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Environment Quality at Maitri Station in Antarctica

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A comprehensive study of air, water and soil quality was undertaken during the austral summer of 1999-2000 at the Indian Polar Research Station "Maitri" in compliance with the statutory requirements of the article 3 of Protocol on Environmental Protection to the Antarctic Treaty. The main objective of the study was to assess the impacts of various scientific programs and their associated logistic support facilities on the fragile ecosystem of Antarctica. Identification of major sources of pollution and quantification of pollutants in different environmental components were carried out through an extensive environmental monitoring program spread over a period of 5-7 weeks. Preliminary studies reveal that the levels of pollution are not alarming but there is scope for concern looking into the critical aspects of Antarctic environment and the carrying capacity of the environment surrounding Maitri station.

Key words : *Antarctica, air, noise, water quality, RBC, reactive barriers*

Introduction

Antarctica is the largest and most pristine wilderness on Earth, covering an area of approximately 13.6 million square km [1]. It is made inhospitable by extreme cold, presence of a massive permanent ice sheet and the floating ice shelves. Anthropogenic activities in Antarctica have the potential of producing both contemporaneous and long-term environmental impacts on the nearly pristine surroundings. "Maitri", India's indigenously designed polar research station in Antarctica is located in the Schirmacher Oasis at 70°45'53" S latitude and 11°44'03" E longitude. It is built on an ice-free rocky moraine at an elevation of 117m above mean sea level.

The station consists of four blocks that comprise of lodging, medical facilities, communication control system, computer room, gymnasium, cold storage, sports room, lounge, dining, kitchen, boiler-room, laundry room, bathrooms and toilets. Three containerized modules of generators are located outside on the southern side of the Maitri station. Priyadarshini Lake (also called Zub Lake) covers an area of 0.35 km^2 and forms the major source of water supply. It is situated about 225 m away from the station in the northern direction. The consumption of water is relatively more in austral summer compared to the rest of the year when it fluctuates between 1.70 (winter) and 5.7 (summer) m^3/day. It is during the austral summer that most scientific activities are carried out in and around the station. In addition, emissions due to electricity generators and toilet incinerators, and volume of wastewater generated are significantly more during this period.

The Protocol on Environmental Protection[2] to the Antarctic Treaty [3] which was adopted in 1991 by the Antarctic Treaty nations provides for the comprehensive protection of the Antarctic environment, and sets out tightly drawn rules governing human activities there. The protocol on environmental protection to the Antarctic Treaty, which has been agreed to by 28 Antarctic Treaty Consultative Parties (ATCPs), including India[4] in 1991, requires environmental impact assessment (EIA) to be applied in the planning and operation of all activities undertaken in Antarctica. Adhering to this protocol, a comprehensive environmental assessment exercise covering air, water and soil was undertaken.

Materials and methods

Water quality assessment

Extensive monitoring of surface water bodies located in the proximity of Maitri station in particular and in the Schirmacher Oasis region in general was undertaken as part of the EIA studies during the austral summer of 1999-2000. The main surface water bodies identified in the region were Priyadarshini Lake, its feeding glacial waters and other lakes (referred as Control Lakes). Rotating Biological Contactors (RBC) installed at Maitri to treat the greywater generated in station, are made of Glass fiber Reinforced Polyester (GRP), which is extremely robust and easy to transport and install. The RBC units are located in separate rooms that are not exposed to sunlight to prevent the growth of algae, which could intervene with microbial attachment[5] and sometimes

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overburden the discs with extra mass. The treated effluent is collected in pond. A seepage channel (observed for short period) arising from near the treated effluent collection pond and apparently joining Priyadarshini Lake was also considered for the study. The water from these different sources was assessed for its physical, inorganic, nutrient, and organic parameters. Additionally, the prevailing levels of some selected heavy metals were also quantified. The important factors that are likely to affect the water quality in the region, especially Priyadarshini Lake, are the closeness of summer camp to it and the emergence of afore-referred seepage channel at higher elevation. In the past, food packets, empty cans, empty fuel drums and other solid wastes sometimes got carried over into the lake due to high wind velocities prevailing in the region. However, in subsequent expeditions everything was removed during environmental cleaning operations and introduction of proper solid waste management practices. In the light of these factors, assessment of water quality was considered essential and of utmost priority.

