Title: SOIL CONTAMINATION DUE TO A PULP AND PAPER INDUSTRY: A CASE STUDY AT JAGIROAD, ASSAM (INDIA)

Soil constitutes the upper layer of the earth's crust. Plants grown on soil provide food and fibers to all human beings and other animals. Out of six major factors affecting the growth of plants, only light is not supplied by soil. The soil supplies water, air, nutrients and mechanical support for the plants and provides the necessary heat energy to support a variety of chemical reactions necessary for plant growth. Sixteen chemical elements, known as plant nutrients are essential for the growth of plants. These are Hydrogen, Carbon and Oxygen from air and water, Phosphorous, Potassium, Sulphur, Calcium, Magnesium, Iron, Boron, Copper, Manganese, Zinc, Molybdenum and Chloride from the soil and Nitrogen from both air and soil.

One of the challenges facing the mankind in recent times is the degradation and pollution of the soil. Since soil is a vital natural resource, its degradation and pollution threaten the basic life support system. The soil is the ultimate receptacle for all the waste generated on the Earth and in a sense, it is the "Sewage Treatment Plant" of nature. However its capacities are not unlimited. Its activities will be seriously hampered if the contaminants interfere with the natural characteristics of soil. Some of these contaminants may make the soil toxic and transform it into deathbed for the plants and the millions of micro- and macro-organisms for which the soil is the habitat. One of the major sources of soil pollution is the industrial effluents, sludge and solid wastes. They are the source of potentially harmful inorganic as well as organic contaminants.

The pulp and paper industry, which has been categorized as one of the twenty most polluting industries in India, discharges huge quantity of colored and toxic wastewaters (effluent) into the environment. A typical pulp and paper mill, depending upon its process and capacity, uses 60,000 -1,00,000 gallon of water per day. This entire amount goes out as waste. About 84% of the total pollution by a paper mill is caused by the pulp mill stream only. The pulp and paper mills also have some gaseous emissions to the atmosphere.
The Nagaon Paper Mill, a public sector pulp and paper mill, under the Hindustan Paper Corporation Limited, is located at Jagiroad, at the intersection of 92°4' E and 26°2' N in Central Assam. The mill commissioned in 1985, has an annual production capacity of 1,00,000 ton of finished paper and uses 4,00,000 ton of bamboo as raw material. The pulp and paper mill uses a large amount of water in the various unit processes and discharges mostly alkaline effluents. The effluents are rich in chemicals (e.g. Caustic Soda, Sulphate and Bisulphate), BOD and COD loads, and suspended solids. The effluent after treatment at the Biological Oxidation Pond is discharged into the Elenga Beel. The Mill also has various gaseous emissions including trace amounts of malodorous H$_2$S and mercaptans, which generate a foul smell in the locality. The emissions to the atmosphere have an average composition of 125 – 140 $\mu$g m$^{-3}$ SPM, 20 – 24 $\mu$g m$^{-3}$ SO$_2$, 12 – 20 $\mu$g m$^{-3}$ NO$_x$ and other trace gases. The paper mill is surrounded by a vast spread of agricultural land used for paddy cultivation in all sides except the southern side that is covered with hills and forests. The farmers use the Elenga Beel water carrying treated effluent from the mill for irrigating the land.

The present work was aimed at evaluating the impact of an existing Pulp and Paper Mill (Nagaon Paper Mill) operating for the last 15 years on the soil quality of the surrounding areas. It is thought that the gaseous emissions and the effluent discharges from the paper mill are having some cumulative influence on the quality of soil in the nearby areas. However, no study has been conducted so far to investigate this and nothing has been known of any positive or negative impact on the soil quality. Reports are often seen in local media about various complaints of the population alleging destruction of crops, low yield, etc., in a large area surrounding the paper mill.

It was therefore proposed to undertake this study with the following principal objectives:

- To measure the soil quality of the area at various distances from the paper mill with respect to important physico-chemical properties such as Texture, Bulk density, Water holding capacity, Hydraulic conductivity, pH, Electrical conductance, Organic matter, Nutrients (NPK), Major elements (Na, Ca, Mg, Fe), Trace elements (Mn, Ni, Cr, Pb, Cd,
Hg), Anions such as Sulphate and Chloride, and the overall chemical composition of the soil in terms of oxides of Si, Al, Fe,

- To observe the seasonal variation in soil quality of the area by measuring soil quality parameters in dry as well as wet seasons over a four-year period,

- To study the mobility of important contaminants, both horizontally (away from the Mill in the principle directions) and vertically downward (in surface soil and sub-surface soil) in an area of radius 3 kilometers with the mill as the reference point,

- To treat the data statistically to arrive at meaningful correlations and conclusions from the study.

The thesis, reporting the results of the investigation, is organized in five chapters, viz., (1) Introduction, (2) Study area, (3) Methodology, (4) Results and discussion, and (5) References.

