



# Occurrence of Polycyclic Aromatic Hydrocarbons (PAHs) in the Lake Water at Grovnes Peninsula Over East Antarctica

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## Abstract

**Purpose** Polycyclic aromatic hydrocarbons (PAHs) are toxic and volatile in nature. They can persist for a long time in the environment. The aim of this work was to investigate the levels of PAHs and their diagnostic ratios in the samples of lake water of Grovnes peninsula, East Antarctica.

**Methods** Total forty five samples were collected from fifteen different lakes of the Northern & Southern Grovnes peninsula. Sixteen compounds of PAHs were estimated in the samples by GC–MS/MS (Gas chromatography-mass spectrometry) technique.

**Results** PAHs levels were found from 10.33 to 44.35  $\mu\text{g ml}^{-1}$  in the lake water samples. Fluorene was detected in all fifteen different lakes. The highest concentration of fluorene was found in the L7BNG lake. PAHs diagnostic ratios were found in the range of 0.76–4.68 for  $\sum\text{LMW}/\sum\text{HMW}$ , 0.44–0.80 for FL/(FL + PYR), 1.00 for ANT/(ANT + PHE), 0.37–0.58 for FLA/(FLA + PYR), 0.44–0.47 for BaA/(BaA + CHR) in all fifteen different lakes.

**Conclusion** The present study confirms the presence of PAHs in a small amount in Grovnes peninsula, East Antarctica. The presence of additional pollutants should be investigated in order to comprehensively assess the scale of environmental pollution in Antarctica.

**Keywords** Grovnes peninsula · Larsemann Hills · East Antarctica · Lakes · PAHs (Polycyclic aromatic hydrocarbons), PAHs diagnostic ratios · GC–MS/MS (Gas chromatography-mass spectrometry)

## 1 Introduction

More than 150 lakes are situated on different islands and peninsulas of Larsemann Hills. The Larsemann Hills (69°24'S, 76°13'E) are an approximately 50  $\text{km}^2$  oasis which are located halfway between the Vestfold Hills and the Amery Ice Shelf on the southeastern coast of Prydz Bay, Princess Elizabeth Land, East Antarctica (Fig. 1). The lakes are the source of precious water and provide habitats for animals [1]. Most of the Antarctic lakes are freshwater lakes which exhibit a wide range of physical and chemical conditions. These lakes may be perennially or annually ice-covered and usually contain simplified truncated food webs.

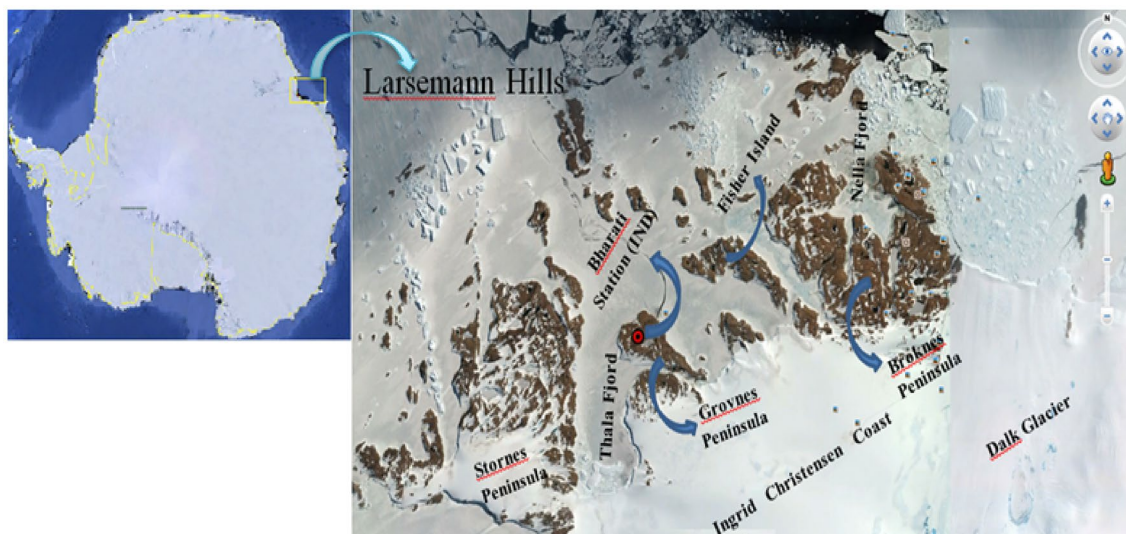
Gillieson [2] has explained that the melted polar ice gets accumulated in the depression around the Larsemann Hills and forms newly freshwater lakes. The ice melting increased in the summer season, which then supplies water to the lakes. While in the winter season, water is frozen and makes Antarctica the largest stock of freshwater on the globe [3, 4]. These lakes are being polluted due to anthropogenic activities such as various research activities, tourism, and logistic support [5]. The environment of Antarctica is changing hastily because anthropogenic activities and their impact are increasing incontinent. However, these effects are not evenly spread on the continent because the human footprints are minor with respect to the size of Antarctica.