Ten sampling locations, denoted as W1 to W10, were selected in different directions in the Priyadarshini Lake for proper assessment of its water quality. Six locations, denoted as GL1a, GL1b, GL2, GL3, GL4a and GL4b, were identified in four glacial lakes located on western side of the station. Three additional locations, denoted as CL1a, CL1b and CL2, were comprised of two freshwater lakes, referred as Control Lakes. These samples from Control Lakes were used to obtain the background concentrations, since the lakes were situated some distance away from the station and assumed to be untouched by the prevailing activities. The sampling locations are depicted in **Fig. 1**. On each sampling occasion, surface water samples were collected using pre-cleaned apparatus and stored in sterilized polypropylene bottles. The sample preservation and their analysis for different water quality parameters were carried out as per the standard procedures set out in the Standard Methods (Standard Methods for the Examination of Water and Wastewater). Certain parameters, viz. pH, conductivity, temperature, turbidity and dissolved oxygen, were estimated immediately upon collection of the samples. Some samples were preserved, which were to be analyzed later for determining nutrient, organic and inorganic parameters as well as levels of heavy metals. All analyses were performed according to the Standard Methods for analysis of water and wastewater [6]. For the analysis of heavy metals, samples were preserved and analyzed by GBC, Atomic Spectrophotometer in laboratory.

