Twenty Sixth Indian Antarctic Expedition 2006-2008
Ministry of Earth Sciences, Technical Publication No. 24, pp 379-396

Water Quality of Some Lakes in Grovnes Promontory, Larsemann Hills, East Antarctica

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ABSTRACT

During the 26th Indian Scientific Expedition to Antarctica, survey of lakes (12 Nos) around the Grovnes promontory (69^0 24' to 69^0 26' S; 76^0 10' to 76^0 15' E), Larsemann Hills of east Antarctica was carried out. The visual on-site details as well as the collection of water samples from the lakes were done mainly to assess the quality of water.

Bio-physicochemical parameters of the lakes water samples were studied and evaluated for drinking purpose. The results were compared with WHO and BIS drinking water standards. It was found that visually some of the lakes were eutrophic and unfit for drinking purposes, while majority of the fresh water lakes were unpolluted and the bio-physicochemical parameters were within the WHO and BIS limits. The eutrophic lakes were mainly due to the growth of algae and mosses, whereas, many lakes were oligotrophic. The data also indicate that the pH ranged between 6.6 and 7.8; the colour and odour were <5 Hazen unit and unobjectionable, suggesting palatable water.

Most of the heavy metals were below the prescribed limits and No Growth Observed for Coliform bacteria. However, the Chloride contents were large ranging from 84 mgl^{-1} in L3 to 1848 mgl^{-1} in L 4. Lead (Pb) in L 4, L 6, L 7 and L 7A were 0.06, 0.04, 0.02 and 0.02 mgl^{-1}, respectively which are higher than the prescribed permissible limits of WHO and BIS. Manganese (Mn) in Lake L3 and L7 were also above the limit with the values of 1.2 and 0.8 mgl^{-1}. Contamination of the lakes water is unlikely, therefore, analysis for further confirmation of the results is recommended.

INTRODUCTION

In the Antarctic periphery, there are about 8 major oases regions, which become deglaciated or ice-free during local summer. The melted water gets accumulated in depressions, forming fresh water lakes and streams of varying sizes.

Coastal valleys drain parts of the mainland into the sea. Moreover, during local summer the polar ice melts to supply fresh water to the existing lakes. Sometimes, the melting become large, forming streams over the oasis regions and adds significant quantity of water into the lakes. Due to overflow of lakes, the streams transport water to the shelf, thereby, changing the physico-chemical characteristics of the water.

In this continent average annual precipitation (expressed in terms of water) is between 50-150mm, most of which falls as snow (Schwerdtfeger 1979). However, due to low temperature the water is frozen and gets locked into the vast polar ice caps, making Antarctica, the largest stock of fresh water on earth.

The aim of the present study is to understand the quality of the lakes water present in the Grovnes Promontory (GP hereafter) for drinking purpose. There is a dearth of published data on the lake water quality of GP, therefore, in this paper we attempt to quantify the various bio-physicochemical parameters required for drinking water. We also compare the results with two important drinking water quality guidelines provided by World Health Organisation (WHO) and Bureau of Indian Standards (BIS). This data we hope will give some insight into the water quality of this promontory; however, we recommend further investigation for far-reaching conclusion.

Description of the Sites

Larsemann Hills is at the Ingrid Christensen Coast of east Antarctica (69° 21’ 00" S to 69° 27’ 00" S and 75° 57’ 00" E to 76° 27’ 00" E). It is an ice-free Antarctic coastal oasis, located between the Amery Ice Shelf and the Vestfold Hills. Isolated islands, peninsulas and nunataks occur along the coastal continental ice. The areas are mainly exposed hilly and rocky terrains. There are two main peninsulas in the Larsemann Hills, of east Antarctica (i) Broknes Peninsula and (ii) Stornes Peninsula. In between these two peninsulas, there are a number of promontories and islands of varying shapes, sizes, heights and water bodies.

Grovnes Promontory (GP) (69° 24’ to 69° 26’ S; 76° 10’ to 76° 15’ E), is situated over the Larsemann Hills of east Antarctica. The ice patches over the lake and the rocky regions are typical characteristics of the oases regions. The polar ice is also seen in the background of the GP, which is one of the main feeders of fresh water to various lakes in this oasis region. This promontory is bordered in the northern part by McLeod Island; eastern part by the Quilty Bay, north-eastern part by Fisher Island, western part by Stornes Peninsula and southern part by the Antarctic continent and polar ice caps.

