ABSTRACT

Title: IMPACT OF OIL EXPLORATION AND DRILLING ON SOIL QUALITY: AN ASSESSMENT WITH RESPECT TO LAKOWA AND RUDRASAGAR OIL FIELDS OF ASSAM.

Solid wastes generated during development and drilling activities in an oil field consist of containers and packaging materials, miscellaneous wastes from equipment assembly, and woody vegetation. Other wastes would include minor amounts of paints, coatings, and spent solvents. Most of these materials are usually transported off-site for disposal. Drilling wastes include hydraulic fluids, pipe dope, used oils and oil filters, rigwash, spilled fuel, drill cuttings, drums and containers, spent and unused solvents, paint and paint washes, sandblast media, scrap metal, solid waste, and garbage. Wastes associated with drilling fluids include oil derivatives (e.g., polycyclic aromatic hydrocarbon (PAHs), spilled chemicals, suspended and dissolved solids, phenols, cadmium, chromium, copper, lead, mercury, nickel, and drilling mud additives (including potentially harmful contaminants such as chromate and barite). Adverse impacts could result if the hazardous wastes are not properly handled. Produced water (water that coexists with oil and gas in the formation and is recovered during well development) generation can be an issue during the drilling/development phase, although it usually becomes a greater waste management concern over the long-term operation of an oil or gas field because water production typically increases with the age of the production well. Regulations govern the disposal of this produced water; the majority of it is disposed of by underground injection either in disposal wells or, in mature producing fields, in enhanced oil recovery wells. In some locations, produced water may carry naturally occurring radioactive materials to the surface. All the different types of wastes have impact on soil and water quality in the oil field area.

The present study was undertaken with a view to estimate the soil quality damages due to the activities in two Assam oil fields, namely, Rudrasagar and Lakowa, in the district of Sibsagar with the following major objectives:

1. To determine the various physico-chemical parameters like pH, total organic carbon, soil texture, electrical conductivity, water holding capacity, major anion content (chloride, sulphate, phosphate), and major cation content (Na, K, Fe, Al) in the soil samples to establish a correlation between these parameters and the total petroleum hydrocarbon content.

2. To determine the heavy metal content (as may be present in the oil field soil or as may be introduced from the spill and leakage of crude oil to the nearby area) in the soil samples and to determine the input from the oil-fields by comparing with a control soil sample.

3. To determine the variation in total petroleum hydrocarbon content in the soil samples of two oil fields (Rudrasagar and Lakowa) with respect to distance and depth.

4. To determine the heavy metal contents of fruits, vegetables and rice paddy grown in the oil field area with respect to any possible impact from the oil field operations.

5. To carry out a laboratory scale study on the effects of pH and NPK fertilizer on remediation of soil spiked with petroleum hydrocarbons.
The thesis is organized into five chapters, viz., (1) Introduction, (2) Study area and Experimental Methodology, (3) Results and discussion, (4) Conclusions from the study and (5) References.

The Chapter 1 (Introduction) starts with a brief description of the Environment in an oil field. The chapter gives an idea about “Environmental pollutants” and a “contaminated site”. Different steps involved in the study of “the contamination-remediation” of a given site, viz, environmental diagnosis, evaluation of risks and implementation of operations of remediation are clearly discussed. This chapter also introduces the macro and micronutrients present in soil and the factors that affect plant growth. Special emphasis is given to the need of adequate treatment and safe disposal of the waste products produced during various oil field operations in order to prevent soil degradation. An account of biodegradation of oil in soil is also given. The chapter ends with the list of the principal objectives of the study.

The Chapter 2 (Study area and Experimental Methodology) starts with a general description of the study area based on visit to the selected Group Gathering Stations and visual observation of the existing environment of the Group Gathering Stations, as observed during survey work. It also gives a brief description of the various discharges to the environment including gaseous emissions, effluent discharges and solid wastes in an oil field. The second part gives a detailed description of the sampling procedures for the collection of soil samples from two oil fields, viz., Rudrasagar and Lakowa over a period of three years. In the first batch of soil samples, five GGSs [2 under Rudrasagar oil field (GGS1, GGS2) and 3 under Lakowa oil field (GGS1, GGS3, GGS9) were chosen for soil study. In the second batch and third batch, four GGSs [2 under Rudrasagar oil field (GGS1, GGS2) and 2 under Lakowa oil field (GGS1, GGS9)] were chosen for soil study. The first batch of soil samples was collected at four directions from a select Group Gathering Station (GGS) in each field at two distances of 50 m and 100 m. At each position, three sets of samples at depths of 0 – 15, 15 –30, and 30 – 45 cm were collected to evaluate the vertical mobility of the soil constituents. In a single location, several samples were collected for each depth at short distances from one another and then were mixed together to obtain a composite, representative sample. The second batch of soil samples (only surface soil) was collected at distances of 25, 75, 150, 225, and 300 m from a GGS in a direction which appears to be receiving most of the discharges from the GGS operations. Several samples were collected at each distance in an angular spread and mixed together to obtain a composite sample. Third batch of soil samples (depth of 0-45 cm) was collected at distances of 25, 50, 100, 150, 200, 300, 400, and 500 m from a GGS. Upto 200 m, soil samples at a particular distance were collected from all the four directions at short distances from one another and then were mixed together to obtain a composite, representative sample. Beyond 200 m, soil samples were collected in a direction which appeared to be receiving most of the discharges from the GGS operations. Soil sample collected from areas far removed from the oil field activities was considered as “CONTROL”. Treatment, preservation and analysis of the samples were carried out using standard procedures. The chapter includes a brief description of the important physico-chemical parameters selected to characterize the soil quality and their measurement methodology.
The following parameters were monitored in the present work:

1. pH, Redox Potential (Eh), Electrical Conductivity, Water Holding Capacity (WHC), Soil Texture, Total Organic Carbon (TOC) and Total Petroleum Hydrocarbon (TPH)
2. Major anion content (Chloride, sulphate, phosphate)
3. Major cation content (Na, K, Fe, Al)
4. Heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn, Hg)

This chapter also includes a detailed description of the plant samples collected from the petroleum contaminated sites. Five GGSs [2 under Rudrasagar oil field (GGS1, GGS2) and 3 under Lakowa oil field (GGS1, GGS3, and GGS9)] were chosen for the collection of fruits and vegetables. The purpose of this collection was to study the uptake of heavy metals (Cd, Cu, Zn, Fe, Mn, Ni and V) by important plant species (rice, tea, papaya, banana, Ziziphus jujuba Lamk., Brassica juncea, Hk. F & Th., and brinjal from petroleum contaminated sites. The laboratory experiment to study the effects of pH and NPK fertilizer on degradation of petroleum hydrocarbons is also described.

The Chapter 3 (Results and discussion) presents the results with reference to the entry of various contaminants released by the oil field operations. The variations with direction, distance and depth in the soil properties have been reported and the impacts of the oil collection, treatment, storage and distribution on the soil quality have been discussed. The normally acidic soil of the agricultural fields was seen to have a tendency to turn alkaline near the GGS due to discharge of alkaline effluent from the oil field operations. It is seen that the pH increases up to 8.00 in Lakowa oil field soil and up to 9.34 in Rudrasagar oil field soil. Near the GGS, redox potential (Eh) has a tendency to turn negative or much less when the values at different distances are compared. The Eh values (mV) are in the ranges of (-) 0.062-146 for Lakowa oil field soil and (-) 0.140-118 for Rudrasagar oil field soil. It is seen that soils near the GGSs have higher electrical conductivity than those away. This indicates accumulation of salts near the GGSs from the operations. Water Holding Capacity (WHC) values show that soil near the GGSs has less capacity to hold water. This trend is indicative of accumulation of hydrophobic organic substances in soil near the GGSs. The soil texture also shows important variations in the contaminated sites. The Total Organic Carbon (TOC, %) values are in the ranges of 0.54-5.85 for Lakowa oil field soil and 0.78-6.82 for Rudrasagar oil field soil while the Total Petroleum Hydrocarbons (TPH, %) were in the ranges of 0.03-1.90 for Lakowa oil field soil and 0.05-10.0 for Rudrasagar oil field soil.

Large amount of chloride in the oil field is a common feature. In general, the accumulation of chloride salts is much more near the GGSs than away. Sulphate and phosphate contents also showed accumulation near the GGS. The anion contents (mg/kg) are found in the ranges of 2.50-297.80 (chloride), 45.0-998.0 (sulphate), 0.16-68.4 (phosphate) for Lakowa oil field soil; and 37.20-818.90 (chloride), 81.0-1012.4 (sulphate), 0.40-56.4 (phosphate) for Rudrasagar oil field soil.

Large amount of Na could be detected in the oil field soil. Potassium amount is also appreciable. Since potassium is a plant nutrient, its amount in soil depends on the utilization of potassium by plant community. The oil field contains large amounts of iron. Similarly aluminium contents of the soil are also high.
The major cation contents (mg/kg) are found in the ranges of 6.0-334.0 (sodium), 1.50-252.9 (potassium), 1766.5-63800 (iron), 3305.0-74675 (aluminium) for Lakowa oil field soil; and 10.5-960.0 (sodium), 4.0-518 (potassium), 1764-61225 (iron), 18605-78025 (aluminium) for Rudrasagar oil field soil.

The results have indicated that the heavy metals released by the oil field operations have spread into considerable distance affecting the soil quality. The heavy metal contents (mg/kg, µg/kg) for Lakowa oil field soil are found in the ranges of 0.20-8.90 (Cd), 10.45-42.20 (Co), 27.9-241.4 (Cr), 7.30-29.75 (Cu), 79.0-9870* (Hg), 8.65-222.5 (Mn), 3.40-171.20 (Ni), 11.00-175.35 (Pb), 12.95-332 (Zn). The heavy metal contents (mg/kg, µg/kg) for Rudrasagar oil field soil are found in the ranges of 0.55-14.50 (Cd), 7.35-43.15 (Co), 17.95-300 (Cr), 3.35-42.25 (Cu), 52.50-4140* (Hg), 70.0-316.0 (Mn), 9.55-126.7 (Ni), 9.50-99.50 (Pb), 8.23-647.5 (Zn).