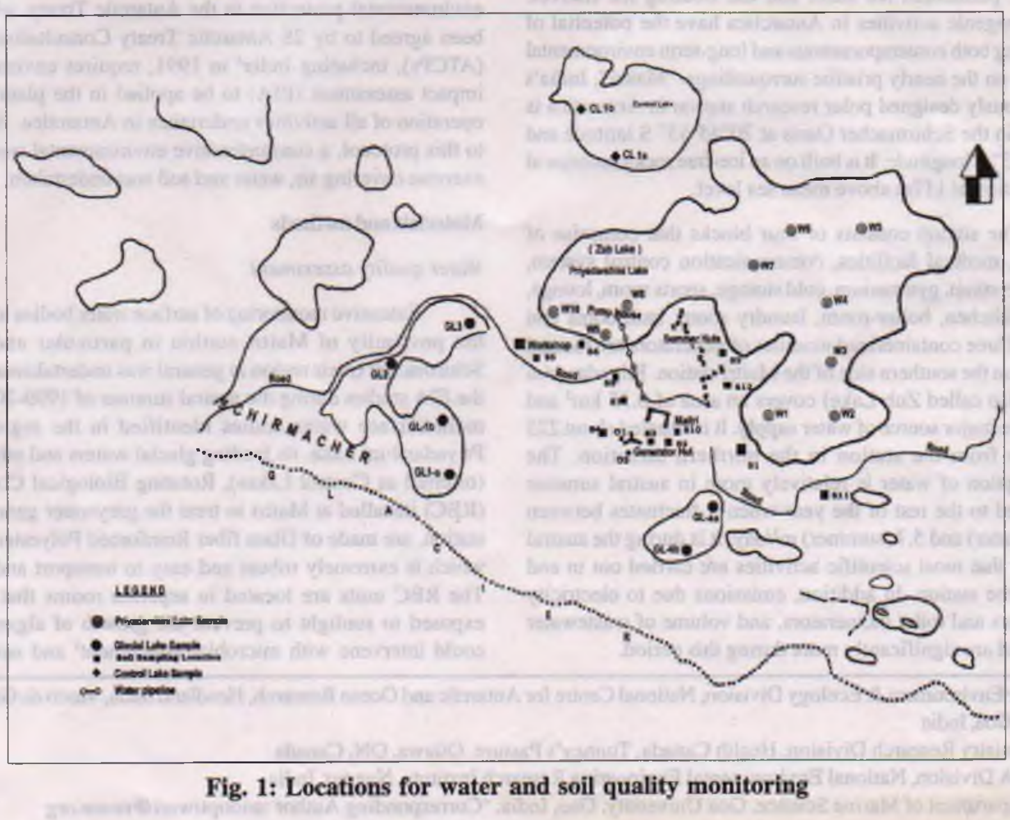

Fig. 1: Locations for water and soil quality monitoring

Air quality assessment

An extensive ambient air quality monitoring (AAQM) was carried out in the Schirmacher region surrounding Maitri station. Total seven locations were identified for this purpose. These were selected in such a way that six of them were located in the downwind direction of a known source(s) of air pollution, while one of the monitoring stations was located in the upwind direction of Maitri station in order to gather information on the background concentration prevailing in the ambient atmosphere. The existing sources of air pollution in the region were identified as generators, boiler, incinerator-based toilets and vehicular (piston pulley, cranes and dozers) movement. Besides exhaust gases, helicopters (during hovering, landing and take off from helipads) and vehicles also contributed towards suspended particulate matter (SPM). The main gaseous pollutants monitored were sulphur dioxide (SO_2) and oxides of nitrogen (NO_x), as the basic fuel was being used as JetA1 – ATF (Aviation turbine fuel). The other parameter of concern monitored was the particulate matter in the atmosphere in the form of SPM. These pollutants were monitored on a 24 hourly basis, continuously for a period of seven days at each location by means of high volume air sampler (HVAS). The particulate matter was determined gravimetrically, while the gaseous pollutants were estimated spectrophotometrically. Micrometeorological parameters such as ambient temperatures, wind-speed and wind-direction were continuously monitored during the entire period of the study.

Soil quality assessment

Soil and sediment play crucial role in ecosystem functioning. In order to carry out a critical assessment of soil, an extensive soil sampling programme was undertaken in and around Maitri station in the Schirmacher region. Total fourteen soil samples S1 to S12 and O1 and O2 representing various areas of activities including the seepage channel, workshop, oil-storage and generator were collected. Locations O1 and O2 represent soil samples collected from oil-spilled areas. The various sampling locations are presented in **Fig.1.** The parameters such as particle size, texture, water holding capacity, pH, nutrient load, cation exchange capacity (CEC), organic content, hydrocarbon, and oil & grease were analyzed. Due to extreme cold conditions and scarcity of nutrients, limited plant growth was observed, except for some species of bryophytes, algae and lichens, which are adapted to endure the extreme weather were found ubiquitously on the rocky plains, lake-sides, hills and nunataks. These species as well as the scattered excreta of migratory birds such as Skuas and Snow Petrels are responsible for presence of organic matter in the Antarctic soil so far as the non-anthropogenic sources are concerned.

Considering the major activities of earlier and ongoing expeditions in the region including emissions from generators, accidental minor oil-spillages, suspected treated wastewater seepage and solid waste dumping, the likelihood of deterioration of soil characteristics has been taken into account. Accordingly, during this expedition the pertinent locations were identified and soil samples were collected for detailed characterization. In the present study, soil sampling locations were classified into areas having activities and areas without any anthropogenic activity so that a proper assessment of soil quality could be carried out.

Eleven soil sampling locations associated with regular anthropogenic activities were identified around the station. Surface coring soil samples were collected using auger and stored in clean and labelled polythene bags covered with aluminum foil. Specific physicochemical parameters such as particle size distribution, texture, water holding capacity, pH, nutrient load, cation exchange capacity, exchangeable cations and percent organic content were determined as per the standard methods. Levels of hydrocarbon and oil & grease in the soils were also estimated to assess the impact of oil-spillages on the land environment.