The ecosystem of this area is simple and in the primary stage of ecological succession. The area is devoid of any higher organisms and plants except for some sea birds, seals, penguins, skuas, algae, lichen and mosses. Thick mosses, algae and lichens crusts were observed mainly near the banks of the lakes. Most of the areas were ice/snow free., butthe lakes were frozen during the present study period. The deepest lake observed was Lake No. 7 (Fig. 1), which is about 16 meter deep.

The elevation of GP ranges between 0 and 101m with an average elevation of about 50 m (NCAOR 2007). It is oriented approximately in

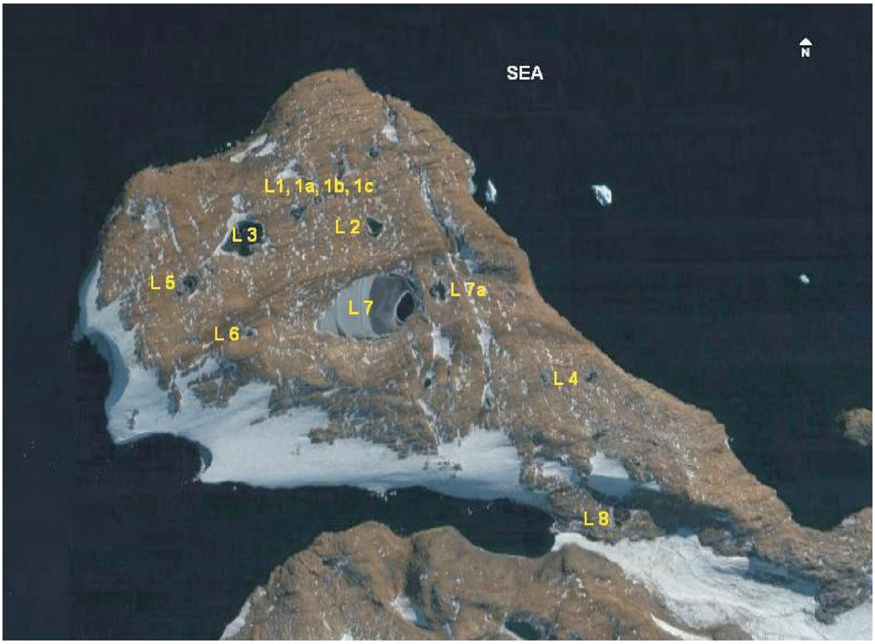

Fig. 1: Map showing the lakes (L) water sampling sites at the Larsemann Hills, Ingrid Christensen coast, east Antarctica

the east-west direction and forms a small obstruction to the flow of the glacier. Towards the north of it lays the shelf ice, while towards its south, lies the polar ice.

Geology of the Site

Three distinct gneissic litho-units and a granitic body have been identified (Beg, 2005). The granitoids are medium to coarse grained with alkali feldspar as porphyroclasts. These granitoids are traversed by thin aplitic veins.

Garnetiferous granitic gneisses: Exposed in the eastern part of the area, the gneisses are composed of quartz, pink-feldspars and very fine crystals of garnet, with biotite defining the foliation planes sympathetic to the general trend of NE-SW. The primary foliations are masked by horizontal to sub-horizontal tensional fractures almost confirming to the topography. Sheeting effects are commonly seen in granites due to the release of superincumbent load. In the extreme east of the exposure, close to polar ice cap, a few enclaves of pink granites are also seen.

The quartz-magnetite-biotite gneiss occupying the higher grounds is marked by the presence of small magnetite crystals evenly distributed throughout. At places small sized garnets are found in pockets. These gneisses are traversed by pegmatite, and aplitic veins have partly digested enclaves of older gneisses.

Garnet bearing quartz-feldspar-biotite gneisses: Most predominant litho-unit of the area, this unit is exposed in the northwestern part of the peninsula and north of lakes L-8 & L-12. These gneisses consist of quartz and feldspar with biotite defining the foliation planes.

