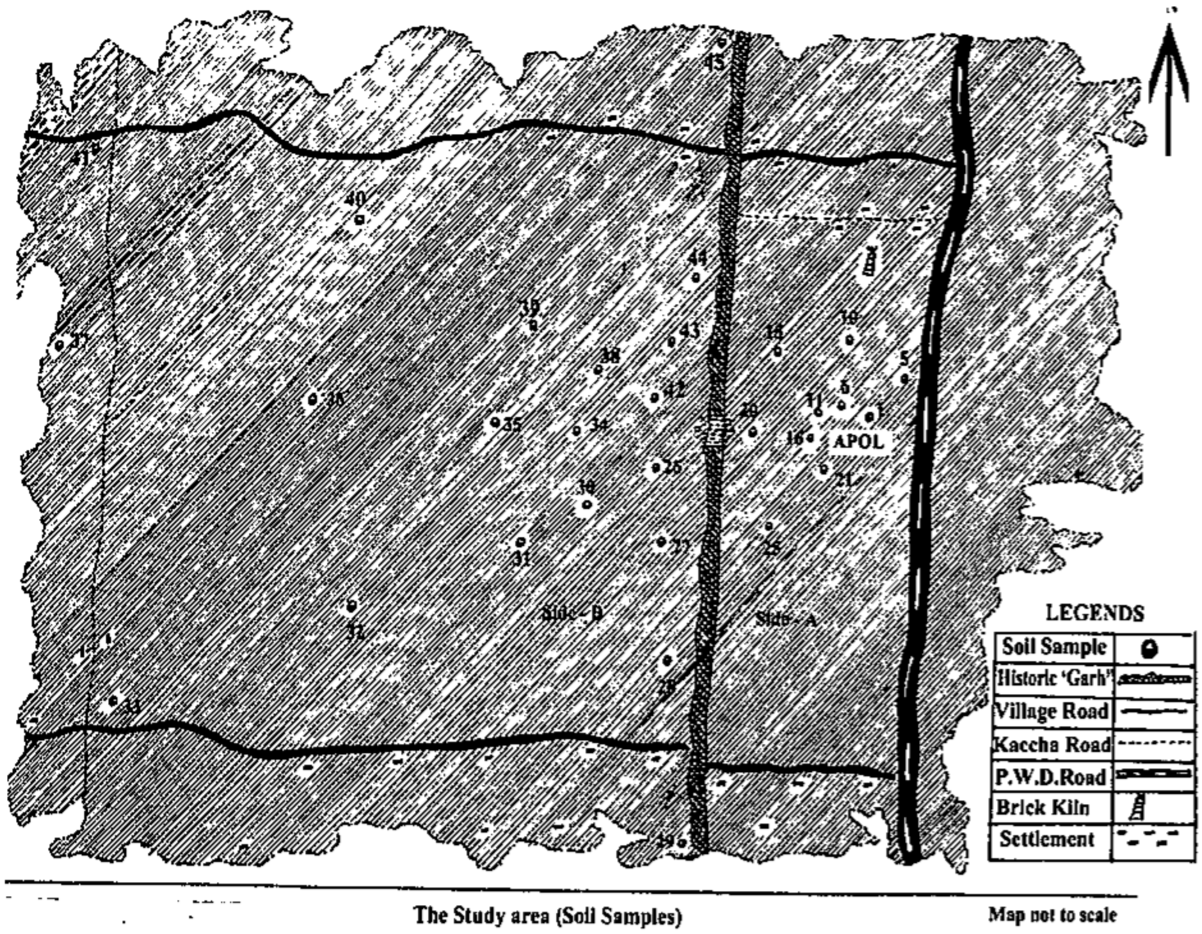


Fig. 2.3. Approximate locations of the soil sampling sites in the study area

Table 2.1a: Frequency of collection of soil samples (side A)

Direction	Distance from the Mill (m)														
	20	40	60	80	100	20	40	60	80	100	20	40	60	80	100
	First Pre-Monsoon					Second Pre-Monsoon					Third Pre-Monsoon				
NE	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
N	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
NW	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
W	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
SW	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Table 2.1b: Frequency of collection of soil samples (side B)

Direction	Distance from the Mill (m)											
	150	200	500	1000	150	200	500	1000	150	200	500	1000
	First Pre-Monsoon				Second Pre-Monsoon				Third Pre-Monsoon			
S					√	√	√	√	√	√	√	√
N					√	√	√	√	√	√	√	√
NW					√	√	√	√	√	√	√	√
W					√	√	√	√	√	√	√	√
SW					√	√	√	√	√	√	√	√

Direction	Distance from the Mill (m)											
	150	200	500	1000	150	200	500	1000	150	200	500	1000
	First Post-Monsoon				Second Post-Monsoon				Third Post-Monsoon			
S	√	√	√	√	√	√	√	√	√	√	√	√
N	√	√	√	√	√	√	√	√	√	√	√	√
NW	√	√	√	√	√	√	√	√	√	√	√	√
W	√	√	√	√	√	√	√	√	√	√	√	√
SW	√	√	√	√	√	√	√	√	√	√	√	√

2.3.3 Water samples

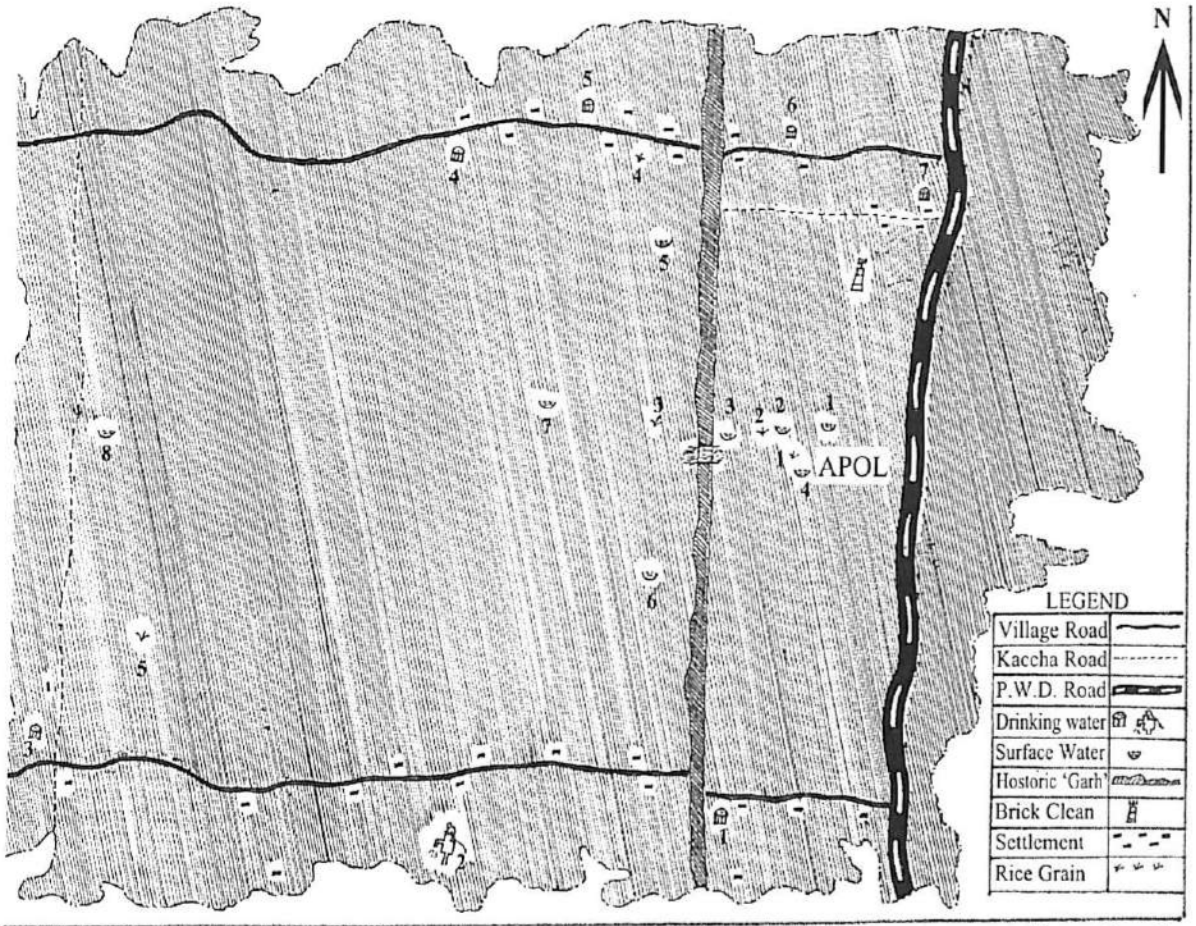
Drinking water samples were collected from 7 sites (one tube well and 6 dug wells, Fig. 2.4) scattered round the mill in five seasons (starting from the post-monsoon season of the first year to the post-monsoon season of the third year) as shown below:

S/N	Source	Distance from the mill
1	Dug well	About 1 km south
2	Tube well	About 1 km south west
3	Dug well	About 1 km south west
4	Dug well	About 1 km north west
5	Dug well	About 1 km north west
6	Dug well	About 1 km north
7	Dug well	About 500 m north

Like soil samples, 'Control" drinking water sample (tube well) was also collected from a far-off area where the effluent from the Mill was not likely to have any effect.

Surface water sample collection was done from 8 sites (4 from side A and 4 from side B) starting from the post-monsoon season of the first year to the pre-monsoon season of the third year. Altogether four sets of surface water samples (2 pre-monsoon, 2 post-monsoon) were collected as shown below:

S/N	Location
1	Surface water accumulation towards the north western boundary of the mill in Side A
2	Surface water accumulation towards the west of the Mill where the effluent is released in Side A
3	Water accumulated at the earthen dam crossing (about 120 m from the boundary wall of the Mill) in Side A
4	Artificial pond filled with effluent water located at the western corner of the boundary in Side A
5	Accumulated water at about 500 m away from the mill (along the earthen dam) in Side B in the northern direction
6	Accumulated water at about 500 m away from the mill (along the earthen dam) in Side B in the southern direction
7	Accumulated water at about 300 m away from the mill in the western direction in Side B
8	Accumulated water at about 800 m away from the mill in the western direction in Side B



The study area (Drinking water, surface water and rice grain) **Map not to scale**

Fig. 2.4. Approximate locations of the sampling sites for drinking water, surface water and rice paddy grains.

2.3.4 Rice grain samples

Rice seeds from 5 sites of the agricultural field in both side A and side B were collected only once during the post-monsoon, harvesting season in the third year along with a 'Control' sample from a field far away from the mill. One of the rice grain (R) samples was taken from close vicinity of the mill (R1) and the other four from distances of about 50 m (R2), 200 m (R3), 500 m (R4) and 1 km (R5) from the mill.

2.4 Selection of parameters for soil analysis and methodology for determination

The parameters selected for analysis along with the method of estimation followed in this work are described below:

2.4.1 pH

The acid-base characteristics of the soil samples can be ascertained from the soil pH. Solubility of various substances present in soil and the potency of toxicity of those substances can be known from its pH. The pH is a very important property of soil as it determines the availability of nutrients, microbial activity and physical condition of the soil. Acidity and alkalinity reflect both H^+ and OH^- ion concentration in soil.

The soil pH was determined by using digital pH-meter (Elico LI 120) in 1:5 soil/water suspension-using buffers for calibration.

2.4.2 Electrical Conductance

Cations and anions present in soil impart electrical conductivity when the soil is made into a suspension in water. Higher the concentration of ions in solution more is its electrical conductance.

Soil conductivity was determined by using a conductivity bridge (Elico CM 180) by using a conductivity cell of cell constant 1.0 in 1:5 soil/water suspensions.

2.4.3 Bulk Density

The soil bulk volume comprises of the soil solids and the pore spaces. The bulk density of soil is calculated for the dry soil and it is assumed that after drying, the soil volume does not change and the pore spaces remain intact.

The bulk density was determined in the laboratory in repacked cubes as per the procedure of Chopra and Konwar (1986) using the following formula for computation:

$$\text{Bulk Density, g/cm}^3 = (W2 - W1) / V \qquad (1)$$

where

W1 = Weight of the empty bottle

W2 = Weight of bottle packed with oven dry soil

V = Volume of the bottle, obtained by measuring the volume of water required to fill it completely

2.4.4 Water holding capacity

Water enters an agricultural or horticultural system as either precipitation from rain, hail, snow or dew or irrigation. Water is absorbed by the soil up to point when all the pores of the soil are full. At this point it has reached its storage capacity. Water, which is absorbed by soil because of its polar character, has not left the soil system through drainage or run-off and it is lost through a combination of evaporation from surface stored water and the soil surface and transpiration (evaporation of water from plant leaves). Together these processes are known as evapotranspiration.