Results and discussion

Water quality

The physicochemical characteristics of various water samples are shown in **Table 1**. The physical characteristics indicated that pH is on acidic side ranging between 5.8-6.5 for glacial lakes and 6.3-6.5 for samples from Priyadarshini Lake. The acidic nature of glacial lakes is indicative of precipitated water with low conductivity, turbidity and dissolved solids, whereas the slightly higher pH in Priyadarshini Lake indicates dissolution of minerals through inlet run-off waters causing increase in conductivity and dissolved solids. The electrical conductivity ranged between 10-28 μS/cm. Hardness varied in the range 5.0 – 10.1 mg/L. During sample collection, it is observed that temperature of surface water varied from -1.0^{0}C to + 3.5^{0}C, where as turbidity of water samples found in between 0.4 to 1.5 NTU. Heavy metals were recorded in the ranges of 0.191 mg/L to 1.655 mg/L for Fe, 0.005 mg/L to 0.39 mg/L for Mn, from BDL (below detectable limit) to 0.348 mg/L for Pb, which were found below detectable limits in all the points. Iron concentrations at many places were recorded at little higher side because of attribution of glacial melt water which comes over the rocks and debris left over due to retreating of Dakshin Gangotri glacier and mixes with water.

The inorganic parameters in terms of sulphate and chloride were found to lie in the ranges of 0.6-1.8 mg/L and 1.8-3.4 mg/L respectively. The nutrient parameters such as nitrate and phosphate were recorded in the ranges of 0.09 to 1.2 mg/L and BDL to 1.8 mg/L respectively. Dissolved oxygen levels in various water samples were found to range between

Table 1: Surface water quality - organic and nutrient characteristics

Particulars of Sample	Denoted as	Dissolved Oxygen	Nitrate	Total PO_4	BOD_5	COD
South-southeast (SSE) side of P. Lake 50m away from western bank	W1	14.0	0.3	BDL	3.1	8.0
Southeast side of P. Lake 75m away from eastern bank	W2	14.0	0.4	0.2	3.3	12.0
East-southeast side of P. Lake 50m away from west bank	W3	14.1	0.4	1.4	3.0	12.4
SSE of P. Lake 60m away from west bank	W4	14.1	0.3	0.7	3.2	14.0
Eastern side of P. Lake	W5	13.5	0.5	1.1	3.2	18.8
NE side of P. Lake	W6	13.5	0.4	0.3	3.0	16.8
Centre of P. Lake	W7	13.7	0.2	0.8	3.8	21.4
Near pump house in P. Lake	W8	14.0	0.1	0.4	3.9	12.4
SW side of P. Lake 3m from seepage channel	W9	12.8	1.2	0.8	4.2	19.6
West-southwest side of P. Lake 5m away from bank	W10	13.7	0.2	0.5	3.6	12.0
Control Lake 1 located north of Maitri station	CL1 (A)	13.4	0.1	0.3	1.4	16.0
Northern side of Control Lake 1	CL1 (B)	13.6	0.05	1.2	1.8	7.2
West side of Control Lake 2	CL2	10.2	0.14	BDL	1.1	12.4
Glacial Lake 1 located southwest of Maitri station	GL1 (A)	12.5	0.1	0.6	1.9	4.4
Glacial Lake 1, sampling point near joining Glacial Lake 2	GL1 (B)	11.8	0.05	1.8	2.2	5.6
Glacial Lake 2 located west of Maitri station	GL2	12.4	0.04	0.9	1.9	4.7
Glacial Lake 3 located northwest of Maitri station	GL3	13.4	0.2	0.2	1.9	15.2
Northeast (NE) side of Glacial Lake 4	GL4 (A)	13.4	0.09	0.4	2.1	10.8
Southeast side of Glacial Lake 4	GL4 (B)	13.8	0.18	0.2	2.7	12.8

Note : All values expressed in mg/L. BDL is below detectable limit; P stands for Priyadarshini; BOD_5 is biochemical oxygen demand measured as difference in dissolved oxygen over a 5-day period; COD is chemical oxygen demand.