PAHs are hydrophobic compounds and ubiquitous in nature [6, 7]. These chemical compounds are migrating globally due to the long-range atmospheric transport mechanism as well as through anthropogenic activities [8]. According to Fuoco et al. [9] and Barrie et al. [10] some amount of PAHs is transported to Antarctica through the migrant species, water and after travel an extensive distance, these

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**Fig. 1** The Continental Map of Antarctica (left) and the Location Map of the Study Area in the Larsemann Hills (right), East Antarctica

pollutants are dumped far from their original place. The soils/sediments have been identified as a final sink for PAHs where they can be released into the water [11]. These toxic compounds are semi-volatile and persist in the atmosphere for a long period [12]. They are highly toxic to organisms due to their carcinogenic and mutagenic potential [13, 14]. The toxicity of PAHs depends on their chemical structure and shares some characteristics like teratogenic, mutagenic, carcinogenic [15].

PAHs are the most frequent petroleum byproducts and are used as energy sources by research stations [16]. In the Antarctic environment, PAHs are usually associated with local activities and come from petroleum products [17]. They have lethal properties, especially in the case of chronic exposure, and may be harmful to the environment [18, 19]. Cripps [20] stated that supply ships and a few tourist vessels carry the major PAHs hazard. Dobbins et al. [21] and Liang et al. [22] have reported that the major source of the PAHs in the lakes of East Antarctica is diesel fuel which is commonly used in Antarctica. Local activities linked with transportation, fuel storage, and borehole drilling have inevitably led to the emission of fuel scums, combustion exhausts. Oil spills rather than long-range atmospheric transport appeared to be the more leading source of PAHs in the Antarctic lakes. Fuel combustion may also be a viable source of PAHs to the Antarctic lakes. Incomplete combustion from the agricultural, industrial, natural, and domestic is the major source of PAHs [23, 24].

PAHs resist biological, photolytic, chemical degradation and can be accidentally formed from industrial activities. Several researchers have reported the presence of PAHs in different components of abiotic and biotic [25–27]. PAHs diagnostic ratio is a new tool to differentiate PAH sources between the

pyrogenic (such as high-temperature combustion of biomass and fossil fuels) and the petrogenic (such as fuels, lubricants, crude oil, and their derivatives). It has been used to distinguish diesel and gasoline combustion emission [28], different crude oil processing products and biomass burning processes including bush, savanna, and grass fires [29]. Mackay et al. [30] stated that the compounds of the PAHs diagnostic ratio have similar physicochemical properties and similar molar mass. Manoli et al. [31] reported that the profile of PAH emission for a source depends on the PAHs producing processes. Low molecular weight PAHs (LMWPAHs) (less than 4 rings) are formed during the low-temperature processes such as wood-burning while high molecular weight PAHs (HMWPAHs) (greater than 3 rings) are formed during the high-temperature processes such as the combustion of fuels in engines [32, 33].

The aim of this study was to estimate the occurrence of PAHs and their diagnostic ratios in the lakes which were near the Bharati research station, on the Grovnes peninsula, East Antarctica. This study is novel itself because this is one of the rare studies which is analyzing PAHs and identify their diagnostic ratios in the Grovnes peninsula. This study exactly falls in the thrust area of the topic water sciences & environment of the journal. In the future, this study can make an important contribution to the checking concentration of PAHs in the Antarctic environment.