Water holding capacity of the soil samples was determined by using circular stainless steel box of known weight (a). The perforated bottom plate of the box was supported on a Whatmann No.1 filter paper and approximately 10 g of the soil was added to the box and weighed (b). The box with the soil was kept dipped overnight with about one fourth of it under water in a Petri dish. After about 16 h, the box was removed from water and allowed to drain off the excess water. When no more water fell from the bottom of the box, it was weighed again (c). The weight of the moist filter paper supported in the box was also measured (m). The water holding capacity was calculated from the following expression :

$$\text{Water holding capacity, \%} = [c - (b + m) \times 100] / (b - a) \qquad (2)$$

2.4.5 Hydraulic Conductivity

Hydraulic conductivity is one of the hydraulic properties of the soil as well as soil's fluid retention characteristics. These properties determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition. . The saturated hydraulic conductivity is an essential parameter in the analysis and modeling of water flow and chemical transport in the soil (Iversen et. al. 2001).

The mathematical expression for the vertical water flow through soil is called Darcey's law. Darcey stated that the rate of flow increased with an increased depth of water above the soil through which it flowed. The flow decreased with an increased depth of soil. Each soil has different combination of pore sizes and the number of pores and each soil has a different flow rate constant, which is called hydraulic conductivity.

For hydraulic conductivity determination of soil sample, a soil core of 15.5 cm height was made inside an aluminium ring and the core was supported on a filter paper placed on a perforated aluminium plate. This arrangement was placed below a funnel clamped to a rack. Water was delivered to the soil core with an aspirator bottle maintaining a constant head of 2.5 cm above the core and water flowing down the core was collected in a beaker in intervals of 30 minutes. The hydraulic conductivity was calculated from the formula

$$\text{Hydraulic Conductivity } (K) \text{ cm/min} = QL / HAT \qquad (3)$$

where

Q = Quantity of water collected in cm3

A = Cross sectional area of the inside of the ring in cm2

L = length of the soil core in cm.

H = Total height of water column (core height + water head) in cm

T = Time of flow in minutes

2.4.6 Organic Matter (OM)

Soil organic matter greatly affects the biology of the soil because it provides the main food source for the community of heterotrophic soil organisms. The soil microbial biomass is a labile pool organic matter and comprises 1%–3% of total soil organic matter (Jenkinson and Ladd, 1981). Soil OM is the sum of different pools of soil OM, i.e., active and passive fractions. The active fractions include living biomass, some detritus, and non-humic matter; it comprises about 10-20 % of the total soil OM. Passive fractions include most of the humus physically protected in clay-humus complexes, most of the humin, and much of the humic acids; the passive fraction accounts for 60-90 % of the OM in most soils. The susceptibility of the active fraction to rapid changes explains why even relatively small changes in total soil OM can produce dramatic changes in important soil properties, such as aggregate stability and nitrogen mineralization, which are associated with this OM fraction. The role of OM in soil in relation to soil fertility and physical conditions is widely recognized (Stevenson, 1986; Johnson, 1986)

Walkey and Black method was used to determine the organic matter content in soil. 5 g of the air-dried soil sample was mixed with 10 ml of 1N $K_2Cr_2O_7$ solution and 20 ml of concentrated H_2SO_4 acid in a 500 ml conical flask. Solid Ag_2SO_4 was added to it by gentle stirring so that silver sulphate goes into solution completely. The contents were diluted to 200 ml by adding distilled water. The colour of the solution turned bluish purple on addition of 1 ml of phosphoric acid and 1 ml of diphenylamine indicator. The solution was titrated with ferrous ammonium sulphate till colour changes to brilliant green. The amount of organic carbon was calculated from the formula:

$$\text{Organic Carbon, \%} = [(x - y) / w] \times 0.003 \times 100 \qquad (4)$$

where

x = volume of $K_2Cr_2O_7$ solution

y = volume of ferrous ammonium sulphate required for titration

w = weight of soil sample

The total organic matter of the soil sample was then calculated from the values of organic carbon, obtained as above, using the formula:

$$\text{Organic matter \%} = \text{Organic Carbon \%} \times 1.724 \qquad (5)$$

2.4.7 Total Nitrogen

Of the total amount of nitrogen present in soil nearly 95-99 % is in the organic form and 1-5 % in the inorganic form as NH_4^+ and nitrate (NO_3^-) (Troch and Thompson 1993). Normally a plant contains N in the range of 0.2 – 4 % of dried plant tissue. Determination of total nitrogen in soil does not indicate how much amount of it present in soil available for plant intake. During growth and development, an average of only 0.5 – 2.5 % and sometimes rarely 5 %, of the total nitrogen is converted into forms accessible to the plant (Rao et al., 1997).

To determine nitrogen in soil, micro-Kjeldahl method (Jackson, 1967) was adopted. 10 g of soil sample in a 500 ml Kjeldahl flask was mixed with 25 ml of distilled water to make a suspension. The digestion catalyst mixture was prepared by mixing together 20 g $CuSO_4$, 3 g HgO, and 1 g selenium powder. 1 g of this mixture was mixed with 20 g sodium sulphate and was added to the suspension along with 35 ml of concentrated H_2SO_4 with gentle swirling motion. The content was heated at low heat for about 10-30 minutes until the frothing stops. The temperature was then raised rotating the flask after every few minutes interval for about two hours. The digested component was then cooled and the supernatant liquid was transferred to a 100 ml volumetric flask. The residue was washed several times with distilled water and after each washing, the supernatant liquid was transferred to the flask

25 ml of that solution was taken in a micro-Kjeldahl flask and 25 ml of 40 % NaOH was added, and then the mixture was distilled by heating. The distillate was collected in a 250 ml of conical flask containing 25 ml of 4 % boric acid and 5 ml of mixed indicator (the mixed indicator consisted of an alcoholic solution of 0.5 % bromocresol and 0.1 % methyl red in 2:1 ratio). About 100 ml of distillate was taken for titration with 0.1N HCl until the colour changes from blue to light pink. A blank titration was also run with distilled water using the other chemicals in same proportion.

Total nitrogen was calculated by using the formula

$$\text{Total N, \%} = [(a - b) / (v \times S)] \times N(HCl) \times 1.4 \times V \quad (6)$$

where

a = ml of HCl acid required for titrating sample solution
b = ml of HCl acid required for titrating blank
N = Normality of acid solution
V = ml of total solution after digestion (= 100ml)
v = ml of digested solution taken for distillation (= 25ml)
S = Weight of the soil taken (10g)

2.4.8 Available phosphorus

Phosphorus in soils ranges from 0.01 to 0.03 % and occurs in several forms and combinations (Gupta, 2000). The total amount of phosphorus present in soil is not available to the plants, only a small fraction of it may be available which is of direct relevance in assessing the phosphorus fertility levels. Available phosphorus means the inorganic form of phosphorus, exclusively orthophosphate, which occurs in several forms and combinations present in soil. Both inorganic and organic forms of phosphorus occur in soils, both are important to plants as sources of this element and the relative amounts in the two forms vary greatly from soil to soil (Zhang and Karathanasis, 1997). Phosphate is a good indicator for P-supply capacity of a soil.

Phosphorus in soil is generally determined as available phosphorus, which can be extracted from soil with 0.002 N H_2SO_4. After extraction, phosphorus was estimated spectrophotometrically by Dickman and Bray (1940) method.

10 g of air-dry soil sample was taken in a 500 ml conical flask and 200 ml of 0.002 N H_2SO_4 was added. The suspension was shaken for about half an hour and filtered through Whatman No. 50 filter paper to get a clear solution. 2 ml of ammonium molybdate solution and 5 drops of stannous chloride reagent were added to 50 ml of the extract and a blue colour developed. The intensity of the blue colour was measured by using spectrophotometer (Perkin Elmer UV visible Lambda EZ 201) at 690 nm. A

standard curve was prepared with standard potassium hydrogen orthophosphate solution in the range of 0.0 to 10 mg/L following the same procedure.

The available phosphorus was calculated from the relation:

$$\text{P, mg/kg} = (\text{mg P/dm}^3 \text{ in soil extract x V})/\ (\text{S x v}) \qquad (7)$$

where V = total volume of the soil extract prepared (200ml)
S = wt. of soil taken in gram
v = volume of the aliquot taken for analysis (50ml)

2.4.9 Soil Texture

The relative proportion of soil particles i.e. sand, clay and silt has profound effect upon the properties of soil including its water supplying power, rate of water intake, aeration, fertility, ease of tillage and susceptibility to erosion. Hydrometer method is used to estimate particle size distribution of soil as below

sand	2.0 to 0.05 mm diameter
silt	0.05 to 0.002 mm diameter
clay	< 0.002 mm diameter

40 g of air-dry soil was taken in a 500 ml conical flask to which 200 ml water was added followed by 8 ml 30 % H_2O_2 solution. The beaker, covered with a watch glass, was placed on a water bath at ~ 70.0 C to decompose organic matter. After 15 minutes, the flask was removed and allowed to cool. The above process was repeated three times and finally the beaker was put on the water bath again for two hours to remove the excess H_2O_2. The suspension was then transferred to a 1-litre cylinder and the volume was made up to 1 litre with distilled water. The mixture was agitated mechanically for one minute by a rubber stopper. After 4 minutes, the hydrometer reading was taken. The temperature of the suspension (t °C) was measured. The hydrometer was pre-calibrated. The suspension was kept undisturbed for 2 hours and hydrometer reading was taken again by dipping it in the suspension.

The sand, silt and clay percentages were then calculated from the following expressions:

$$\text{Sand \%} = 100 - P_4 \qquad (8)$$

$$\text{Silt \%} = P_4 - P_{120} \qquad (9)$$

$$\text{Clay \%} = P_{120} \qquad (10)$$

where

P_4 = $[(R_4 \pm r) \times 100] / W$

P_{120} = $[(R120 \pm r) \times 100] / W$

R_4 = hydrometer reading at 4 min

R_{120} = hydrometer reading at 120 min

r = temperature correction $= \pm (t - 67) \times 0.2$

W = oven dry wt. of soil sample

t = temperature in ^{0}C at the time of measurement.

2.4.10. Oil and grease

Many aerobic and anaerobic processes are always present in soil and constituents like oil and grease may interfere with these. Oil and grease also form a very thin film on soil that reduces permeability and water holding capacity. Oil and grease also forms a very thin film reduces permeability and water holding capacity of soil (Devi, 1996). Fat, oil, and grease have a high C/N ratio (90:1) and, if applied to agricultural soils, may affect the availability of N to crops, due to soil N immobilization during its decomposition (Rashid and Voroney, 2004)

For determination of oil and grease, 1g of soil sample was taken in a cellulose extraction thimble. The thimble was filled with glass wool. Extraction of oil and grease was then done in a Soxhlet apparatus, using petroleum ether at a rate of 20 cycles / h for eight hours. The solvent from the extraction flask was then removed from the flask and taken in a pre-weighed beaker. The beaker was placed in a water bath at very low flame.

After removal of the solvent, the beaker was kept in a desiccator for one hour and weighed again. Oil and grease of air-dried soil is given by;

$$\text{Oil and grease (mg/kg)} = [(\text{Wt gain by flask} \times 100) / \text{weight of soil taken}] \times 1000 \qquad (11)$$

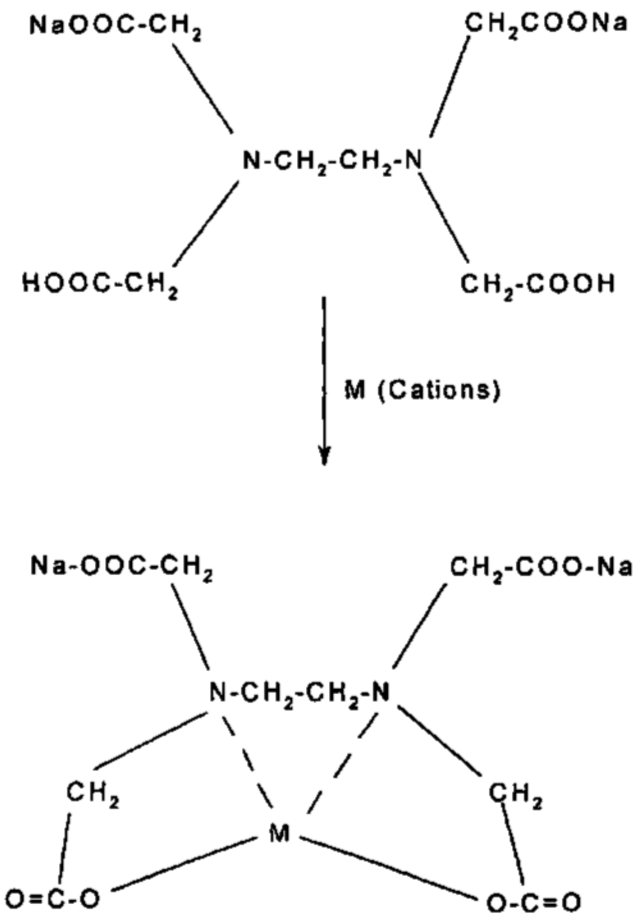
2.4.11. Exchangeable cations- Calcium, Magnesium, Sodium, Potassium

The exchangeable Ca^{2+} and Mg^{2+} ions in soil are extracted with a neutral 1.0 N NH_4OAc solution when the cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) are replaced with NH_4^+ ions. In the extracted solution, $Ca^{2+}$and Mg^{2+} ions were determined by the complexometric titration method using erhylenediaminetetracetic acid (EDTA), and Na^+ and K^+ were determined by the flame photometric method.