The area exposes Late Proterozoic rocks comprising gneisses with intrusive granite bodies (Stuwe et al., 1989; Beg, 2005). The highest elevation in Larsemann Hills is observed to be 153 m above msl in the Broknes peninsula. Wind, snow/ice and chemical processes have been the main agencies responsible for the weathering and erosion.

Soil

The remarkable characteristic of the Larsemann Hills is the absence of moraine deposits as in most coastal areas of east Antarctica (Gasparon et al., 2004). Due to low temperatures, weak chemical weathering processes take place, resulting in the enrichment and migration of chemical elements. The soils are mainly sandy, having unconsolidated matrix of talus, moraines, beach deposits and vegetation fragments. Rock outcrops are rich in lichen colonies; this is mainly observed in the Stornes peninsula.

The average ratio of SiO_2/Al_2O_3 is 5.79, which shows a weak chemical weathering property of the soil. Compared with the parent rock, SiO_2 and Al_2O_3 have been eluviated. There is a trend of increasingly strong weathering from south to north (Wang, et al., 1997).

Surface Characteristics

Weak development of the weathering forms on the rock surfaces and fresh traces of glacial impact, indicate recent ice disappearance. The weathering of rocks releases minerals, an essential component for the sustenance and growth of the ecosystem (Hall and Walton, 1992). It may be noted that the weathering of rocks leads to the formation of sandy soil, which cannot support normal forms of plant and animal lives. At the same time, brown rocks absorb solar energy, leading to a much higher temperature of the rock surfaces, thus providing a better habitat for the unique micro flora and fauna of Antarctica.

Climate of the Experimental Site

GP can be classified as a true cold desert of Antarctica (Wharton, 1993; Schwerdtfeger, 1979). The weather forms depend on the position of the circumpolar trough, solar parameters, flow of katabatic winds and the position of various cyclones along the periphery of Antarctica. The circumpolar trough has a biannual movement, leading to the surface pressure level to be the highest during summer and winter periods (Gajananda, 2003).

In contrast to the seasons normally observed over the Northern Hemisphere, the seasons of Antarctica have been divided as follows:

In summer, the surface of the oasis warms up due to the solar heating of the dark rocks having lower albedo. Daytime air temperatures from December to February frequently exceed 4°C, with the mean monthly temperature a little above 0°C. Pack ice is extensively seen inshore throughout the summer, and the fjords and embayment are rarely ice-free. Snow cover is generally thicker and more persistent on Stornes

Peninsula than Broknes Peninsula. Severe weather is experienced in the region with the occurrence of storms and the intensity of some lows exceeds that of a tropical cyclone/hurricane with central pressures as low as 930 hPa and maximum winds of 50 meter/second. The extreme minimum temperature recorded so far is – 40^{o} C (Turner and Pendlebury, 2004).

Annual mean wind speed of 7 m/s and maximum wind speed 50 m/s have been recorded at the nearby Zhongshan station. Annual mean gale days are about 171 (47%). Precipitation occurs as snow and is unlikely to exceed 250 mm water equivalent annually (Hogdson et al., 2001). Observations made at Zhonshang station situated close to the site, depicts that katabatic winds are dominant in January and October (Turner and Pendlebury, 2004).

The relative humidity is 57% on a yearly basis. It is higher in the Larsemann Hills only when the temperature is above 0^{o} C, leading to a higher content of water in air in mid-summer. Additionally, during a snowstorm or blowing snow episode, the relative humidity is higher too, sometimes in excess of 90% but absolute humidity remains low (Turner and Pendlebury, 2004).

Lake Water Characteristics

There are over 150 freshwater lakes in the Larsemann Hills, ranging from small ponds less than 1 m deep to glacial lakes up to 10 ha and 38 m deep. Some of these water bodies are ice-free for brief periods or partially ice free in the summer months when the water temperature increase rapidly, reaching $+8^{o}$ C in some of the shallower ones. For the remainder of the year (8–10 months) they are covered with ca 2m of ice (Hodgson et al., 2006). The lakes around the Larsemann Hills site are in general young excepting the major lake (Gillieson et al., 1990). The waters have low conductivity and turbidity.