10.2 to 14.1 mg/L at temperatures 0-1°C indicating a very high reaeration capacity of the surface water bodies and very little photosynthetic activity therein. The concentrations of chloride, nitrates, BOD_5 (biochemical oxygen demand) and COD (chemical oxygen demand) in the samples from Priyadarshini Lake were found well within the permissible limits[7]. However, their levels were on a relatively higher side compared to those of control lakes. This might be due to incoming seepage and decomposition of moss from surrounding areas. Nitrification[8] inside the RBC is probably hampered due to low alkalinity in the wastewater. It is also observed that oil and grease which mix in the influent, making the film over the liquid and thus disrupting the oxygen transfer at sediments tank, however, in the biological chamber due to continuous movement of the disc oil and grease start emulsifying. Microbial growth is observed on the disc but of grey color, which is a clear indication of overloading on the treatment system. The biomass development in aerobic unit did not always cover the entire disk surface[9]. It was also observed that the values of dissolved solids, electrical conductivity and nutrients in the glacial lake lying on west were on the higher side as compared to the one situated on the eastern side of Maitri station. This can be explained on the basis of geological setting of different water bodies. The water bodies lying on western side are located at a lower contour compared to those situated on eastern side. Moreover, the water body on west of the station lies at a distance of 210 m from the point of discharge of treated effluent from pond. Therefore, possibility of contamination of glacier water through seeped wastewater cannot be ruled out. But the kitchen, laundry and bathroom mainly produce grey water. Human excreta were burnt in the incinerators and ash was collected and removed from Antarctica Treaty area. Heavy metal levels in all the water samples were recorded well within the permissible limits of drinking water. The results indicate that except for the seepage channel, all the water samples possessed characteristics for drinking water quality as stipulated by the USEPA. To receive the higher effluent quality through RBC in cold climate, bioaugmentation of nitrifying bacteria for short solids retention time nitrification, is an attractive alternative for wastewater treatment plants in cold climate[10] and mixing of centrate from kitchen RBC can be used as a source for bioaugmentation of other RBC.

Ambient air quality

Based on the micrometeorological data gathered during the study period, a windrose diagram was designed. The windrose diagram depicting prevailing wind pattern for January 2000 is shown in **Fig. 2.** It can be observed from the windrose that the prevalent wind directions were from ESE, E and SSE. Wind prevailed from ESE and E directions for 23.5% and 16.5% of the time respectively. For 13.5% of the time, the wind direction was recorded as SE and SSE. Calm period was recorded for 5% of time. The maximum wind velocity was found to be more than 10.8 m/s for 16% of the time. For 34.5 % of the time, it was found to lie between 5.1 and 8.2 m/s. The result of air quality monitoring for suspended particulate matter is presented in **Tables 2**. The 98 percentile values were computed for each of the gaseous pollutant. It was found that the 98 percentile values for suspended particulate matter varied in the range 6.0 to 69.7µg/m³. The higher level of the SPM was recorded due to arrest of airborne particles in the high wind uplifted from the crushed rocks that converted into soil. Organic particles were observed in minute quantities. The concentrations of SO_2 and NOx were found to lie in the range BDL to 10.1µg/m³ (98 percentile value) and BDL to 21.1µg/m³ (98 percentile value) respectively as the high volume samplers were kept very close to the generator vent where plume was expected to touch the ground level. The concentrations of gaseous pollutants as well as the particulate matter for locations in the downwind direction of the generators were significantly higher compared to the one in upwind direction because of emissions from fuel utilization for energy production day in and day out. The value of suspended particulate matter recorded near the incinerator toilets of summer camp was also slightly high owing to proximity to pollution source. The prevailing high wind velocities in the region are responsible for fast mixing of air pollutants with fresh air and their subsequent dilution. However, fast winds may carry fine air borne particulates to far off places.