## 2 Experimental Section

### 2.1 Sampling Sites and Collection

Larsemann Hills are the biggest area of East Antarctica's coastline and has the two major peninsulas Stornes and

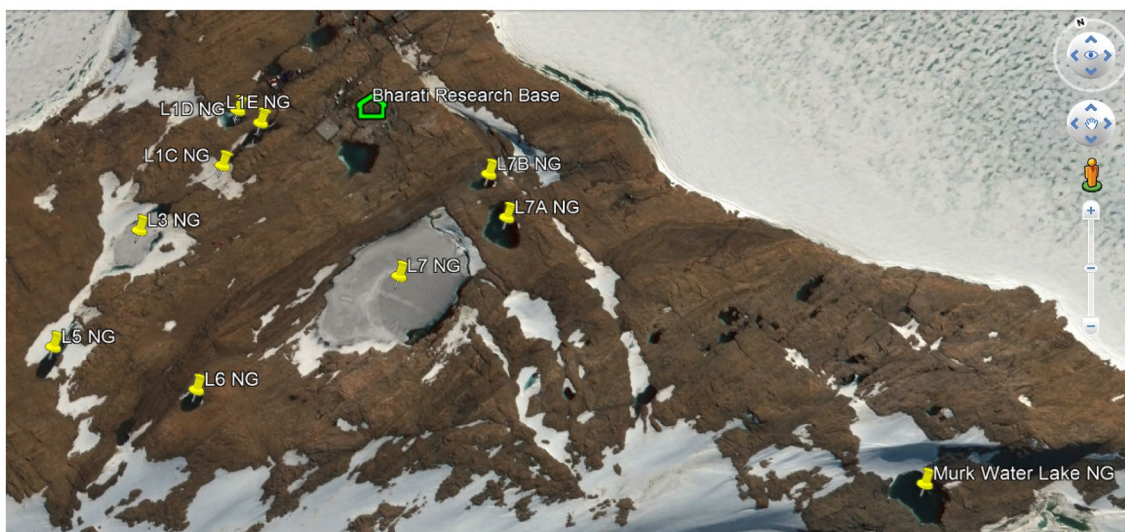
Broknæs, 130 nearshore islands, and four minor peninsulas [34]. Grovnes peninsula is situated between Broknæs and Stornes peninsula. It is divided into Northern and Southern Grovnes peninsula. The sampling sites for the study were on the Grovnes peninsula, which are shown in Figs. 2 and 3.

A total of forty five surface samples, 1.0 L each from fifteen lakes in triplicate were collected randomly during the 34th Indian Scientific Expedition to Antarctica (ISEA). The sample collection was carried out from 2014 to 2015 by helicopter. Thirty samples were collected from the ten different lakes of the Northern Grovnes peninsula and fifteen samples were collected from the five different lakes of the Southern Grovnes peninsula. The samples were collected in pre-cleaned

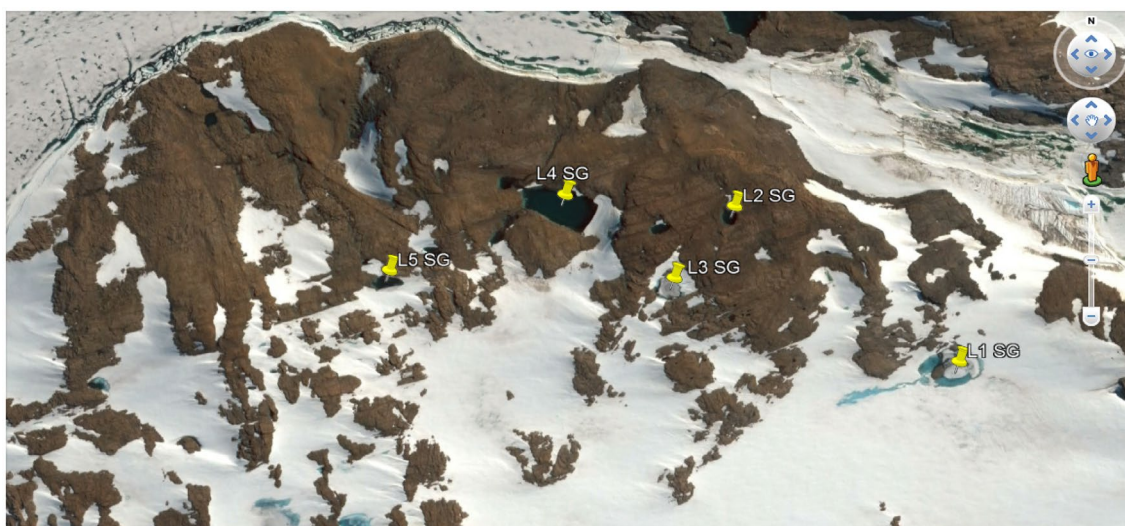
amber glass bottles. By using the method USEPA-1699 [35], the sampling bottles were pre-treated using deionized water, then rinsed with lake water before use. After that they were stored at  $-4\text{ }^{\circ}\text{C}$ . The lake's identification, coordinates, and depth are given in Table 1.