Anthropogenic Impact - Background Information

Human occupation commenced in this area in 1986, with the establishment of four scientific bases by Australia (Law Base), Russia (Progress I and II) and China (Zhongshan) situated around 10 km away in NE direction from the site. All these stations are situated within a radius of 2 km from each other. Ninety-three organic compounds including

Table 1–Different Seasons of GP

Seasons	**Months of the season**
Summer	December to February
Autumn	March to May
Winter	June to August
Spring	September to November

nalkanes, lipidal isopentadienes, aromatic hydrocarbons, polycyclic aromatics, alcohols, aldehydes, ketones, esters, monocarboxylic acids and phthalic esters in the range of 0.027-4.79 mg/L have been known from the Mochou and Heart lakes of the of Broknes area.

Organic compounds like BHC, DDT and PCBs have also been detected in the water at concentrations of 0.012-0.356 mgl^{-1} (Li et al., 1997). Occasional ship-based tourist visits have also been made to the area since 1992.

MATERIALS AND METHOD

Water Sampling: Sampling of lake's surface waters from 12 locations at GP, Larsemann Hills, east Antarctica were carried out during March 7-15, 2007 (Table 2). A total of 12 (twelve) surface water samples (composites, HNO_3 and H_2SO_4 preserved samples) were collected and stored at 4^o C for further bio-physicochemical analyses. Preliminary field observations of certain vital data for surface waters were carried out onsite and the data are presented in Table 2.

Daytime ambient air temperatures during the study period (March 7-16, 2007) ranged between -0.5^o C to -9^o C. The maximum wind speed recorded was about 8 ms^{-1}, blowing mainly from 90 to 135 degrees directions. The average relative humidity was about 52.75%.

RESULT AND DISCUSSION

Table 2 shows the onsite observation of the water quality of the 12 lakes in GP, Larsemann Hills of east Antarctica. Lakes in the Larsemann Hills area are mostly saline in nature (Gillieson et al, 1990) and are characterised by low microbial diversity (Burgess and Kaup, 1997).

Conductivity

Conductivity (also known as electrical conductivity or soluble salts) is a term used to measure the total concentration of salts in the water. The higher the conductivity, the more the salts that are dissolved in the water. The conductivity of the water in the GP varied between 142.8 and 1184 µs cm^{-1}. However, another east Antarctic oasis (Schrimacher Oasis) has the conductivity of the water in the range between 8 and 15 µs cm^{-1} (Gajananda et al., 2004).

Total Dissolved Solids (TDS)

A term closely related to conductivity is total dissolved solids or TDS. It is important to note that TDS measurements are used to determine the acceptability of drinking water. From Table 2 it is found that the TDS ranged between 158.4 to 6257 ppm. The TDS of L 4 was high (6257 ppm), which may be due to the presence of algae and other in vertebrate organisms. If the level of TDS exceeds the normal values, it may cause gastro intestinal irritation and on prolonged consumption of water beyond the prescribed limit of TDS may reduce the palatability.

Oxidation-reduction Potential (ORP)

Redox or ORP is a measure of a systems capacity to oxidize the material. In reduction-oxidation reactions one chemical species loses, another gains electrons. ORP is important as an indicator for understanding the mechanism of chemically supporting fish, plant, and invertebrate life. ORP is measured indirectly as the ability of an aquatic system to conduct electricity, in millivolts (mV). ORP changes rapidly thus it is necessary to monitor it on a continuous basis. ORP above 400 mV is dangerous to life. In the present data (Table 2) the ORP values are in the range of 54 to 147 mV.

Trophic Status

In terms of ecological status of the lakes, visual and sieving of the lakes water were carried out to determine the trophic status. Based on these observations, following points are made: a) the trophic status of the lakes ranged from oligotrophic to eutrophic in nature, b) some coastal lakes are mesotrophic, and c) inland lakes are mostly oligotrophic. To mention here lake L 4 was eutrophic with decomposed biological materials. This was also evident from the pungent smell (H_2S) coming out after agitating the lake bottom. The depth of lake L 4 was approximately 3m.