The most widely used salt of EDTA is the disodium salt with the formula Na_2H_2Y, $2H_2O$ where Y is the tetravalent anion of EDTA. When $Ca^{2+}$is treated with H_2Y^{2-} a very stable complex is formed. The generalized reaction of EDTA with Ca^{2+} ion is shown below:

$$Ca^{2+} + H_2Y^{2-} \longrightarrow CaY^{2-} + 2H^+$$

Mg^{2+} ion forms a similar complex, MgY^{2-}, which is far less stable than the Ca-complex. The characteristic reaction showing the complex formation of EDTA with a metal cation M is as follows (Hesse, 1971)



Preparation of the ammonium acetate extract: 50 g of the air-dried sample was treated with 40% alcohol and filtered through Whatman No. 50 filter paper. The soil was washed four times with 50 ml portion of 40 % alcohol. Then the soil was treated with 100 ml 1.0 N NH_4OAc solution and kept overnight. The suspension was filtered through Whatmann No.42 filter paper and the volume was made up to 500 ml with distilled water. A portion of the NH_4 acetate extract was evaporated to dryness to eliminate the interference of organic matter. The residue was dissolved in aqua regia. Again it was evaporated to dryness. Then residue was dissolved in distilled water to make up the original volume of the extract evaporated.

Calcium and magnesium: 50 ml of aliquot was taken in a conical flask with 1 ml of NH_4Cl – NH_4OH buffer solution and about 100 mg of Eriochrome Black T indicator. The solution becomes wine red and it was titrated with 0.01 N EDTA solution till the colour changes to blue.

Calcium: 50ml of the aliquot was taken in a conical flask with 2ml of 10% NaOH and about 100 mg murexide indicator. The pink colour solution was then titrated with 0.01 N EDTA solution until the pink colour changes to dark purple.

Calculation

$$\text{Ca, meq/kg} = (A \times 400.8 \times V) / (v \times 20.04 \times S) \qquad (12)$$

$$\text{Mg, meq/kg} = [\,(B-A) \times 400.8 \times V\,] / [v \times S \times 1.645 \times 12.16] \qquad (13)$$

where,

A = volume of EDTA (ml) used for Ca^{2+} determination

B = volume of EDTA (ml) used for Ca^{2+} - Mg^{2+} determination

V = volume of the soil extract prepared (500 ml)

v = volume of the soil extract titrated (50ml)

S = weight of the soil sample taken (50g).

Sodium and Potassium: Na^+ and K^+ in the filtrate of NH_4.acetate extract were determined by the flame photometric method (Elico Model CL 361).

2.4.12 Trace Metals

(a) Al, Cu, Fe, Mn and Zn: Some of these elements are essential for plant growth but they are utilized only in minute quantities in contrast to the macronutrients like N, P and K, which comprise a proportionally larger percentage of plant weight. When present in excess, these can also be toxic to plants.

(b) Heavy Metals: The effects of various heavy metals such as As, Cd, Cr, Hg, Ni, Pb, etc. in soil is governed by the nature and extent to which they are bound to clay minerals and soil organic matter.

These metals were extracted from soil as follows: Air-dried soil samples were ground to obtain a fine powder and screened through a 80 mesh sieve. The extraction was carried out as per procedure given by Pinta (1975). 1.0 g of the sieved sample was digested with 35 ml of acid mixture (consisting of 4 parts of conc. H_2SO_4, 2 parts of conc. HCl and 1 part of conc. HNO_3). The mixture was heated gently at first and then more strongly until white fumes were no longer evolved. The residue was treated with 1:1 dil HCl, filtered through Whatman No. 42 and washed with distilled water several times. The final volume was made up to 100 ml with distilled water. The concentration of the metals was measured with the atomic absorption spectrophotometer (Varian SpectrAA 220). The metal content in the soil samples was found by using following formula:

$$\text{Metal Concentration, mg/kg} = (P \times Q \times R) / W \qquad (14)$$

Where, P = Concentration of metal in digested solution
Q = Final volume of digested solution (ml).
R = Dilution ratio
W = Amount of soil taken (1g).

The detailed experimental conditions for AAS analysis are given in Table 2.2

Table 2.2: Analytical conditions for atomic absorption spectroscopic analysis.

Element	Wavelength (nm)	Slit width (nm)	Working range (ppm)	Lamp current (mA)	Type of flame	Fuel gas flow rate (L/min)	Air flow rate (L/min)
Al	309.3	0.5	0.3 – 250.0	10	C_2H_2-N_2O	1	3.5 (N_2O)
Cd	228.8	0.5	0.02 – 3.0	4	Air- C_2H_2	1	3.5
Cr	357.9	0.2	0.06 –15.0	7	Air – C_2H_2	1	3.5
Cu	324.7	0.5	0.03-10.0	4	Air- C_2H_2	1	3.5
Fe	248.3	0.2	0.06-15.0	5	Air-C2H2	1	3.5
Hg	253.7	0.5	2.00 - 400.0	4	Cold vapour	- -	3.5 (N_2)
Mn	279.5	0.2	0.02 – 5.0	5	Air -C_2H_2	1	3.5
Ni	232.0	0.2	0.1 –20.0	4	Air- C_2H_2	1	3.5
Pb	217.0	1.0	0.1 – 30.0	5	Air- C_2H_2	1	3.5
Zn	213.9	1.0	0.01 – 2.0	5	Air -C_2H_2	1	3.5

2.4.13 Major and Minor Oxides

X-ray fluorescence (XRF) spectrometer has been found to be a very efficient tool for measuring major and minor oxides in soil samples. For multi-element analysis of geochemical samples, it has become a proven technique and has been widely used as a rapid and accurate analysis method (Chen, 1985). Analysis of a group of elemental oxides in a single trial is possible in XRF.

Chemical composition of the soil samples with respect to major and minor oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO, TiO_2, K_2O, Na_2O, MgO, CaO and P_2O_5) was determined by XRF measurement (Philips PW 1480 with Au-Cr dual anode system) at University Science instrumentation Centre, Gauhati University by applying pressed pellet technique. As soil standards are not available, rock standards were used for quantification of the results. Therefore, some discrepancies cannot be ruled out. **Sample preparation**: Soil sample for XRF measurement was prepared by the method of Thompson et al. (1996). The soil sample was ground to a fine powder and sieved with a 200-mesh sieve. 1.0 g of the sieved sample was mixed with a 0.5 g of boric acid and was thoroughly mixed in an agate mortar to get a fine homogeneous mixture. A deformable aluminium metal cup was filled with the mixture and was pressed in a cylindrical die of 40 mm diameter by means of a hydraulic press (AIMIL, Model 315) applying pressure in the range of 125 kN to 175 kN for about 5 minutes. A pressed pellet of circular size of 40 mm diameter with smooth face surface was obtained. The pellet was taken in a sample holder and inserted into the XRF instrument for analysis. This method was rapid and convenient, yielding high X-Ray intensity and facilitating matrix modification.

2.4.14 Identification of clay minerals with XRD analysis

XRD measurements were done to identify the clay fractions of the soil samples at the University Science instrumentation Centre, Gauhati University using Philips X –Ray spectrometer (PW 1710) using Cu anode. The scanning range was from 5.0 to 30.0 (2θ) in the continuous scan mode. The identification of clay minerals was done by using standard technique (Jackson, 1975; Moore and Reynolds Jr. 1989; Imam 1994).

(i) Aesthetic quality of water: Total hardness, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), conductance, pH, Cl^-, SO_4^-, PO_4^{--}, Na, K, Ca, Mg, Cu, Fe, Mn, Zn.

(ii) Inorganic constituents of significance to health: F^-, NO_3^-, Pb, Ni, Cr, As, Hg.

The analysis was carried out at the department of Chemistry, Gauhati University using standard methods (APHA, 1995).

2.5.1 pH

At a given temperature, the intensity of the acidic or basic character of water is indicated by pH or hydrogen ion activity. Measurement of pH is thus one of the most important and frequently used tests in water chemistry. It measures acid – base behavior of water system. Water pH in natural conditions is controlled by carbonate – bicarbonate equilibrium. The pH of drinking water lies generally between 6.5 and 8.5 (WHO,1995; BIS, 1981). Low pH causes corrosion in the distribution system and increases the metal contamination of drinking water (Trivedy and Goel, 1984).

All pH measurements were done using a digital pH meter (Model LI-127, ELICO). The instrument was calibrated for each set of measurement with standard buffer solutions.

2.5.2 Conductance

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electrical current. It depends upon temperature, concentration and types of ions present (Hem, 1985). This ability depends on the presence of ions, their concentration and mobility. The extent of mineralization in water can be qualitatively measured by electrical conductance of water. It is an excellent indicator of dissolved solids present in water. EC measurement is an excellent indicator of TDS which is a measure of salinity that affects the taste of potable water (Unnisa and Khalillullah, 2004).

pH measurement was done using a digital pH meter (Model LI-127, ELICO). The instrument was calibrated for each set of measurement with standard buffer solutions.

2.5.3 Solids

Solids comprises amount of dissolved compounds and suspended particles present in water. It refers to matter suspended or dissolved in water. Solids may affect water or effluent quality adversely in a number of ways. The Total Dissolved Solids (TDS) normally consist of carbonates, chlorides, sulphates and nitrates of Na, K, Ca and Mg (Sudarshan and Reddy, 1991). Water with high dissolved solids generally is inferior in quality. TDS indicates the general nature of salinity of water (Singh, et al., 2004). Excessive TDS content gives an unpalatable mineral taste and has physiological and corrosive actions. It results in laxative action, affects cardiac patients, causes toxemia in pregnant woman (Trivedy, 1990). TDS corrodes and encrusts metal surfaces, damages water pipes, water heaters, toilet flushing system, clothes and dishwashers. Excessive TDS destroys aquatic plants, thus adversely affecting fish and other aquatic life (Alabaster, 1972) and water containing TDS in excess of 500 mg /L is not recommended for use in irrigation (Dierberg, 1991).

Insoluble particulate matter present in water is responsible for turbidity of water. These may be in organic or inorganic form, together known as Total Suspended Solids (TSS). TSS shelters micro organisms, reduces swimming efficiency of fishes and other aquatic life resulting in less growth and exposes aquatic life to micro organisms (Gower, 1980). The inorganic and biological particulate matter affects light penetration into water, thereby resulting in a decline of primary production, which cuts down food for fish (Joseph et al., 1984). If water with excessive TSS is used for irrigation, it leads to crust formation on topsoil preventing water and air penetration (Joy et al., 1990).

Total solids were determined by taking unfiltered water and evaporating it in a hot plate. 50 ml of water was taken in a pre-weighed (W1) clean 100 ml beaker. It was then allowed to evaporate carefully in a hot plate to dryness. The beaker was then allowed to cool for sometime and kept in a desiccator. The weight of the beaker was taken again (W2) and the total solids present in the water sample were measured as follows:

$$\text{Total Solids (TS), mg/L} = (W2 - W1) \times 1000 / V \qquad (15)$$

where, W2 = Final weight of the beaker and residue in g

W1 = Initial weight of the beaker in g

V = Volume of sample taken (50 ml)

For determining TDS of water samples, 50 ml of filtered water was taken in a 100 ml beaker. The weight of the empty beaker was taken (W1). The water was allowed to evaporate carefully on a hot plate. When no more water was there in the beaker it was allowed to cool for some time and kept in a desiccator and finally, the weight was taken (W2). TDS content was obtained from the relation

$$\text{TDS mg/L} = (W2 - W1) \times 1000/V \qquad (16)$$

where, W1 = Final weight of the beaker and residue in g,

W2 = Initial weight of the beaker in g,

V = Volume of water sample taken (50 ml).