## 2.2 Requirements (Instruments/Reagents)

GC–MS/MS (Model-7000, Agilent), electronic weighing balance (Sartorius), rotary evaporator (Buchi), separatory funnel (2000 ml), glass chromatography column (250 mm length  $\times$  10 mm width) and round bottom (RB) (250 ml) flask were used for the PAHs analysis. The standard for



**Fig. 2** Location of Sampling Sites Mark with Pinpoints on Northern Grovnes Peninsula, East Antarctica



**Fig. 3** Location of Sampling Sites Mark with Pinpoints on Southern Grovnes Peninsula, East Antarctica

**Table 1** Identification of Lakes with their Coordinates and Sampling Depth

| S. No                      | Lake Identification | Latitude      | Longitude     | Date of Sampling | Sampling Depth |
|----------------------------|---------------------|---------------|---------------|------------------|----------------|
| Northern Grovnes Peninsula |                     |               |               |                  |                |
| 1                          | L1CNG               | 69°24'25.43"S | 76°11'17.66"E | 25-12-2014       | Surface        |
| 2                          | L1DNG               | 69°24'22.41"S | 76°11'22.26"E | 25-12-2014       |                |
| 3                          | L1ENG               | 69°24'23.51"S | 76°11'25.20"E | 26-12-2014       |                |
| 4                          | L3NG                | 69°24'27.72"S | 76°11'2.70"E  | 26-12-2014       |                |
| 5                          | L5NG                | 69°24'32.83"S | 76°10'45.75"E | 27-12-2014       |                |
| 6                          | L6NG                | 69°24'37.30"S | 76°11'5.13"E  | 27-12-2014       |                |
| 7                          | L7NG                | 69°24'34.32"S | 76°11'39.41"E | 28-12-2014       |                |
| 8                          | L7ANG               | 69°24'32.78"S | 76°11'57.96"E | 28-12-2014       |                |
| 9                          | L7BNG               | 69°24'30.05"S | 76°11'57.38"E | 29-12-2014       |                |
| 10                         | Murk Water Lake NG  | 69°24'53.37"S | 76°12'46.16"E | 30-12-2014       |                |
| Southern Grovnes Peninsula |                     |               |               |                  |                |
| 11                         | L1SG                | 69°25'13.70"S | 76°13'18.33"E | 02-01-2015       | Surface        |
| 12                         | L2SG                | 69°25' 5.10"S | 76°12'45.05"E | 03-01-2015       |                |
| 13                         | L3SG                | 69°25'09.07"S | 76°12'36.1"E  | 03-01-2015       |                |
| 14                         | L4SG                | 69°25'04.46"S | 76°12'19.93"E | 04-01-2015       |                |
| 15                         | L5SG                | 69°25'08.65"S | 76°11'53.9"E  | 04-01-2015       |                |

PAHs (XA11729V) was procured from Supelco. Hexane (SJ75F71067), cyclohexane (29,029,090), pentane (109,660), and methylene dichloride (2,233,940,917) were procured from Merck. Silica gel (S8171) of mesh size (100–200) and anhydrous sodium sulfate (Q14446) were purchased from Fisher Scientific. Before the use, silica gel was activated at 130 °C for 16 h and anhydrous sodium sulfate was kept at 400 °C for 4 h.

## 2.3 Analytical Methods

### 2.3.1 Sample Extraction

The lake water samples were extracted through the USEPA 3510B [36] method with slight modification. One liter of each lake water sample was taken into the glass separatory funnel and then 60 ml methylene dichloride was added. The sample was shaken for 1–2 min and released the extra pressure. The funnel was kept for 5–10 min on the stand to allow the organic layer separation from the water layer. The lower layer of methylene chloride was taken into an RB flask. This procedure was repeated two more times. The collected solvent was vaporized at 45 °C by the rotary evaporator. Then the final residue solution (2 ml) in cyclohexane was ready for a cleanup.

### 2.3.2 Sample Cleanup

The final residue solution was cleaned up through the USEPA 3630C [37] method. The glass chromatography column was organized with sodium sulfate and silica gel. Approx. 5 g silica gel and 2–3 g of sodium sulfate were

transferred into the column. The column was prewashed with 50 ml of pentane. The final extract solution was transferred into the column. A 50 ml of solution (pentane: methylene chloride, 1:1) was transferred into the column and then the column elution was collected into the RB flask with the flow rate of 0.5 ml. The whole process was repeated two times and the collected solvent was evaporated at 45 °C by the rotary evaporator. The residue was re-dissolved in 1 ml of hexane and then was transferred into a GC vial for the analysis of PAHs by GC–MS/MS.