Table 2–On-site observation of water quality of 12 lakes in Grovnes Promontory, Larsemann Hills, East Antarctica

Samples ID	Date	Lat.	Long.	Elev (m)	Cond. (µS/cm)	Tem (ºC)	pH	Total Dissolve Solids (ppm)	ORP (mV)	BP (mb)	Remarks
L-1	7/3/07	69º24.427‘S	76º11.293‘E	35.1	255.1 at 0.9ºC	-0.3	7.14	175.9	95	-	Oligotrophic
L-1A	9/3/07	69º24.335‘S	76º11.5‘E	27.7	505.5	2.6	7.52	356.4	115 at 2.6ºC	-	Mesotrophic
L-1B	9/3/07	69º24.310‘S	76º11.662‘E	29	503.5	1.5	7.52 at 1.4ºC	356.8	97 at 1.4ºC	-	Oligotrophic
L-1C	9/3/07	69º24.365‘S	76º11.365‘E	36	613.4 at 0.7ºC	0.4	7.82 at 0.7ºC	434.7 at 0.7ºC	121 at 0.7ºC	981.7	Oligotrophic
L-2	9/3/07	69º24.434‘S	76º11.709‘E	28	1066 at 1.9 ºC	2.7	7.8 at 0.1ºC	769.3 at 1.9ºC	99 at 0.1ºC	980.2	Mesotrophic
L-3	8/3/07	69º24.458‘S	76º11.124‘E	31	229.7 at 0.4ºC	0.4	7.4	158.4	75	987.5	Oligotrophic
L-4	15/3/07	69º25.084‘S	76º12.838‘E		7616		6.78	6257	127 at 20 ºC	-	Eutrophic
L-5	10/3/07	69º24.512‘S	76º10.823‘E	38	366.6 at 0.5ºC	1.5	8.08 at 0.6ºC	258.6 at 0.6ºC	54 at 0.6ºC	976.5	Oligotrophic
L-6	11/3/07	69º24.613‘S	76º11.042‘E	50	363.4 at 0.8ºC	-0.1	8.16 at 0.7ºC	282.7 at 0.9ºC	107 at 0.8ºC	983.3	Oligotrophic, Crater like feature
L-7	8/3/07	69º24.578‘S	76º11.593‘E	35	142.8 at -0.6ºC	-0.4	7.08	997.2	147	986.1	Oligotrophic
L-7A	9/3/07	69º24.546‘S	76º11.917‘E		1184 at 0.6ºC	0.7	7.76	857.1	124	-	Oligotrophic, Area not frozen
L-8	10/3/07	69º24.898‘S	76º12.733‘E		531.5 at 0.3ºC	0	7.86 at 0ºC	377.2 at 0.3ºC	153 at 0ºC	992.7	Oligotrophic

ORP= Oxidation-Reduction Potential; BP= Barometric Pressure during the sampling period

Table 3–Physico-chemical parameters of 12 lakes in Grovnes Promontory, Larsemann Hills, East Antarctica

	Date of Sampling	9.3.07	9.3.07	9.3.07	9.3.07	9.3.07	8.3.07	15.3.07	10.3.07	11.3.07	8.3.07	9.3.07	10.3.07		
								Site Name							
S. No.	**Parameter**	**L – 1**	**L-1A**	**L-1B**	**L-1C**	**L-2**	**L-3**	**L-4**	**L-5**	**L-6**	**L-7**	**L-7A**	**L-8**	**WHO***	**BIS****
1	**Color, Hazen unit**	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	5	5
2	**Odor**	UO	UO	UO	UO	UO	UO	OB	UO	UO	UO	UO	OB	NG	UO
3	**Turbidity as NTU**	1	3	3	1	5	1	13.5	3	3	2	1	2	NG	5
4	**pH**	6.9	6.6	6.9	6.9	7.2	7.3	6.7	6.9	7.7	7.8	7.4	7.2	NG	6.5-8.5
5	**Total Hardness as $CaCO_3$, mg/l**	29	70	63.5	72	87	28	823.5	51	372	324	112	88	NG	300
6	**Iron as Fe, mg/l**	0.03	0.04	0.04	0.05	0.03	0.03	0.50	0.04	0.1	0.07	0.06	0.06	NG	0.3
7	**Chloride as Cl, mg/l**	112	156	93	166	198	84	1848	107.5	1060	704	340	144	NG	250
8	**Fluoride as F, mg/l**	0.4	<0.1	0.6	0.4	0.5	<0.1	0.55	0.35	0.6	0.6	0.2	0.3	1.5	1
9	**Dissolved Solids, mg/l**	230	346	245	392	437	177	13349.5	243.5	2392	1981	731	360	NG	500
10	**Magnesium as Mg, mg/l**	3	6	7	6.5	8	4	113	4.5	34	33	9	8	NG	30
11	**Calcium as Ca, mg/l**	7	18	14	17.5	21	5	141	13.5	91	74	30	22	NG	75
12	**Copper as Cu, mg/l**	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.06	0.02	2	0.05