Total suspended solids present in a particular volume of water can be calculated as follows,

$$\text{TSS} = \text{TS} - \text{TDS} \qquad (17)$$

2.5.4 Total Hardness

Hardness of water may be due to the presence of a number of dissolved polyvalent ions viz, Ca^{2+}, Mg^{2+}, Sr^{2+}, Fe^{2+}, Ba^{2+}, and Mn^{2+}. Amongst these, the first two are considered as the principal hardness causing ions in natural waters. The main source of these ions is sedimentary rocks, seepage and runoff from soils. Originally, water hardness was understood be a measure of the capacity of water to precipitate soap (Garg, 2003). Soap is precipitated chiefly by calcium and magnesium ions present. In conformity with the current practice, total hardness is defined as the sum of calcium and magnesium concentrations both expressed as calcium carbonate in mg/L. Hardness of water has a correlation with heart and kidney problem (Keller, 1979).

The total hardness of the water sample was measured by EDTA-complexometric method with Eriochrome Black T as an indicator:

Total hardness = mL EDTA used x 1000 / mL sample (18)

2.5.5 Total Alkalinity

Alkalinity of water is mainly due to the soluble carbonate and bicarbonate. The higher amount of alkalinity in groundwater imparts bitter taste to water and high values of alkalinity in surface water are indicative of the eutrophic nature of the water body (Kannan, 1991).

The total alkalinity is measured by acidimetric titration using different indicators that work in alkaline pH range (above 8.2) or in acidic pH range (below 6.0). For titration, the following reagents were prepared:

a) Phenolphthalein indicator – 0.25% solution in 60 % ethanol.
b) Methyl orange indicator – 0.5 % solution in 95 % alcohol.
c) Standard sulphuric acid - 0.02 N H_2SO_4

50 ml of water sample was taken in a beaker. To it, 2-3 drops of phenolphthalein indicator was added. Occurrence of pink colour indicates presence of carbonate and it was then titrated with standard 0.02 N H_2SO_4 until the colour just disappears. The volume of H_2SO_4 is noted. To this colourless solution, 1-2 drops of methyl orange indicator were added and the titration was continued till the colour changes from yellow to rose red. This corresponded to the total alkalinity. Final reading of H_2SO_4 volume was recorded.

Total Alkalinity, mg/L = (v x 0.02) x 1000/ mL of sample taken (i.e.50ml) (19)

where, v = ml of 0.02 N H_2SO_4 used with phenolphthalein and methyl orange indicators.

2.5.6 Sulphate

Sulphate is an indicator of hydrogeology and leaching of fertilizers into ground water (Madhuri et al., 2004). Water becomes rich with sulphate from different sources. A large amount of SO_2 gas is released into atmosphere from coal and oil burning. It is a major component in air and highly soluble in water. SO_2 causes acid rain which damage plants and other aquatic systems and is ultimately transferred to water system through precipitation. When water is acidic, more sulphate content leads to corrosion of metals in the distribution system.

For determination of sulphate in water, the following reagents were required:

(i) Conditioning reagent: 75 mg of NaCl, 30 ml of conc. HCl, 100 ml 95% ethanol in 300 ml distilled water was taken together and to it 50 ml glycerol solution was added and mixed together

(ii) $BaCl_2$ dry crystals

(iii) Standard sulphate solution: 1479 g of anhydrous Na_2SO_4 was taken in 1 L of distilled water. This solution contained 100 mg/L of sulphate

100 ml of clear water sample was taken with 0.5ml of conditioning reagent. The sample was allowed to stir on a magnetic stirrer and a spoonful of $BaCl_2$ crystals were added and stirred for another 1 minute. After allowing the mixture to stand exactly for 4 minutes, optical density was measured on a spectrophotometer (Hitachi U3210) at 420 nm. A standard curve was prepared by the same procedure taking standard solutions of 5, 10, 15, 20, 30, and 40 mg/L. The sulphate content of the water sample was read from the calibration curve.

2.5.7 Nitrate

Nitrogen is present everywhere. Generally it comes to water as nitrate. Atmosphere N comes to earth as acid rain or is fixed in soil by bacteria. Most common sources of nitrate in water are domestic wastes, industrial effluents, fertilizers, decayed matter, sewage sludge, etc. Consumption of nitrate-rich water by infants causes methaemoglobinaemia. Nitrates can be readily converted to nitrite inside the body and the nitrites can give rise to the carcinogenic nitrosamines (Nawlakhe et al., 1995).

Nitrate was determined with the following reagents:

a) Standard nitrate solution: 0.7218g/L KNO_3 was dissolved in 1 L of distilled water (1.00 mL = 100 μg NO_3^--N)

b) Intermediate nitrate solution: 100 ml of stock nitrate solution diluted to 1000 ml with distilled water (1.00 ml= 10 μg NO_3^- - N)

c) 1 N HCl

50 ml of clear water sample was taken with 1 ml of HCl and was mixed thoroughly. Absorbance was read with a UV-Visible spectrophotometric (Hitachi U3210) at 220 nm to obtain NO_3^- reading and at 275 nm to determine interference due to dissolved organic matter. NO_3 calibration standards in the range 0 to 7 mg NO_3-N/L were prepared by diluting 50 ml of intermediate nitrate solution. The correction was applied for both sample and standard, by subtracting two times the absorbance reading at 275 nm from the reading at 220 nm to obtain absorbance due to NO_3. A standard curve was constructed for absorbances of NO_3-N of standard solutions.

2.5.8 Phosphate

Phosphorus remains in water as phosphate. Phosphorus is essential for the growth of organisms and can be the nutrient that limits the primary productivity of a body of water that stimulates the growth of photosynthetic aquatic micro and microorganisms in nuisance quantities. Soluble phosphorus can be lost in surface runoff waters, but is usually found adsorbed to soil particles transported by erosion. Phosphorus in runoff has been implicated in eutrophication (excessive algal growth) of lakes and streams.

The concentration of phosphate in water was measured spectrophotometrically. 100ml filtered water sample was taken with 4 ml ammonium molybdate solution and 5 drops of $SnCl_2$ solution. After 12 minutes optical density was measured spectrophotometrically at 690 nm ((Hitachi U3210). A standard curve was prepared by the same procedure taking blank and standard solutions of concentration 0.01, 0.02, 0.05, 0.1, 0.2, and 0.5 mg/L and the phosphate concentration of sample water was read from the curve.

2.5.9 Chloride

Chloride is a harmless constituent of all natural water and is generally not classified as a harmful constituent. In potable water, the salty taste produced by chloride concentration is variable and dependent on the chemical composition of water. Some waters containing 250 mg/L may have a detectable salty taste if the cation is sodium. On the other hand the typical salty taste may be absent in waters containing as much as 1000 mg/L when the predominant cations are Ca and Mg (Garg, 2003). Lochart et al. (1995) have reported that the taste threshold for chloride ion in water varies between 210 to 300 mg/L and also high concentration of chloride in water would cause unpleasant taste. In surface water, the high concentration of chloride is normally due to sewage and many of the soluble salts found in soil (Banerjee, 1994). Chloride may come to the water sources from animal and human waste. Chloride is the best indicator of pollution (Rai, 1975) and it is the most troublesome anion for irrigation in the sense that it is toxic to the plants.

Chloride was estimated by the argentometric titration method. 50 ml of sample was taken with 5-6 drops of 5% K_2CrO_4 and titrated with 0.02 M $AgNO_3$ till reddish brown precipitation was obtained. Chloride content is calculated as follows:

$$\text{Chloride, mg/L} = [(\text{Titre reading} \times 0.02) \times 1000 \times 35.5] / \text{Volume of sample (50 ml)}$$

2.5.10 Fluoride

Fluoride comes to ground water from geological deposits, geochemistry of the location and the application of fertilizer like rock phosphate or fluorapatite. When water passes over or through fluoride bearing mineral deposits, a portion is dissolved and the water then contains a certain quantity of fluoride (Murali Krishna et al., 2003). Fluoride ions are likely to be leached out gradually, particularly on alkaline soils and move along with waterfront. Water with high fluoride content may cause serious health hazards including dental and skeletal fluorosis along with secondary neurological complications (Susheela, 1993). The water samples, which show higher concentration of fluoride, assume importance in view of the fact that fluorides in drinking water are responsible for human ailments, like dental anomalies and bone deformation (Sinha and Kant, 2003). More content of fluoride in surface water affects hatching of eggs in fish (Barik and Patel, 2004).

Fluoride was estimated spectophotometrically by the SPADNS method. Fluoride reacts with the coloured complex of zirconyl acid and SPADNS [Sodium-2-(parasulphopherylaze) 1,8-dihydroxy–3,6-naphthalene disulphonate] forming colorless $[Zr F_6]^{-2}$ and releasing the dye. The decrease in intensity of the colour can be used to determine fluoride. The following reagents were prepared

a. SPADNS solution. 479 g of SPADNS was dissolved in 250ml distilled water.

b. 133 mg zirconyl chloride octahydride ($ZrOCl_2$, $8H_2O$) was dissolved in 25ml distilled water to which 350 ml of conc. HCl was added. The volume was made up by distilled water to 500 ml.

c. 221 mg of NaF was dissolved in 1 L of distilled water. 100 ml of the solution was made up to 1 L with distilled water to obtain a 100 ppm fluoride solution. A series of standard solutions containing 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, and 6.0 mg F/L was prepared.

d. Reference solution. 10ml of SPADNS solution was taken and the volume was made up to 100 ml with distilled water. To it, 7 ml conc. HCl and 3 ml distilled water were added. The resulting solution was used for setting the instrument reference point (zero).

To determine F^- in water samples, 50 ml of sample was taken and to it, 5 ml each of SPADNS and zirconyl acid reagents were added and mixed. After a few minutes, absorbance was measured at 570 nm (Hitachi U3210). Fluoride concentration was read directly by operating the instrument in photometry mode calibrating against a blank and standard solution.

2.5.11 Oil and grease

Oil and grease are used in domestic and industrial activities. These come to the environment as wastes in different forms with water or soil. If this waste is not managed properly, it can cause major environmental problems. Animal and vegetable -based oil and grease often enter the wastewater collection system in the liquid form. An important property of oil and grease is its ability to separate and float on the water, in other words, they are hydrophobic compounds. Once in the wastewater collection system, these oil and grease cool and solidify. Grease will cling to sewer pipes and the surface causing a clog to form from the top of the pipe. These blockages and subsequent spills are unsightly, clean up is difficult, time consuming and costly (Fats, oil and grease manual, 2002). Again oil and grease present in surface water prevent O_2 from entering water. It also coats fish gills causing problems to aquatic biota even at low concentration.

To determine oil and grease, 250 ml water sample was taken in a separating funnel with of 10 ml. H_2SO_4 (1:2 mixture of H_2SO_4 , 50 ml conc. H_2SO_4 acid and 100 ml distill water) and 50 ml petroleum ether, and a little ethanol. The whole solution was shaken for a while and was allowed to stand for some time. The lower layer was discarded and the petroleum ether was drained out through a filter paper soaked in a pre-weighted (W1, g) glass beaker. Some more petroleum ether was allowed to pass through the filter paper so that no oil and grease remain stuck to the paper. The beaker was kept in a hot water bath so as to evaporate the ether. The weight of the beaker was recorded with the residue (W2, g) remaining. The oil and grease was calculated from the following relation:

Oil and grease, mg/L = [(W2 – W1) x 1000] / Volume of sample (50 ml)

2.5.12 Phenol

It is well known that phenol compounds enter pools with the sewage of woodworking enterprises, oil refining, and coal mining and chemical industries. However, a huge variety of phenol compounds are generated *in vivo*. Natural compounds in surface waters are encountered not only as free dissolved species; they also take part in condensation and polymerization reactions and produce humic complexes and polyaromatic compounds. The phenol concentration in aquatic ecosystems depends on the season (Tchaikovskaya et al., 2001). The phenol compounds differ by their toxic and organoleptic properties, chemical inertness, and sensitivity to microbiological cleavage. Therefore, some of them are rapidly oxidized in the aquatic environment or are metabolized by microbial communities, whereas others remain unchanged for a long time or are accumulated in a pool, thereby bringing the actual threat to microorganisms (Kondratieva, 2000). The US Environmental Protection Agency (EPA) has decided that waters (lakes, streams) should be limited to 0.3 milligrams phenol per liter of water (0.3 mg/L) to protect human health from the possible harmful effects of exposure to phenol by drinking water and eating contaminated water plants and animals.

Phenol is determined spectrophotometrically. For this purpose, the following reagents were prepared

A. Stock phenol solution was prepared by taking 1 g phenol in freshly boiled and cooled 1 L distilled water.

B. Phenol solution of intermediate strength was prepared by taking 10 ml of the above solution in freshly boiled and cooled 1 L distilled water (1ml = 10μg phenol).