Table 2: Ambient air quality - cumulative percentile of suspended particulate matter

Location	Min	Avg.	Cumulative Percentiles			Max
			50	75	98	
Near Aditya generator	32.0	45.3	47.0	52.0	56.6	57.0
Near Bhaskara generator	52.0	61.3	62.0	66.0	69.7	70.0
Near Boiler exhaust	42.0	49.3	48.0	53.0	57.6	58.0
Near Workshop	5.0	7.0	7.0	8.0	8.9	9.0
Near helipad	9.0	10.3	10.0	11.0	11.9	12.0
Downwind of toilet modules of summer-camp*	15.0	18.3	18.0	20.0	21.8	22.0
Upwind direction of Maitri station	3.0	4.7	5.0	5.5	6.0	6.0

*Note : All values expressed as 24 hourly averages in µg/m³; *Located approx. 100m from Maitri station*

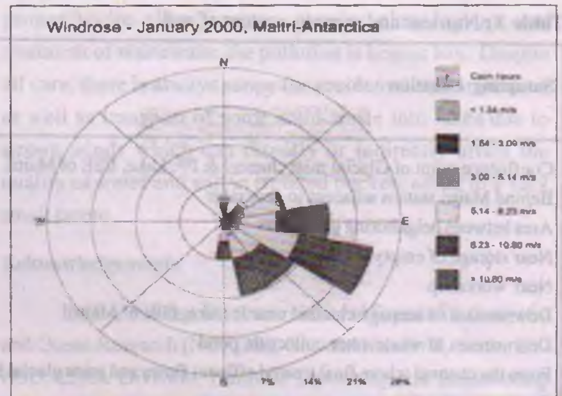

Fig. 2: Windrose indicating characteristics of prevailing wind pattern during study period

Soil quality

In general, the soil in the region was of coarse type and poor in nutrient and organic contents. Organic contents were found to be more in the seepage channel. The physical nature of soils, as presented in **Tables 3 and 4,** is characterized by selecting specific parameters, viz. particle size distribution, water holding capacity and soil textural class. Knowledge of particle size distribution leads to important conclusions about the oxygen content and origin of soils. The particle size distribution of soils collected from impact zone in terms of percentage of sand, silt and clay is shown in **Table 4**. Percent compositions of different particles were found: clay 6 to 17%, silt 1 to 14%, coarse sand 31 to 58% and fine sand 28 to 40%. The results indicate that the area is dominated by sandy and loamy sand type of soil. The water holding capacity of the soil in the study area varied between 19.56 and 40.73%. The sediments collected were found to be rich in coarse particle size, moderate in crystalline particles and dominated by pebbles characteristic of a terminal moraine, a type of glacial deposit. The pH of soil is an important factor, which indicates whether it is alkaline or acidic in nature. It is controlled by high concentration of basic cations and excess organic matter. The

Table 3 : Nutrient and organic content of soil

Sampling Location	Denoted as	pH	Organic Carbon (%)	Organic Matter (%)	Total Nitrogen (mg/100 g)
Confluence point of Glacial melt channel & P*. Lake, ESE of Maitri	S1	7.2	0.5	0.8	90.0
Behind Maitri station adjacent to generator	S2	7.8	0.4	0.7	34.0
Area between neighboring generators	S3	7.9	0.3	0.5	78.4
Near storage of empty oil drums	S4	7.6	0.1	0.13	56.0
Near workshop	S5	7.3	0.2	0.4	56.0
Downstream of seepage channel near P. Lake, NW of Maitri	S6	8.2	0.2	0.4	11.2
Downstream of wastewater collection pond	S7	7.8	0.2	0.3	44.8
From the channel where final treated effluent flows and joins glacial lake	S8	8.2	0.4	0.7	78.4
Near summer-camp	S9	6.8	0.2	0.4	34.0
15m away in southeast direction of Maitri	S10	7.4	0.2	0.4	22.4
East of Maitri on Hill	S11	7.6	0.3	0.5	22.4
Near summer-camp bathroom	S12	8.2	0.2	0.4	34.0
Area behind generators	O1	7.5	0.8	1.3	22.4
Near oil handling area adjacent to generators	O2	7.6	2.7	4.6	22.4