The Chapter 1 (Introduction) starts with a brief description of soil chemistry. It outlines the importance of soil emphasizing on the essential elements for plant growth and the macro and micronutrients present in soil. The role of industrial effluents and solid wastes vis-à-vis soil quality has been brought out on the basis of published reports. This is elaborated with particular reference to discharge of effluents, solid wastes and other emissions by the pulp and paper industry. The available literature is reviewed on the basis of their relevance to the present study and the contributing factors towards soil degradation are highlighted.

The Chapter 2 (Study area) is divided into two parts. The first part starts with a general description of the study area with special emphasis on the geographical background, location, drainage system, climate, land use pattern, etc. It also gives a brief description of the process units in the Nagaon Paper Mill and its environmental management practices with a description of the various discharges to the environment including gaseous emissions, effluent discharges and solid wastes. The second part formulates the objectives of the study on the basis of the exhaustive literature survey.
The Chapter 3 (Methodology) gives a detailed description of the sampling seasons and the different sampling sites. Two seasons (a) dry season (January-March) and (b) wet season (August-October) has been selected for sampling and analysis during four consecutive years, 1998 to 2001. Soil samples were collected from 19 sampling stations, spreading over an area of 3-kilometer radius around the mill. Two sets of samples were collected from each site at depths of 0 – 15 cm (surface soil) and 15 – 30 cm (sub-surface soil). One set of samples was collected at the mill site, six sets were collected from the northern side (at distances 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 km distances from the mill), one set was collected from the south (at a distance of 0.5 km from the mill), four sets were collected from the east (at distances of 0.5, 1.0, 2.0, and 3.0 km from the mill), and another six sets were collected from the western side (at distances of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 km from the mill). Four sets of samples were also collected from the treated effluent discharge route at distances of 0.5 km from one another. The chapter includes a brief description of the importance of the physico-chemical parameters selected for monitoring and their measurement methodology.

The Chapter 4 (Results and discussion) presents the results obtained from the experimental measurements along with a detailed discussion parameter-wise.

The soil texture in the paper mill area shows that sand dominates over clay and silt. The texture of the soil was found to be sandy, sandy loam and loamy sand. The bulk density values for the sub-surface soil are higher than those of the surface soil. The values are from 0.712 – 1.72 g cm\(^{-3}\) for surface soil and 0.786 – 1.79 g cm\(^{-3}\) for sub-surface soil. The wet season values are generally higher than the dry season values and the values show an increasing trend away from the mill. The water holding capacity of the soil is very small near the mill indicating accumulation of hydrophobic wastes. The surface soil has less water holding capacity than the sub-surface soil. The dry season values are from 30.8 – 79.4 % for surface soil and 31.8 – 80.2 % for subsurface soil, while the wet season values are from 37.7 – 79.7 % and from 37.9 – 80.9 % for surface and sub-surface soil respectively. The hydraulic conductivity shows a decreasing trend with distance away from the mill, which indicates that the water retaining capacity of the soil improves with distance. The values are in the ranges of 0.205 – 0.644 cm min\(^{-1}\) for surface soil and 0.198 – 0.555 cm min\(^{-1}\) for subsurface soil. The carbon content of the soil is also found to be high (0.78 –
2.83 % for surface soil and 0.63 - 2.75 % for subsurface soil in dry season and 0.92 - 2.62 % for surface soil and 0.92 - 2.29 % for subsurface soil in wet season). The highest values are observed closest to the mill.

Soil pH was found to be in the range 5.25 - 9.15 for surface soil and 5.15 - 8.90 for subsurface soil. The highest value of 9.15 appeared closest to the mill. The values show a decreasing trend with distance away from the mill. The negative impact on the soil pH can be attributed to leakage and spread of alkaline effluent generated by the mill. The electrical conductance of the soil samples also show a decreasing trend with distance from the mill. The differences in conductance between the surface soil and the subsurface soil are not very significant but the values are much lower in the wet season, the reason being attributed to the washing away of some of the soluble salts by the monsoon rains. The exchangeable cations, Na\(^+\), K\(^+\), Ca\(^{2+}\) and Mg\(^{2+}\), showed a clear enrichment close to the mill decreasing almost linearly with distance. The Na\(^+\) content ranges from 3.3 – 18.3 meq kg\(^{-1}\) and 3.2 – 16.2 meq kg\(^{-1}\) for surface and subsurface soil in dry season and 2.8 – 17.2 meq kg\(^{-1}\) and 2.7 – 15.4 meq kg\(^{-1}\) for surface and subsurface soil in wet season. The concentration of potassium ranges from 1.0 – 6.8 meq kg\(^{-1}\) and 1.0-6.3 meq kg\(^{-1}\) for surface and subsurface soil in both the seasons.