C. Standard phenol solution was prepared by taking 50 ml of the above solution in freshly boiled and cooled 1 L distilled water (1 ml = 1 μg phenol).

D. 0.5 N NH_4OH.

E. Phosphate buffer was prepared by taking 104.5 g K_2HPO_4 and 72.3 g KH_2PO_4 in 1 L distilled water.

F. 2 g of 4-aminoantipyrine was dissolved in 100 ml distilled water.

G. 8 g potassium ferricyanide, $K_3Fe(CN)_6$ was dissolved in 100 ml D/W.

100 ml of water sample was taken with 2.5 ml of NH_4OH and 2 ml of phosphate buffer. To this, 1 ml of 4-aminopyrine and 1 ml $K_3Fe(CN)_6$ were added and mixed well. After 15 min, absorbance was read at 500 nm spectrophotometrically (Hitachi U3210). A calibration curve was obtained with the standard solutions of phenol in the same way and with the help of this, the concentration of phenol in the various water samples was determined.

2.5.13 Common metals, Ca, Mg, Na, K

Ca, Mg, Na, and K are most common metals present in almost all sources of water. In drinking water, the presence of these elements may be beneficial for human being but toxic if concentration is more as well as used for a long period. The presence of calcium in water supplies results from passage through or over deposits of limestone, dolomite, gypsum and gypsiferous shale. It is an essential constituent of human being and low content causes rickets and defective teeth. It is also one of the nutrients required by different organisms. Ca in excess may increase the total hardness of water preventing lather with soap and increase the boiling point of water (Mohan et al. 2000). Increase in calcium ion concentration tends to cause precipitation of insoluble calcium phosphate. Calcium with chloride induces acidosis as the cation is not readily absorbed and so an excess Ca ion enters the blood and displaces the plasma bicarbonate resulting in clotting of blood (Bell et al. 1961).

The concentration of Mg in water is comparatively less than Ca. Excess Mg^{2+} causes scale formation in public distribution system (Singanan et al. 1996). Excessive consumption of magnesium acts as a depressant to the central nervous system, including narcosis. Too much magnesium reacts with carbonate causing belching and creates diarrhea. Calcium forms a double non-ionisable compound with magnesium and is therefore antidotal and leads to a cathartic action (Lohani, 2005). Magnesium hardness when exceeds ISI permissible limits (30-50 mg/L) may be cathartic and diuretic (Lalitha et al. 2004). Drinking water with high concentration of chloride may corrode the iron pipes in presence of Mg^{2+} ions used for ground water pumping (Jayashree, 2002). High salts like chloride, magnesium and calcium indicate a saline taste (Patil et al. 2003). Ca and Mg in water are responsible for scale formation in boilers, pipes and utensils.

Calcium was determined titrimetrically with EDTA solution using murexide as an indicator from the following formula:

$$\text{Calcium, mg/L} = (\text{Volume of EDTA used} \times 400.8) / (\text{Volume of sample taken})$$

Both calcium and magnesium form a complex of wine red colour with eriochrome black T at pH 10.0. The EDTA has got a strong affinity for Ca^{++} and Mg^{++} and therefore, the complex with the dye breaks down and a new complex of blue colour is formed.

Magnesium, mg/L = [(y-x) x 400.8] / [ml of sample taken x 1.645]

where, y = EDTA used in hardness determination

x = EDTA used in calcium determination for the same volume of sample.

Sodium is the most common alkaline metal found in water. The ground and surface waters having high concentration of sodium are not good for consumption. It gives bitter taste to water and is dangerous for heart and kidney patients whereas high sodium in surface water is toxic for plants and aquatic life (Kellar, 1979). Persons affected with certain diseases require low sodium concentration. Intake of 100 mg/L of Na is known to raise blood pressure in children (Calabrese and Tuthill, 1977).

Potassium is another naturally occurring alkali metal found in natural sources of water. The concentration of this element is generally found low in comparison to sodium. Main source of this element in water is from weathering of rocks. It has similar chemistry with sodium. It has no adverse effect on human beings. For plants potassium is an essential element for growth.

Sodium and potassium were determined flame photometrically (Model CL 361) using standard calibration technique.

2.5.14 Trace metals, Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn

Aluminum. Al is the most abundant metal in the earth's crust (Storey and Masters, 1995; Glynn et al., 1999). Typically, a portion of the alum added to the raw water is not removed during treatment and remains as residual aluminum in treated water (Driscoll and Letterman, 1988; Van Benschoten and Edzwald, 1990). There is considerable concern throughout the world over the levels of aluminum found in drinking water sources (raw water) and treated drinking water (Srinivasan et al., 1999). A high (3.6 to 6 µg/L) concentration of aluminum may precipitate as aluminum hydroxide giving rise to consumer complaints (Srinivasan et al., 1999; Lopez et al., 2002). Aluminum is also a suspected causative agent of neurological disorders such as Alzheimer's disease and presenile dementia (Srinivasan et al., 1999; Lopez et al., 2002; Gardner and Gunn, 1991; Jekel, 1991). The EPA drinking water standard for aluminum is 50 μg /L (Dezuane, 1997). Aluminium is acutely toxic to fish in acid waters (Chappell et al, 1991).

Arsenic. It is widely thought that naturally occurring arsenic dissolves out of certain rock formations when ground water levels drop significantly. Arsenic is ubiquitous in the environment, usually being present in small amounts in all rocks, soils, waters, air and biological tissues (Nriagu and Pacyna, 1988). Surface arsenic-related pollutants enter the ground water system by gradually moving with the flow of ground water from rains. Elevated concentrations were found in polluted environment (Nriagu and Azcue 1990). Prolonged exposure to arsenic can cause very serious health problems. Exposure to arsenic has been identified as a long-term cause of skin lesions, gangrene, cardiovascular disease, pulmonary disease, neurological disease, hypertension, peripheral vascular disease, diabetes mellitus, skin cancer, bladder cancer, lung cancer and cancer of the kidneys. In high concentrations, arsenic poisoning can also lead to an acute condition called arsenicosis (MAGC, 2001). The maximum permissible limit in drinking water is 0.01 mg/L (WHO, 2004).

Cadmium. Cd is found as natural deposits as ores. The greatest use of cadmium is primarily for metal plating and coating operations including pigment. Major industrial releases of cadmium are due to waste streams and leaching of landfills, and from a variety of operations that involve cadmium or zinc. In particular, cadmium can be released to drinking water from the corrosion of some galvanized plumbing and water main pipe materials. Some cadmium compounds are able to leach through soils to ground water. When cadmium compounds do bind to the sediments of rivers, they can be more easily bioaccumulated or re-dissolved when sediments are disturbed, such as during flooding. Its tendency to accumulate in aquatic life is high in some species, low in others. The cadmium-rich sludge can pollute surface waters as well as soils.

Chromium. Leaching from topsoil and rocks is the most important natural source of chromium entry into water. Cr can strongly attach to soil and only a small amount can dissolve in water and move deeper in the soil to underground water. It is recognized as an extremely significant pollutant due to its high toxicity and large solubility in water (Pinto et al., 2004). Chromium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high levels of chromium (Lenntech, 2006). The maximum permissible limit of chromium in drinking water as per WHO is 0.05 mg/L.

Chromium is used in metal alloys and pigments for paints, cement, paper, rubber, and other materials. Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and also circulatory and nerve tissues. Electroplating, leather tanning, and textile industries release relatively large amounts of chromium in surface waters. Solid wastes from chromate-processing facilities, when disposed of improperly in landfills, can be sources of contamination for groundwater, where the chromium residence time might be several years

Copper. It is recognized as a harmless and essential element. Copper in our diet is necessary for good health. Drinking water normally contributes approximately 150 µg/day. The levels of copper in surface and groundwater are generally very low. High levels of copper may come from fertilizers, septic systems, animal feedlots, industrial waste, and food processing waste. Copper may occur in drinking water either from contaminated well water or corroded copper pipes. Corrosion of pipes is by far the greatest cause for concern (NSF, 2003). Copper salts are discharged through industrial wastewaters. Also they are used to control of biological growth in reservoirs and water transport lines.

Although copper is an essential micronutrient, but in high concentration causes taste and odor in water and also has physiological effects in humans. Presence of copper along with zinc, iron and lead is network corrosion suggestive (Zuan, 1997). In aquatic system large amount of Cu is harmful to organisms but its concentration is governed by other factors like total hardness and pH (Dixit and Witcomb, 1983). Immediate effects from fish constitute a high proportion of the diet (Galal-Gorchev, 1991). Methylation of inorganic mercury is an important process in water and occurs in both fresh water and seawater (IPCS, 1989). Bacteria (*Pseudomonas* spp.) isolated from mucous material on the surface of fish and soil was able to methylate mercury under aerobic conditions. Some anaerobic bacteria that possess methane synthetase are also capable of mercury methylation (Wood & Wang, 1983). Once methylmercury1 is released from microbes, it enters the food chain as a consequence of rapid diffusion and tight binding to proteins in aquatic biota.

Manganese. Mn generally occurs with iron. It is an essential component of diet for normal humans but in excess, does not have any adverse effect (Lohani, 2005). It is involved in glucose utilization (Forstner and Wittmann, 1983). The maximum permissible limit for Mn in drinking water is 0.4 mg/L (WHO, 2004). Manganese accelerates bacterial growths (e.g. manengobacteria), which have taste and odor problems in drinking water (Maleki et al. 2005). At high concentrations in water, it will deposit on food during cooking, stains on sanitary ware, discolouration of laundry, deposits on plumbing fittings and cooking utensils. The presence of high level of Mn renders water unsuitable in certain industrial applications such as textile dyeing, food processing, distilling and brewing, paper, plastic and photographic plate industries.

Nickel. Small amounts of nickel are needed by the human body to produce red blood cells, however, in excessive amounts, it can become mildly toxic. Short-term over-exposure to nickel is not known to cause any health problems, but long-term exposure can cause decreased body weight, heart and liver damage, and skin irritation. The EPA does not currently regulate nickel levels in drinking water. There are no acceptable standards for nickel (Amman, 1995). Nickel can accumulate in aquatic life, but its presence is not magnified along food chains. Nickel salts enter surface waters through industrial wastewater. Nickel compounds have lower toxicity in comparison with other compounds. Presence of nickel inclined to carbonyl ions has remarkable toxicity. There are some reports on serious damages due to accidental drinking of water polluted by nickel (WHO, 1991) through leaching from Ni containing pipes etc. Water-soluble 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, 1991).

Lead. Pb in the environment arises from both natural and anthropogenic sources. Exposure can occur through drinking water, food, air, soil and dust from old paint containing lead. In the general non-smoking, adult population the major exposure pathway is from food and water. Food, air, water and dust/soil are the major potential exposure pathways for infants and young children. For infants up to 4 or 5 months of age, air, milk formulae and water are the significant sources. In humans exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure (Lenntech, 2006). The maximum permissible concentration of Pb in drinking water is 0.1 mg /L (WHO,2004).

Zinc. In natural surface waters, the concentration of zinc is usually below 10 µg/l, and in groundwater, 10–40 µg/l (Elinder, 1986). In tap water, the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings (Nriagu, 1980). Zn is required for human metabolism and growth. Drinking water usually makes a negligible contribution to zinc intake unless high concentrations of zinc occur as a result of corrosion of piping and fittings. Under certain circumstances, tap water can provide up to 10 % of the daily intake (Gillies and Paulin 1982; Lahermo, 1990). However, drinking water containing zinc at levels above 3 mg/litre tends to be opalescent, develops a greasy film when boiled, and has an undesirable astringent taste (WHO, 1996).

2.5.15 Extraction of the metals and Analysis

In this work, nitric acid digestion technique (APHA 1995) was used. For this purpose, a volume of 100 mL each of acid-preserved, well-mixed water samples was taken in a beaker, 5 mL of conc. HNO_3 was added and the mixture was slowly evaporated on a hot plate in a fume-hood to a volume of 10 – 20 mL of clear solution.

The beaker walls were washed with double-distilled water and the volume was remade to 100 mL in a volumetric flask.

The metals were estimated using AAS technique (Varian SpectrAA 220) with air acetylene flame and standards prepared in triple distilled water.

2.5.16 Extraction and determination of heavy metals in rice and husk

The collected rice grains were separated from husk. The husks and seeds were dried separately in an oven at ~50^0C and ground finely by a grinding machine. 1 g of finely ground rice grain and 1 g of husk were kept separately in crucibles and subsequently placed in a muffle furnace at a temperature 500 – 550 oC for a period of 4 hours. Thereafter, the crucibles were cooled and the residues were treated with an excess of 1N HNO_3 and evaporated to dryness on a hot plate. They were again placed in the muffle furnace at 500 ±10 oC for about 10 minutes. The perfectly clean white ash was then cooled. These were further treated with about 5 ml of 1N HNO_3 and swirled to dissolve the residue with addition of 5 ml of distilled water. The mixtures was filtered a number of times by washing the residue with small amounts of distilled water. It is collected in a volumetric flask and was made up to 50 ml by adding distilled water. The metals were determined with AAS using the formula:

$$\text{Metal, mg/L} = (\text{AAS reading} \times L \times M) / W$$

Where, L = Fill up volume in sample dissolution

M = Further dilution ratio.