(Contd.)

Table 3–Contd.

	Date of Sampling	9.3.07	9.3.07	9.3.07	9.3.07	9.3.07	8.3.07	15.3.07	10.3.07	11.3.07	8.3.07	9.3.07	10.3.07		
								Site Name							
S. No.	**Parameter**	**L – 1**	**L-1A**	**L-1B**	**L-1C**	**L-2**	**L-3**	**L-4**	**L-5**	**L-6**	**L-7**	**L-7A**	**L-8**	**WHO***	**BIS****
13	**Manganese as Mn, mg/l**	<0.01	0.03	0.2	0.05	0.01	1.2	0.11	0.04	0.04	0.8	<0.01	0.1	0.4	0.1
14	**Sulfates as SO_4, mg/l**	9	19	21	30	44.5	13	408.25	14.5	147	409	45	28	NG	200
15	**Nitrates as NO_3, mg/l**	2	<1	1	3	9.5	<1	22.75	1	18	14	8	1	50	45
16	**Mercury as Hg, mg/l**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.001
17	**Cadmium as Cd, mg/l**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	—	<0.01	<0.01	<0.01	<0.01	0.003	0.01
18	**Selenium as Se, mg/l**	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	0.007	0.006	<0.005	<0.005	<0.005	<0.005	0.01	0.01
19	**Arsenic as As, mg/l**	<0.005	<0.005	<0.005	<0.005	<0.005	—	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	0.05
20	**Cyanide as CN, mg/l**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	—	<0.01	—	—	<0.01	<0.01	0.07	0.05
21	**Lead as Pb, mg/l**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	0.04	0.02	0.02	<0.01	0.01	0.05
22	**Zinc as Zn, mg/l**	0.2	0.1	0.2	0.25	0.1	0.1	0.23	0.1	0.1	0.1	0.2	<0.01	NG	5
23	**Chromium as Cr^{+6}, mg/l**	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	—	0.05	0.05

(Contd.)

Table 3–Contd.

	Date of Sampling	9.3.07	9.3.07	9.3.07	9.3.07	9.3.07	8.3.07	15.3.07	10.3.07	11.3.07	8.3.07	9.3.07	10.3.07		
								Site Name							
S. No.	**Parameter**	**L – 1**	**L-1A**	**L-1B**	**L-1C**	**L-2**	**L-3**	**L-4**	**L-5**	**L-6**	**L-7**	**L-7A**	**L-8**	**WHO***	**BIS****
24	**Alkalinity as $CaCO_3$, mg/l**	8	10	11	7.5	29.5	9	176	9	72	74	48	34	NG	200
25	**MPN Coliforms/ 100 ml**	NGO	NGO	NGO	NGO	NGO	NGO	NGO	NGO	NGO	NGO	NGO	NGO	ND	ND
26	**Test for detection of *E. Coli***	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND	ND

UO = Unobjectionable; OB= Objectionable; NG= No Guidelines; NGO= No growth observed; NA= Not Applicable; ND= Must not be detectable in any 100ml (WHO) and 200ml (BIS) sample.

*WHO = World Health Organization, Drinking Water Limits (http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf)

**BIS = Bureau of Indian Standard/Specification for Drinking Water (BIS: 10500 - 1991) http://www.wbphed.gov.in/Bureau%20of%20Indian.html

With the above observation carried out onsite, the detailed analyses of the water samples collected from these 12 lakes were carried out. The results obtained from the analysis of the water samples of GP, Larsemann Hills of east Antarctica during March 2007 are presented in Table 3. World Health Organisation (WHO) and Bureau of Indian Standards (BIS) drinking water standards are also tabulated (WHO, 2006; BIS 1993). Following observation are made from the analysis of data.