Calcium and Magnesium are present in large amounts in the soil. The values are conspicuously high at the sites near the mill and gradually decrease with distance. The dry season values range from 20.9 – 100.9 meq kg\(^{-1}\) for surface soil and 18.1 – 89.7 meq kg\(^{-1}\) for subsurface soil and the wet season values are from 23.2 – 101.9 meq kg\(^{-1}\) and 21.3 – 92.8 meq kg\(^{-1}\) for surface and subsurface soil respectively. Large amounts of nitrogen and phosphorous are found in the soil around the mill. The ranges of concentration of these parameters are: nitrogen, 0.034 – 0.282 %, 0.034 – 0.234%; phosphorous, 10.7 – 102.0 mg kg\(^{-1}\) and 10.5 – 114.7 mg kg\(^{-1}\) for surface and subsurface soil respectively. Wet season values are found to be less than the dry season values. The concentrations of both the parameters show a decreasing trend away from the mill.

The soil in the present study appears to have adequate boron content for normal growth of plants ranging from 0.98 – 4.82 mg kg\(^{-1}\) for dry season and 0.95 – 4.59 mg kg\(^{-1}\) for wet season considering both surface and subsurface soil.
The chloride content of the soil is within the range 2.26 – 9.88 meq kg\(^{-1}\) for dry seasons and 1.56 – 9.81 meq kg\(^{-1}\) for wet seasons in the surface soil and 1.05 – 8.05 meq kg\(^{-1}\) for dry seasons and 0.99 – 7.26 meq kg\(^{-1}\) for wet seasons in the subsurface soil. Both boron and chloride have an increasing trend towards the mill.

The sulphate values demonstrate a decline with depth and season. The values decrease significantly in the wet seasons. The values are from 8.25 – 77.89 mg kg\(^{-1}\) for surface soil and 6.87 – 68.39 mg kg\(^{-1}\) for subsurface soil in the dry season and 7.25 – 60.59 mg kg\(^{-1}\) for surface soil and 5.53 – 56.32 mg kg\(^{-1}\) for subsurface soil in the wet season.

Iron contents of the soil are found to be high at the sites closest to the mill. The large iron content near the mill might have been contributed by the fly ash dumping in the area. Iron content varies from 3.57 – 19.82 meq kg\(^{-1}\) for dry seasons and 4.41 – 20.12 meq kg\(^{-1}\) for wet seasons for both surface and subsurface soil. Wet season values are found to be higher than dry season values.

Of the trace metals, nickel (2.60 – 31.20 mg kg\(^{-1}\)) and chromium (0 – 50 mg kg\(^{-1}\)) do not show any directional trend. Lead, mercury and manganese show a definite decreasing trend away from the mill. The lead content varies from 20 – 115 mg kg\(^{-1}\) for the surface soil and 15 – 80 mg kg\(^{-1}\) for the subsurface soil. Manganese content varies from 30 – 450 mg kg\(^{-1}\) for surface soil and 25 – 450 mg kg\(^{-1}\) for subsurface soil. High amount of mercury is found around the mill ranging from 3.35 – 14.65 mg kg\(^{-1}\). Subsurface values are found to be less than the surface soil values in most cases. The toxic metal cadmium is found in the range 0 – 2.95 mg kg\(^{-1}\). The high values of lead, mercury and other trace metals may have an adverse effect on the agricultural produce and may enter the food chain or they may leach downward to the ground water causing in both cases health hazards to men and animals.

Determination of soil chemical composition shows that the soil samples contain an appreciable amount of volatile matter (loss on ignition, 5.8-16.0 weight percent). The SiO\(_2\) content of all the samples were > 50%. The variation of Al\(_2\)O\(_3\) content is considerably wide and also shows a definite directional trend decreasing away from the mill. Similar trends were also observed for
Fe$_2$O$_3$ (4.51-8.58 weight percent) and MnO (0.05-0.270 weight percent). The highest values for Fe$_2$O$_3$ and MnO$_2$ are observed close to the mill. The fly ash dumping in the low lying areas near the mill must have led to an enhancement of these oxides near the mill.

Most of the parameters have high values for the soil samples collected from along the treated effluent flow route, particularly pH (8.43-9.67), conductance (0.867-1.325 mS cm$^{-1}$), Iron (11.06-13.24 meq kg$^{-1}$), organic carbon (1.098-1.396%). This may be due to the deposition of various salts and suspended and dissolved organic carbon present in the effluent. Other parameters were found in the ranges: calcium (84.39-93.16 meq kg$^{-1}$), magnesium (32.36-36.59 meq kg$^{-1}$), potassium (1.27-2.81 meq kg$^{-1}$), chloride (3.82-4.96 meq kg$^{-1}$), boron (2.1-2.6 mg kg$^{-1}$) and sulphate (30.9-39.3 mg kg$^{-1}$).

The results have been discussed with reference to the entry of various contaminants from the paper mill. The chapter finally enumerates a number of conclusions about the overall soil quality with the significant observation that the effluents and other waste materials from the paper mill have contributed to alteration of soil quality in the vicinity of the mill and the natural soil composition has been affected.

The thesis ends with a complete list of References to the research publications and books that have been consulted during the course of the work.