W = The weighed amount of the sample.

The detailed experimental conditions used for AAS analysis are given in Table2.2

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				

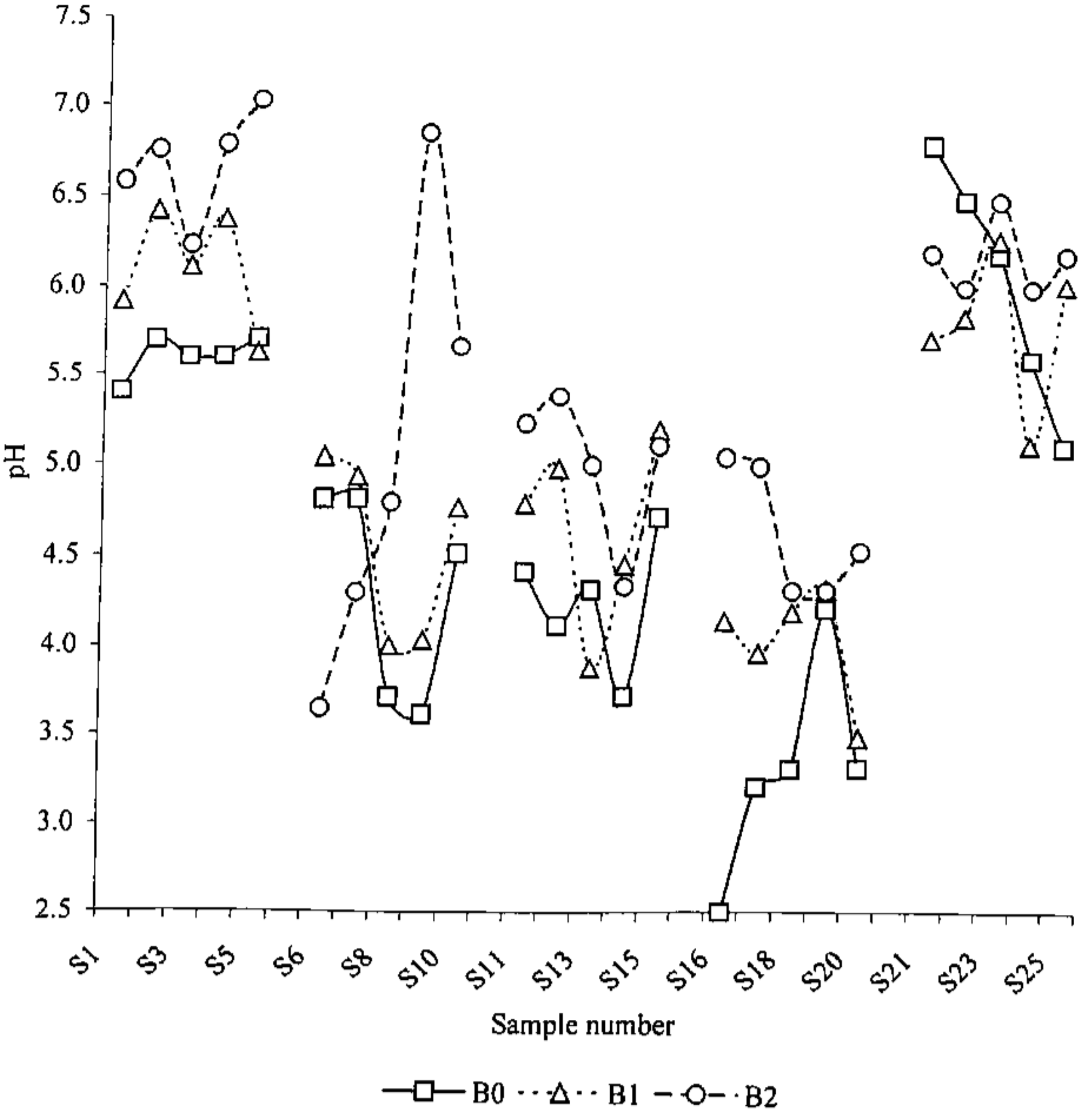


Fig. 3.1. Variation of pH in Side A with distance and direction from the Mill (S1 to S5 NE, S6 to S10 N, S11 to S15 NW, S16 to S20 W, S21 to S25 SW directions)

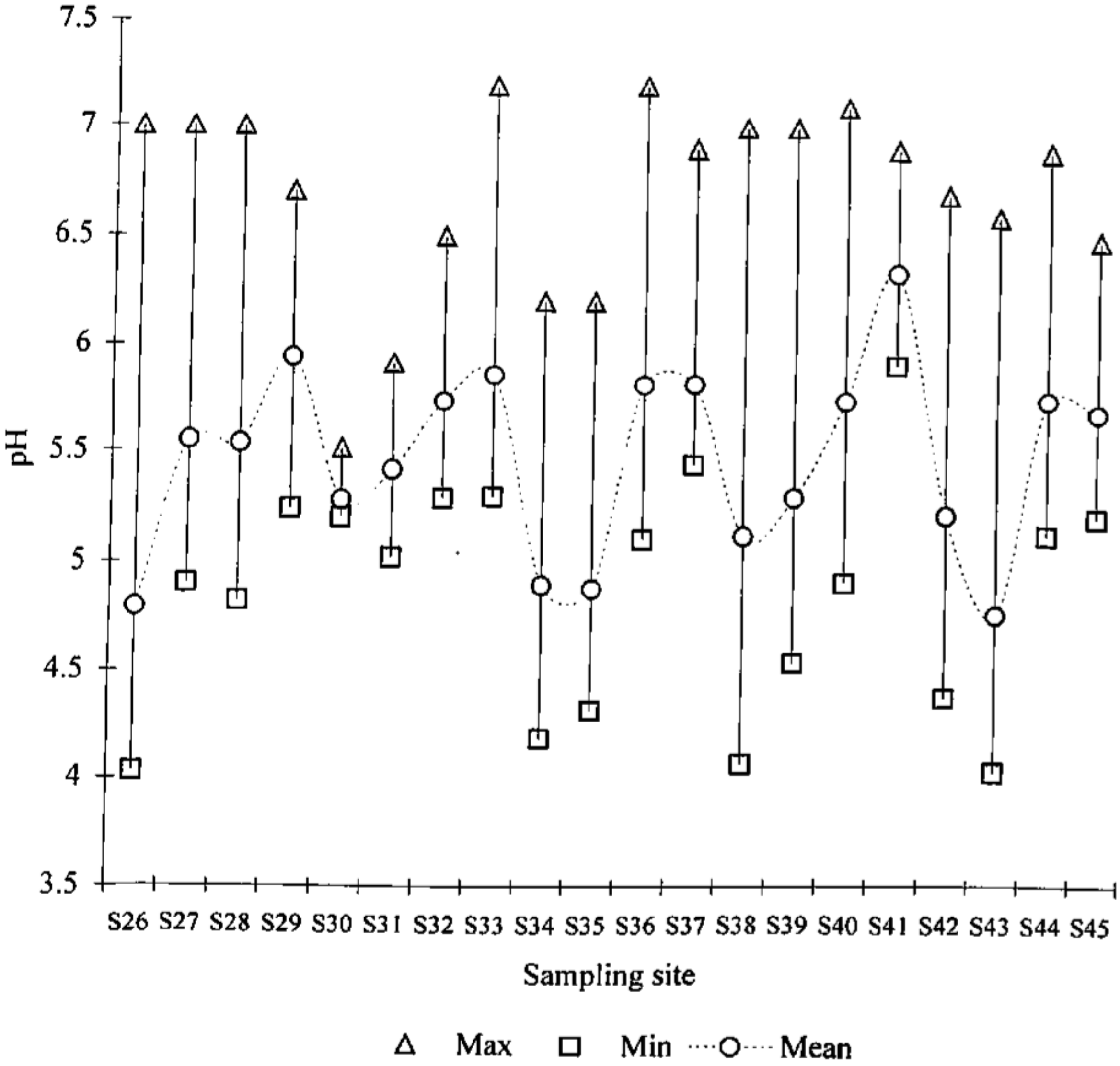


Fig. 3.2. Pattern of variation of the soil pH in Side B with respect to the minimum, the maximum and the mean values measured for all the batches of samples.

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).

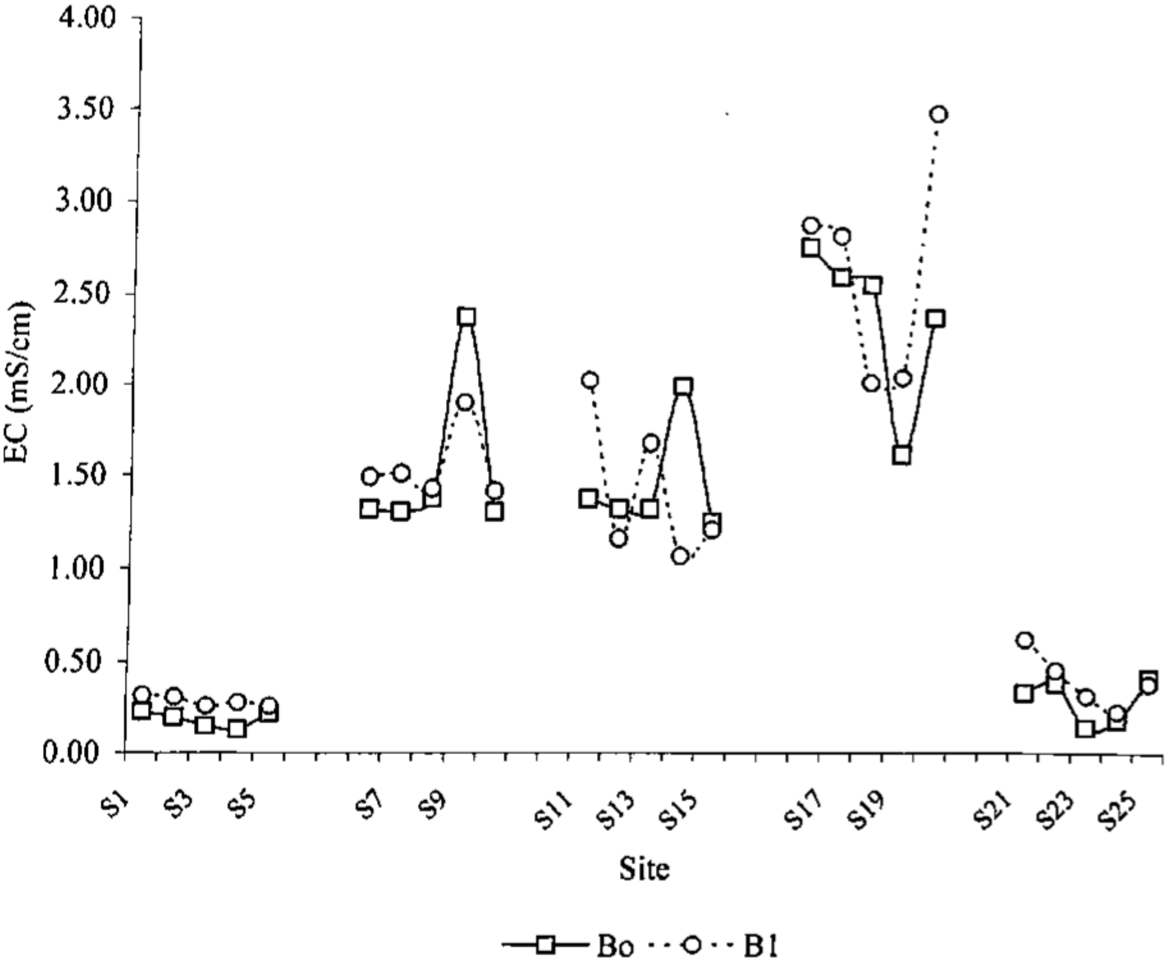


Fig. 3.3. Variation of electrical conductivity of soil (Side A) during the batches B0 and B1 (both pre-monsoon).