Physical Characteristics

Colour, Odour, Turbidity, Dissolved Solids, pH and Total Hardness: These are summarised in Table 3. Following inferences can be drawn from the analytical values.

Samples collected from all the sources exhibited no colour, which is evident as the value was below 5 Hazen unit. Odour was detected in L4 and L8, however, other lakes water did not have any odour. The water of L 4 was found to be turbid with the value of 13.5 NTU. Desirable limit of turbidity as per IS: 10500-1991 is 5 NTU. The turbidity of other lake water was below the prescribed limit. Colour and turbidity in water, if present above the permissible normal values, have unaesthetic impact value and consumers acceptance decreases.

pH values were found in range of 6.6-7.8 in all the samples, which is the acceptable pH range. As the Antarctic soils are sandy, the water drains easily and leaching of nutrients occurs frequently. The waters of the GP showed an average value of 7.1 pH for all the sites. In L6 and L7, the pH was higher at 7.7 and 7.8, this could be attributed to the bed-rock.

Total Hardness is a measure of water's ability to form scale in pipes, produce suds from soap, or leave spots on leaves. The units used to report hardness are calcium carbonate equivalents ($CaCO_3$). Hardness is a measure of the combined concentration of calcium and magnesium in the water which are insoluble salts of ions, like calcium carbonate, that form scale. The total hardness ranged in the present samples from 28 to 823.5 mgl^{-1}. L4 has the highest value of 823.5 mgl^{-1}, L 6 has the value of 372 mgl^{-1} followed by L 7 with avalue of 324 mgl^{-1} which are above the prescribed BIS limit.

Inorganic Non-metallic Constituents

Following inorganic non-metallic constituents such as calcium, magnesium, chloride, sulphate, bicarbonate alkalinity, nitrate and fluoride are summarised in Table 3. The inference drawn from the analytical values are as follows:

Calcium was observed in range of 5-141 mgl^{-1} in the samples. Desirable limit of calcium in drinking water is 75 mgl^{-1}. Analysis results indicate that, calcium in all samples except in L 4 and L 6 (141 and 91 mgl^{-1}), is within the desirable limit of drinking water.

Magnesium (as Mg) was found in range of 3-113 mgl^{-1} in the samples. The desirable limit is 30. Lake L 4 and L 6 exceeded the limit with the value 113 and 34 mgl^{-1}. Higher concentration of calcium and magnesium in water may lead to encrustation in water supply structure and adverse effects on domestic use.

Chlorides (as Cl) were in the range of 84-1848 mgl^{-1} in case of all the samples. Desirable limit of it is 250 mgl^{-1}. Beyond the permissible limits, taste, corrosion and palatability may be affected. L 4, L 6, L 7 and L 8 exceed the permissible limit of chloride (Table 3). As there is intrusion of seawater the average chloride concentration in the lakes is very high.

Sulphate occurs in all natural water sources. This is an important nutrient used by plants and animals. The source of this element may be the parental bedrock. Sulphate (as SO_4) was found in range of 9-409 mgl^{-1}. Desirable limit of sulphate is 200 mgl^{-1}. Beyond the permissible limits, sulphate may cause gastro-intestinal irritation, when magnesium and sodium are also present. The lakes such as L 4 and L 7 exceed the limit of BIS.

Desirable limit for bicarbonate alkalinity as $CaCO_3$ in drinking water is 200 mg/l. Analytical result indicates that bicarbonates alkalinity is within the permissible limit.

Beyond desirable limits nitrate (as NO_3) may cause methaemoglobinemia. In surface water, nitrate is a nutrient taken up by plants and assimilated into cell protein. Analytical results suggests that nitrate in all the samples are found well below the desirable limit of 45 mgl^{-1}, and varied between <1-22.75 mgl^{-1}.