### 2.4 Chromatographic Analysis

GC–MS/MS was used for the estimation of PAHs. The final sample solution (1 µl) was introduced into the system. The column HP-5MS (30 m × 0.25 mm × 0.25 µm, Agilent) was used for the separation of compounds. Helium was the carrier gas with a constant flow of 1 ml/min and nitrogen was the make-up gas. The temperature of the injector and detector was set at 280 °C. The initial temperature of GC oven was set at 70 °C for 2 min and ramped at 25 °C/minute, to 150 °C and then ramped at 3 °C/minute, to 200 °C and then ramped at 8 °C/minute to 280 °C for 10 min [38]. The overall time for the analysis was 41.87 min. The temperature of the transfer line was set at 280 °C and the quadrupole (Q1 & Q2) temperature was 180 °C.

### 2.5 Quality Assurance/Quality Control (QA/QC)

PAHs were quantified with their standards of different concentrations (10 pg ml<sup>-1</sup>, 25 pg ml<sup>-1</sup>, 50 pg ml<sup>-1</sup>, 100 pg ml<sup>-1</sup>, and 250 pg ml<sup>-1</sup>) by using GC–MS/MS

technique. Each lake water sample was evaluated in triplicate and then the mean value was taken. With every set of five samples, one blank was examined to check the contamination. For the recovery test, seven injections of the same concentration of a particular compound were injected into the system and the recovery rate was found between 40 and 100%, which fulfilled the acceptance criteria of the recovery limit of the USEPA 1699 [35] method. The limit of detection (LOD) for PAHs was  $10.00 \text{ pg ml}^{-1}$  while the RSD was  $< 2.0\%$ . The multiple reaction monitoring (MRM) of PAHs is listed below in Table 2 and basic detail (abbreviation, number of rings & molar mass) is shown in Table 3.

### 3 Results

In this study, the concentration of PAHs was varied from  $10.33 \text{ pg ml}^{-1}$  to  $44.35 \text{ pg ml}^{-1}$  in the fifteen lakes of Grovnes peninsula, East Antarctica. Fluorene was higher in the samples of L7BNG.

#### 3.1 Estimation of PAHs in the Samples of the Northern Grovnes peninsula

The concentration of PAHs was found from  $10.45 \text{ pg ml}^{-1}$  to  $44.35 \text{ pg ml}^{-1}$  in the ten lakes of the Northern Grovnes peninsula. The concentrations of PAHs compounds are shown in Fig. 4 and Tables 4 and 5.