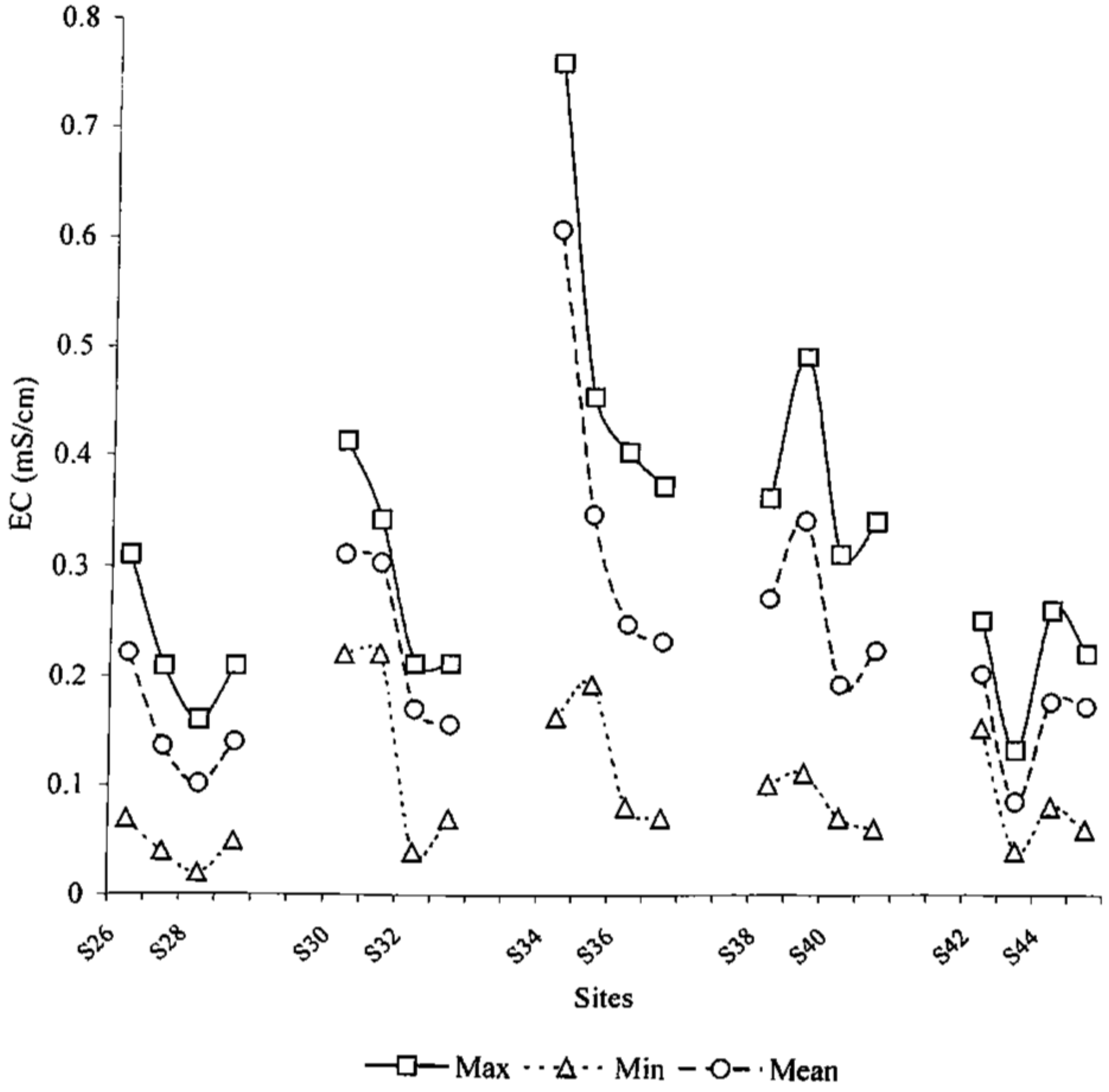


Fig. 3.4. Variation of the minimum, the maximum and the mean values of electrical conductivity of soil (Side B) for all the batches

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.

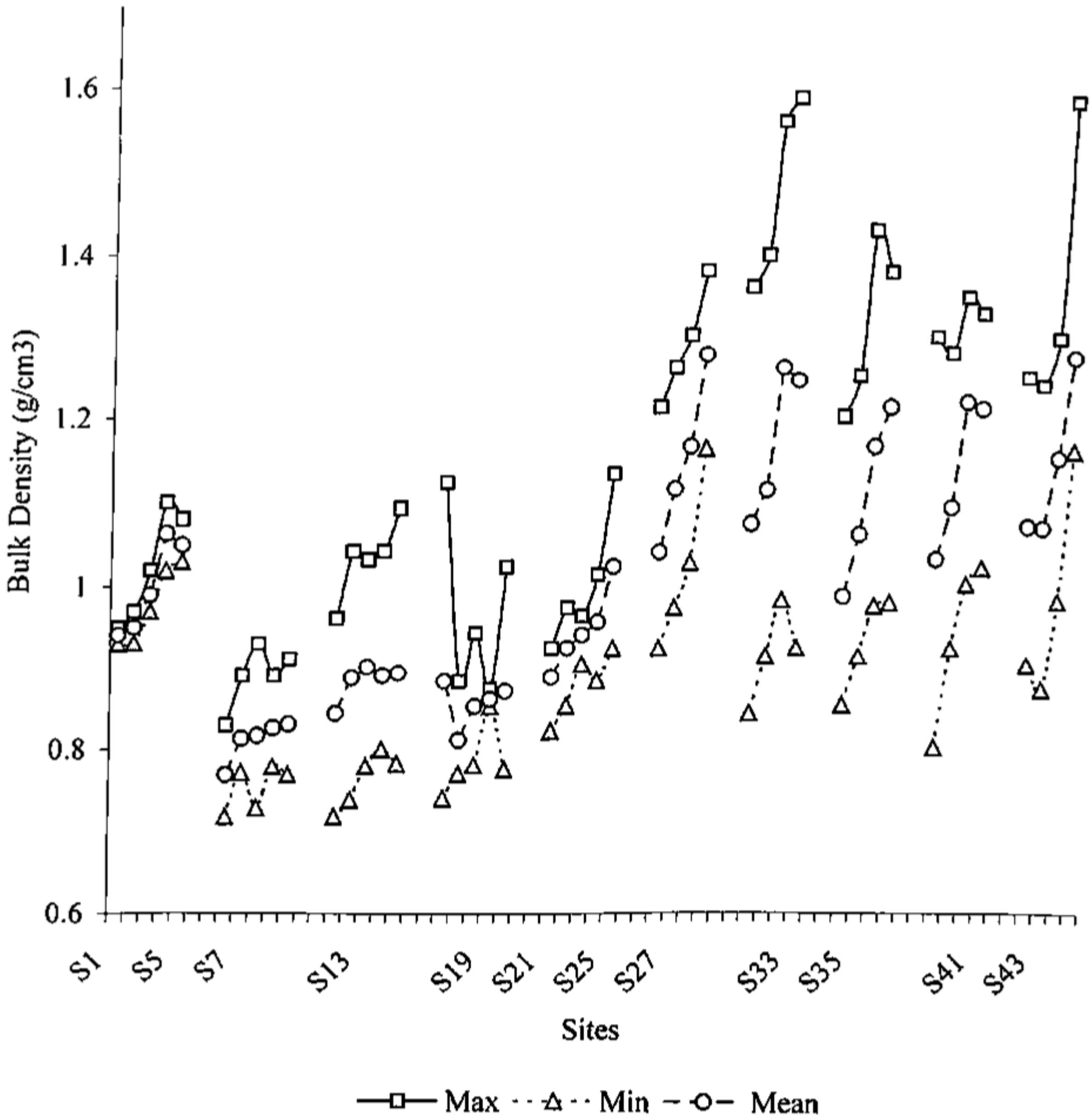


Fig. 3.5. Variation of the minimum, the maximum and the mean values of Bulk Density of the soil for all the batches with respect to sampling sites in different directions

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.

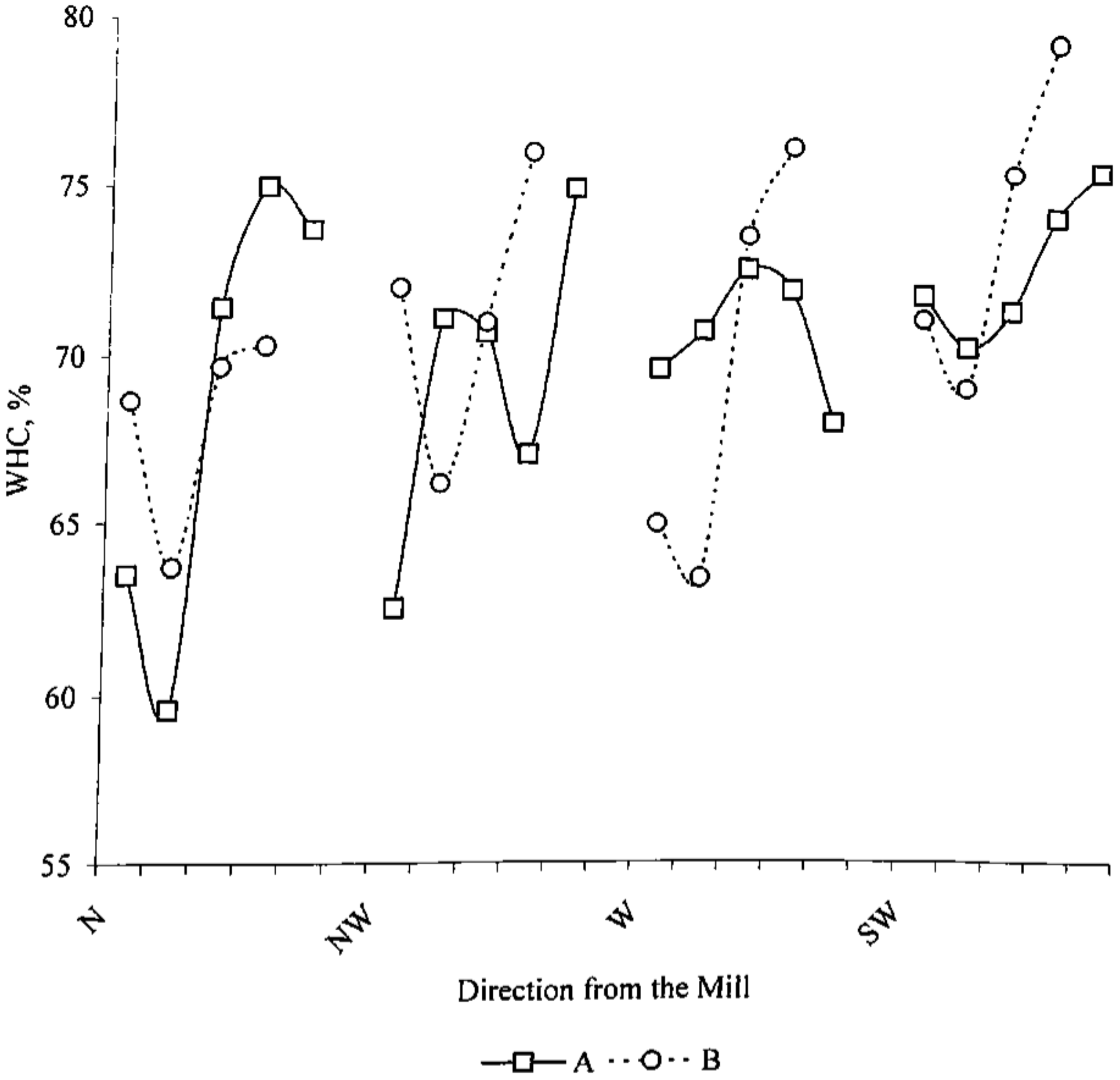


Fig. 3.6. Directional trends in average water holding capacity of the soil for Sides A and B (along N North, NW Northwest, W West and SW Southwest; points from left to right in each direction indicates increasing distance) in the pre-monsoon season.