**P stands for Priyadarshini*

Table 4: Physical characteristics of soil

Sampling Location	Denoted as	Particle size distribution (%) Coarse sand	Fine sand	Silt	Clay	Texture	Bulk density (g/cc)	Water holding capacity (%)	Porosity
Confluence point of Glacial melt channel & P*. Lake, ESE of Maitri	S1	44	39	11	6	Loamy sand	1.4	27.1	38.87
Behind Maitri station adjacent to generator	S2	52	34	5	9	Sandy	1.29	28.56	37.76
Area between neighboring generators	S3	55	28	7	10	Loamy sand	1.43	27.60	40.22
Near storage of empty oil drums	S4	58	32	2	8	Loamy sand	1.58	23.28	37.59
Near workshop	S5	31	38	14	17	Sandy loam	1.56	22.59	36.24
Downstream of seepage channel near P. Lake, NW of Maitri	S6	49	35	7	9	Loamy sand	1.46	23.40	35.07
Downstream of wastewater collection pond	S7	56	35	1	8	Sandy	1.39	27.03	38.32
From the channel where final treated effluent flows and joins glacial lake	S8	52	38	3	7	Sandy	1.39	31.26	44.66
Near summer-camp	S9	50	38	4	8	Sandy	1.31	23.56	31.66
15m away in southeast direction of Maitri	S10	42	38	13	7	Loamy sand	1.5	23.64	36.38
East of Maitri on Hill	S11	50	33	4	13	Sandy loam	1.75	19.56	35.07
Near summer-camp bathroom	S12	43	38	10	9	Loamy sand	1.38	24.0	33.82
Area behind generators	O1	52	34	5	9	Sandy	1.51	26.90	41.28
Near oil handling area adjacent to generators	O2	50	40	2	8	Sandy	1.10	40.73	45.72

**P stands for Priyadarshini*

physicochemical chemical properties are summarised in **Tables 3 and 4**. The pH of soil in the study area was found to be alkaline and in the range of 6.8-8.2. The nutrient load in terms of total nitrogen and percent organic matter ranged from 11.2 to 90 mg/100g and 0.13 to 4.6% respectively. Among the exchangeable cations, Ca^{++}, Mg^{++}, Na^{+} and K^{+} were found to lie in the range of 0.2 to 3.08 meq/100g, 0.88 to 1.76 meq/100g, 0.6 to 2.96 meq/100g and 0.23 to 1.1 meq/100g respectively. The cation exchange capacity (CEC) is an important property of soil that is generally used for characterizing its ability to supply cation nutrients to plants. It is the consequence of positive electric charges on clay and humus particles in soils and is balanced by adsorption of positively charged counter ions. CEC largely determines the storage capacity of soil for plant nutrient ions. The CEC of the soils in the region was found to be in the range of 4.5 to 8.4 meq/100g. The concentration of hydrocarbon was found to vary from 0.1 to 1.3μg/g while that of oil & grease was found to lie in the range of 8 to 4156 mg/100g of soil. The high values represent samples taken from oil-spilled soil located near oil handling area adjacent to one of the generators. A practical solution for hydrocarbon contaminated soils is bioremediation by indigenous microorganism[11] and low temperature (0-7 °C) can still allow oil bioremediation. The seepage through pond can also be controlled through application of Permeable Reactive Barriers (PRBs). It will contribute significantly to the transient management of contaminated surface and subsurface waters in Antarctica. PRB are viewed as an ideal remediation methodology for use in Antarctica since they are passive, simple to install require little to no maintenance and should be able to cope well with the changing flow regimes and weather condition that occur during summer months [12].

Conclusion

The environmental assessment exercise throws light on the status of water, air and soil quality of the Schirmacher region, where Indian Polar Research Station, Maitri is located in Antarctica. The year round maintenance combined with the increased scientific activity during austral summer every year at the Maitri station results into transport of materials to and from Antarctic continent. Anthropogenic activity of any kind is bound to disturb the fragile ecosystem. The temperature inside the RBC should maintain 12^0-20^0C throughout the year effectively for denitrification[13]. However, owing to good environmental practices adopted at Maitri station including proper waste classification, regular cleaning up, and treatment of wastewater the pollution is kept at bay. Despite all care, there is always scope for accidental contamination as well as transport of some solid waste into lakes due to strong winds which can directly or indirectly affect the quality of water and soil in isolated pockets albeit to a very small extent.

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