The trends in distance wise variation of pH, electrical conductivity, sulphate, phosphate, sodium and potassium are almost similar but they differ from the trend in distance wise variation of TPH. Hence these parameters are affected mostly by formation or produced water contamination. The trends in distance variation of TPH, TOC and WHC indicate significant relationships among them. With respect to most of the soil properties the Rudrasagar oil field appears to be more contaminated than the Lakowa oil field. In general, the distribution of the contaminants is found to be non-uniform in different directions. An important observation is that the anions are found more in the surface soil and they have not penetrated much into the soil. In most of the cases no clear trend could be seen for variation of soil properties with depth. In general, the bottom soils were found to be least contaminated than the others.

Accumulation of metals (Cd, Cu, Zn, Fe, Mn, Ni, and V) in plants varied depending on the site. Plants grown in crude oil contaminated sites contain higher concentration of heavy metals than those grown in uncontaminated sites. The contamination level varied with the type of element and also with the type of plant tissue. Results reveal that in all the cases, Fe and Mn contents are in appreciable amount. *Brassica juncea, Hk. F. & Th.* leaves contain much more Fe and Mn than the other plant samples. *Ziziphus jujuba Lamk.* and brinjal are poor sources of vanadium.

The metal contents (mg/kg dry weight) in rice grain samples collected from the contaminated sites are found in the ranges of 1.58-1.75 (Cd), 3.55-3.85 (Cu), 4.55-7.20 (Zn), 45-61 (Fe), 15-38 (Mn), 3.23-5.65 (Ni), 4.35-9.85 (V). The metal contents (mg/kg dry weight) in rice husk samples collected from the contaminated sites are found in the ranges of 1.43-1.68 (Cd), 2.50-2.62 (Cu), 3.50-6.61 (Zn), 91.5-170 (Fe), 95-250 (Mn), BDL-BDL (Ni), 3.60-4.40 (V).

The metal contents (mg/kg dry weight) in papaia fruit samples collected from the contaminated sites are found in the ranges of 1.10-1.30 (Cd), 6.30-9.40 (Cu), 4.42-10.34 (Zn), 94-170 (Fe), 17-30 (Mn), 4.30-4.89 (Ni), 37.20-66.00 (V). The metal contents (mg/kg dry weight) in *brinjal* samples collected from the contaminated sites are found in the ranges of 1.48-1.50 (Cd), 12.87-13.10 (Cu), 4.58-4.90 (Zn), 129-135 (Fe), 24-26 (Mn), 6.77-7.12 (Ni), 0.10-0.20 (V).

The metal contents (mg/kg dry weight) in tea leaves collected from the contaminated sites are found in the ranges of BDL-BDL (Cd), 25-29 (Cu), 9.00-11.00 (Zn), 278-415 (Fe), 346-648 (Mn), 7.60-7.70 (Ni), 42.00-45.00 (V). The metal contents (mg/kg dry weight) in *Brassica juncea, Hk. F. & Th.* leaves collected from the contaminated sites are found in the ranges of BDL-BDL (Cd), BDL-BDL (Cu), 13.30-13.40 (Zn), 2693-2762 (Fe), 1185-1190 (Mn), BDL-BDL (Ni), 7.20-7.39 (V).
The metal contents (mg/kg dry weight) in *banana* samples collected from the contaminated sites are found in the ranges of 1.27-1.35 (Cd), 1.80-1.95 (Cu), 5.93-6.00 (Zn), 112-114 (Fe), 168-171 (Mn), 6.10-6.40 (Ni), 1.40-1.60 (V). The metal contents (mg/kg dry weight) in *Ziziphus jujuba Lamk* fruit samples collected from the contaminated sites are found in the ranges of 0.87-0.90 (Cd), 4.62-4.78 (Cu), 18.20-18.25 (Zn), 120-122 (Fe), 21.3-22.0 (Mn), 6.26-6.27 (Ni), 0.25-1.0 (V).

Tea leaves are important sources of Fe, Mn, V, Zn, Cu, and Ni but they are not major sources of Cd. Rice grains and rice husks are important sources of Cd. An interesting fact is that papaya fruits contain all the elements in good amounts. Accumulation of Cd in *Brassica juncea, Hk. F. &Th.* leaves and tea leaves is less though Cd is considered to be absorbed effectively by leaf system. In general, Cd is the least abundant element in most of the plant samples. The results indicate that the consumption of edible plant parts collected from contaminated area may pose a serious risk to human health.

The effects of pH and NPK fertilizer on degradation of petroleum hydrocarbons were also discussed on the basis of the results obtained from the Remediation Experiments. It is found that significant degradation of petroleum hydrocarbons occurs at pH 7.5. The degradation (at initial TPH 3.0 %) continued to improve with increase in concentration of NPK fertilizer. Soil responded most positively to 90 % NPK fertilizer and it is observed that the experiments will help in preparing a suitable strategy for remediation of petroleum hydrocarbon contaminated soil.

The Chapter 4 gives the important conclusions that can be drawn from the study. The thesis ends with the Chapter 5 that gives a complete list of References consulted during the course of the work.