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				

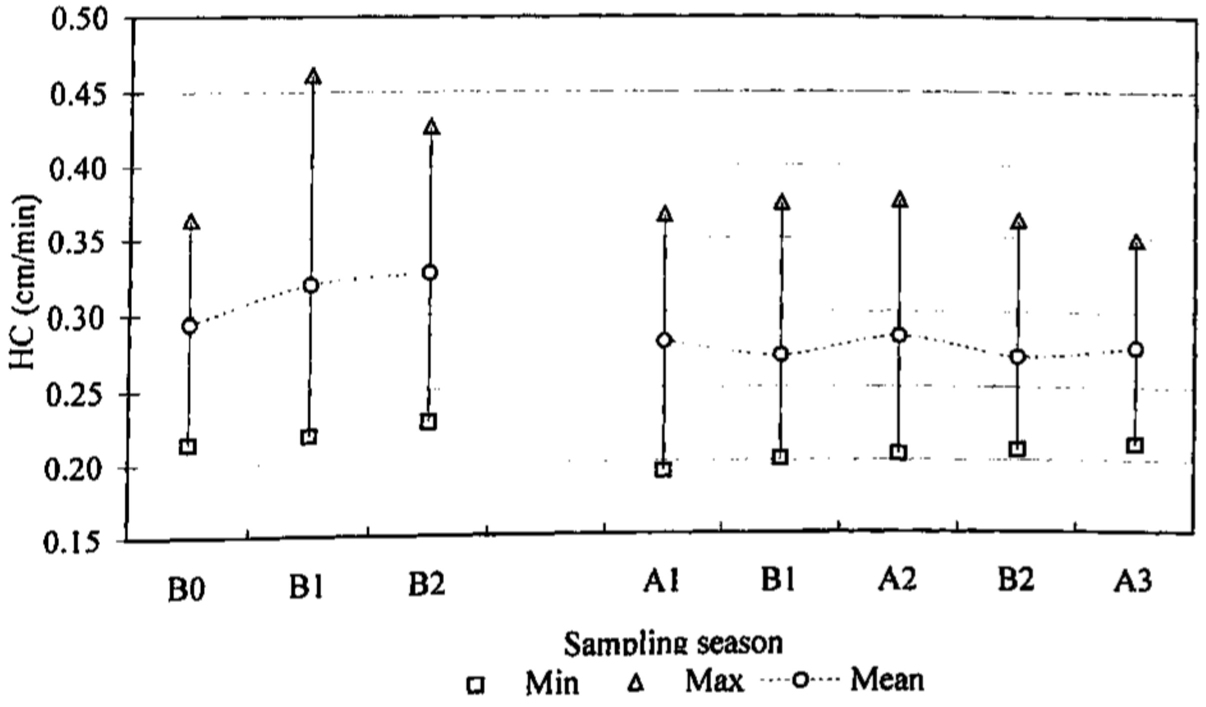


Fig. 3.7. Temporal trends in the minimum, the maximum and the mean values of hydraulic conductivity of the soil for Side A (first three sets from the left) and Side B.

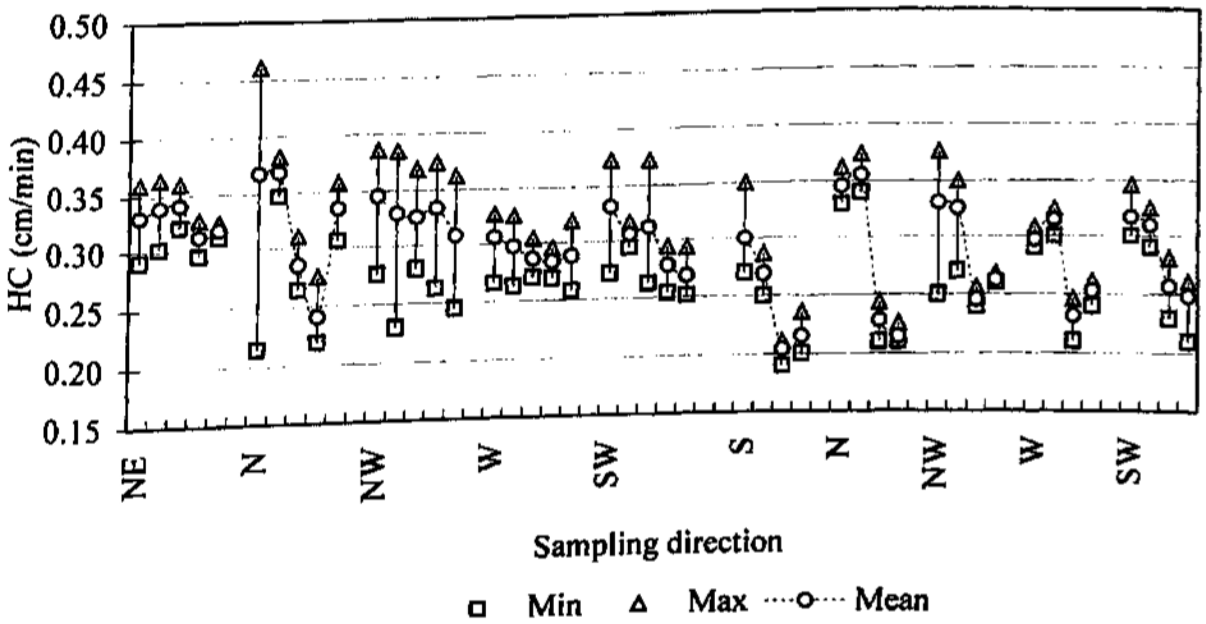


Fig. 3.8. Spatial trends in the minimum, the maximum and the mean values of hydraulic conductivity of the soil for Sides A (first five sets from the left) and B (along NE Northeast, N North, NW Northwest, W West, SW Southwest; S South. The points from left to right in each direction indicate increasing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

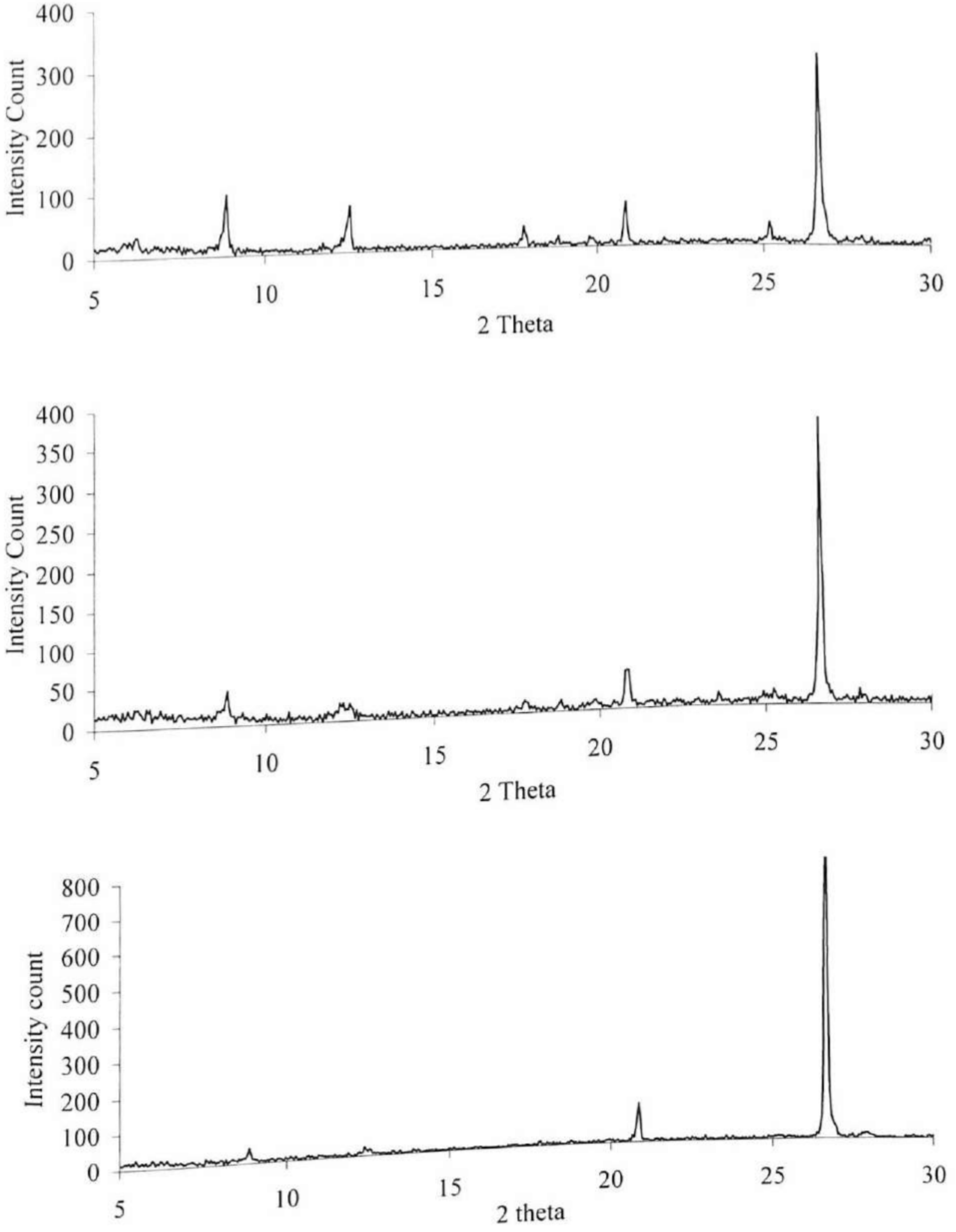


Fig. 3.9. XRD patterns of soil samples from the study area (a) Control soil (top), (b) Sample 1 (middle), (c) Sample 2 (bottom).

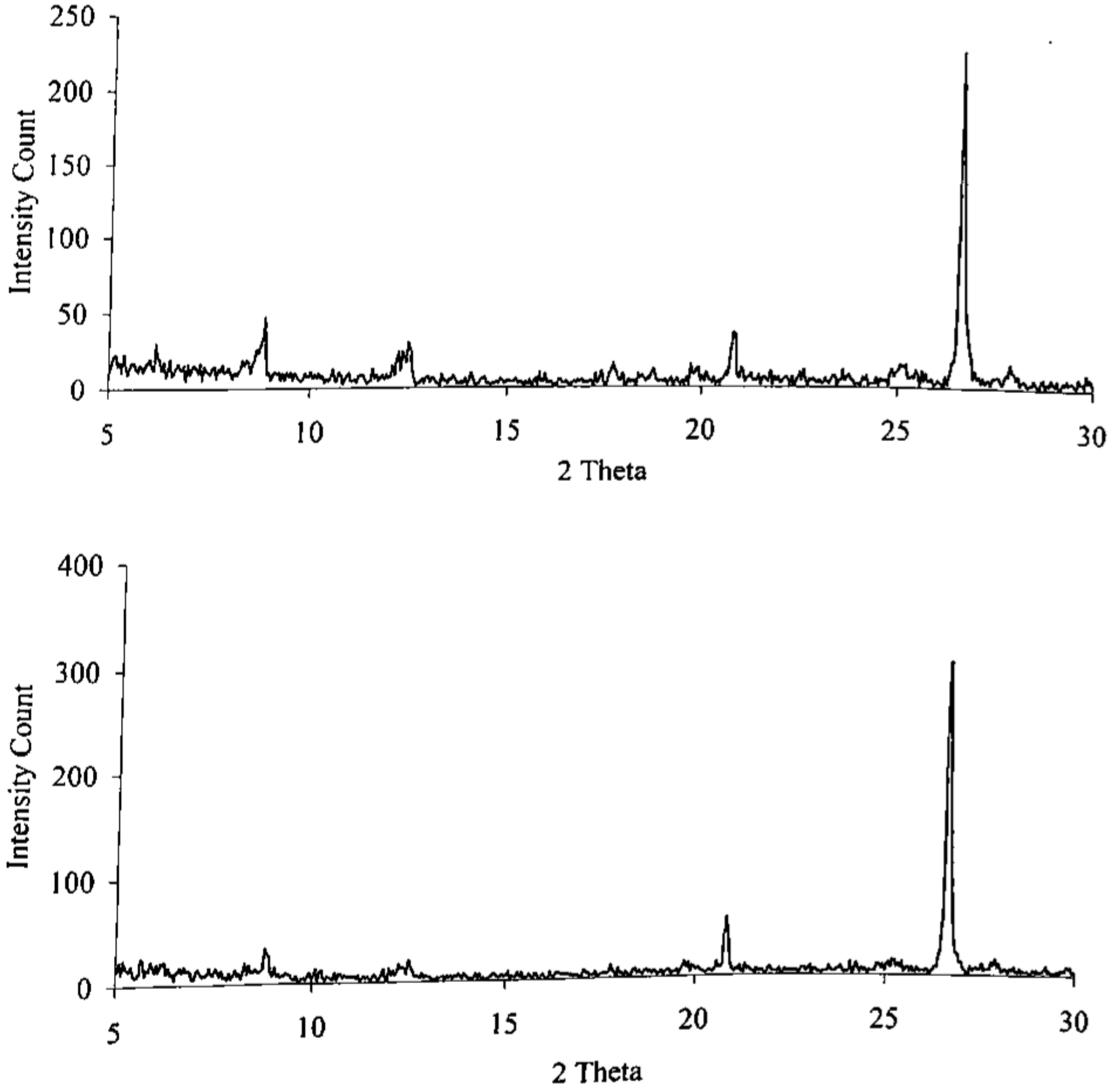


Fig. 3.9 continued. XRD patterns of soil samples from the study area (d) Sample 3 (top), and (e) Sample 4 (bottom).

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				