Above 1.5 mg/l fluoride which is the permissible limit in drinking water as per WHO standard, may cause fluorosis of varying nature. As indicated by analytical results, fluoride (as F) was found in the range <0.1 to 0.6 mgl^{-1}, which is within the limit.

Inorganic Metallic Constituents

If water sources are contaminated with toxic metals above the prescribed norms, water becomes toxic and in some cases even carcinogenic. The analytical results are summarised in Table 3. Following inferences can be drawn from the analytical values:

Copper in all samples was found in the range of <0.01 to 0.06 mgl^{-1}, which is below the limit as the permissible limit of copper is 2 mgl^{-1} according to WHO. Manganese in the lake water samples such as L 3 and L 7 were higher than the permissible limit. Concentrations of the manganese at or above the guideline value may affect the appearance, taste or odour of the water.

Iron is not hazardous to health but aesthetic value of water may be reduced appreciably due to coloration of water, which may be yellowish brown to black and turbidity formed by precipitation of oxides. Excess iron in water imparts bitter characteristics and metallic taste. In addition, carrying capacity of pipeline in the distribution system may reduce due to the deposition of iron oxide and bacterial slimes as a result of the growth of microorganism (iron utilizing bacteria) in iron bearing water. BIS desirable limit of iron in water is 0.3 mgl^{-1}. Water samples drawn from L 4 indicate higher concentration of iron (0.5 mgl^{-1}).

Heavy Metals

Mercury, cadmium, arsenic, selenium and chromium were analysed and found to be below the detection limit. However, further study of various lakes water for heavy metals will help in determining the exact values and understand the sources.

Lead was found in the range of <0.01-0.06 mg/l, which is not desirable in comparison to WHO guidelines. Lakes water of L 4, L 6, L 7 and L 7a has the values of 0.06, 0.04, 0.02 and 0.02 mgl^{-1}. These values are above the international guideline of WHO, and as per BIS the value of L 4 exceeds the prescribed limits (Table 3) and that is the matter of concern for consumption. It is also recommended for further investigation of the sources of the lead in the lakes water. The source of lead may be parental metamorphic or igneous rocks.

Cyanide

Cyanide, if present beyond the acceptable level, imparts toxicity in water. As evident by analysis results, all the samples showed the value of <0.01 mgl^{-1} (Table 3), which is below the WHO and BIS permissible limit.

Microbiological Quality

Water samples shall be free from coliform group of bacteria. In present study (Table 3), all the surface lake water samples were free from coliform bacteria. The test for detection of *E. coli* showed no observed growth. Therefore, microbiologically the lakes water of GP are free from microbial contamination and safe to drink.

CONCLUSION

The most undesirable constituents of drinking water are those capable of having a direct impact to the members of the Indian Antarctic Expeditions. In the present study, bio-physicochemical parameters were studied and evaluated for drinking water quality. The following conclusion are made:

1. The present study shows that some of the lakes water sources of the Grovnes Promontory (GP) have water of very high purity for drinking purposes, as most of the parameters are below the permissible limit of drinking water set by World Health Organisation (WHO) and Bureau of Indian Standards (BIS).
2. Some of the lakes have exceeded the prescribed limits of both the organisations. These are mainly due to eutrophic nature of the lakes.
3. The present work can serve as a baseline data for assessment of drinking water quality from lakes of GP. However, we recommend that before any logical conclusions for uptake of drinking water from the lakes further analysis of the various heavy metals and pesticides content of the water of GP for drinking purpose are needed.

ACKNOWLEDGEMENTS

We are thankful to the Management of Shriram Institute for Industrial Research for nominating KG and RK Singh to participate in the 26th ISEA. We also thank the Dr. Rasik Ravindra (Director), Dr. N. Khare, Dr. Rahul Mohan, Dr. Anoop Tiwari and all the employees of National Centre for Antarctic and Ocean Research, Goa for giving assistance and support to work at Larsemann Hills, east Antarctica. The support and co-operation rendered by the 26th Indian Scientific Expedition to Antarctica, Leader and Station Commander Shri. Jayapaul D, Shri Ajay Dhar, Incharge of the Larsemann Hills component and the entire team are thankfully acknowledged. The financial assistance given by the Ministry of Earth Sciences, Government of India is also thankfully acknowledged.

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