**Table 2** Multiple Reaction Monitoring (MRM) of Different Compounds of PAHs

| Compound Name           | Quantifier/ Qualifier | Precursor ion (amu) (Q1) | Product ion (amu) (Q3) | Dwell Time (Second) | Collision Energy (eV) |
|-------------------------|-----------------------|--------------------------|------------------------|---------------------|-----------------------|
| Naphthalene             | Quantifier            | 128.1                    | 78.1                   | 10                  | 20                    |
| Naphthalene             | Qualifier             | 102.1                    | 76.1                   | 10                  | 15                    |
| Acenaphthylene          | Quantifier            | 152.1                    | 102.1                  | 10                  | 30                    |
| Acenaphthylene          | Qualifier             | 150.1                    | 98                     | 10                  | 30                    |
| Acenaphthene            | Quantifier            | 154.1                    | 127                    | 10                  | 40                    |
| Acenaphthene            | Qualifier             | 152.1                    | 126                    | 10                  | 30                    |
| Fluorene                | Quantifier            | 165.1                    | 164.1                  | 10                  | 20                    |
| Fluorene                | Qualifier             | 165.1                    | 115.1                  | 10                  | 30                    |
| Phenanthrene            | Quantifier            | 176.1                    | 150.1                  | 10                  | 25                    |
| Phenanthrene            | Qualifier             | 179.1                    | 153.1                  | 10                  | 25                    |
| Anthracene              | Quantifier            | 178.1                    | 151.1                  | 10                  | 30                    |
| Anthracene              | Qualifier             | 152.1                    | 151.1                  | 10                  | 15                    |
| Fluoranthene            | Quantifier            | 202.1                    | 152.1                  | 10                  | 30                    |
| Fluoranthene            | Qualifier             | 200.1                    | 174                    | 10                  | 25                    |
| Pyrene                  | Quantifier            | 200.1                    | 150                    | 10                  | 30                    |
| Pyrene                  | Qualifier             | 200.1                    | 174                    | 10                  | 25                    |
| Benz[a]anthracene       | Quantifier            | 229.1                    | 227.1                  | 10                  | 30                    |
| Benz[a]anthracene       | Qualifier             | 114                      | 101.1                  | 10                  | 10                    |
| Chrysene                | Quantifier            | 113.1                    | 112.1                  | 10                  | 10                    |
| Chrysene                | Qualifier             | 113.1                    | 100.1                  | 10                  | 10                    |
| Benzo[b]fluoranthene    | Quantifier            | 113                      | 112.1                  | 10                  | 10                    |
| Benzo[b]fluoranthene    | Qualifier             | 126                      | 113.1                  | 10                  | 10                    |
| Benzo[k]fluoranthene    | Quantifier            | 250.1                    | 248.1                  | 10                  | 40                    |
| Benzo[k]fluoranthene    | Qualifier             | 126.1                    | 113.1                  | 10                  | 10                    |
| Benzo[a]pyrene          | Quantifier            | 250.1                    | 248                    | 10                  | 40                    |
| Benzo[a]pyrene          | Qualifier             | 125                      | 124.1                  | 10                  | 10                    |
| Indeno[1,2,3-cd] pyrene | Quantifier            | 137                      | 136                    | 10                  | 15                    |
| Indeno[1,2,3-cd] pyrene | Qualifier             | 138.1                    | 125.1                  | 10                  | 15                    |
| Dibenz[a,h]anthracene   | Quantifier            | 276.1                    | 274.1                  | 10                  | 35                    |
| Dibenz[a,h]anthracene   | Qualifier             | 125                      | 124.1                  | 10                  | 10                    |
| Benzo[g,h,i]perylene    | Quantifier            | 137.0                    | 136                    | 10                  | 15                    |
| Benzo[g,h,i]perylene    | Qualifier             | 138                      | 125                    | 10                  | 15                    |

**Table 3** Different PAHs Compounds with their Abbreviation, Number of Rings and Molar Mass

| S. No | Compound Name           | Abbreviation | Number of Rings | Molar Mass [gm] |
|-------|-------------------------|--------------|-----------------|-----------------|
| 1     | Naphthalene             | NP           | 2               | 128.17          |
| 2     | Acenaphthylene          | ACY          | 3               | 152.19          |
| 3     | Acenaphthene            | ACE          | 3               | 154.21          |
| 4     | Fluorene                | FL           | 3               | 166.22          |
| 5     | Phenanthrene            | PHE          | 3               | 178.23          |
| 6     | Anthracene              | ANT          | 3               | 178.23          |
| 7     | Fluoranthene            | FLA          | 4               | 202.25          |
| 8     | Pyrene                  | PYR          | 4               | 202.25          |
| 9     | Benz[a]anthracene       | BaA          | 4               | 228.29          |
| 10    | Chrysene                | CHR          | 4               | 228.29          |
| 11    | Benzo[b]fluoranthene    | BbF          | 5               | 252.31          |
| 12    | Benzo[k]fluoranthene    | BkF          | 5               | 252.31          |
| 13    | Benzo[a]pyrene          | BaP          | 5               | 252.31          |
| 14    | Indeno[1,2,3-cd] pyrene | IcdP         | 6               | 276.33          |
| 15    | Dibenz[a,h]anthracene   | DahA         | 5               | 278.35          |
| 16    | Benzo[g,h,i]perylene    | BghiP        | 6               | 276.33          |

### 3.1.1 L1CNG Lake

Naphthalene was the main pollutant with a high concentration of  $26.33 \pm 1.53$  pg ml<sup>-1</sup>, followed by fluorene  $21.00 \pm 1.00$  pg ml<sup>-1</sup>, anthracene  $18.00 \pm 4.58$  pg ml<sup>-1</sup>, pyrene  $18.00 \pm 2.65$  pg ml<sup>-1</sup>, acenaphthene  $14.68 \pm 1.54$  pg ml<sup>-1</sup>, fluoranthene  $13.01 \pm 1.72$  pg ml<sup>-1</sup>, chrysene  $11.47 \pm 0.80$  pg ml<sup>-1</sup> while other compounds were found in BDL.

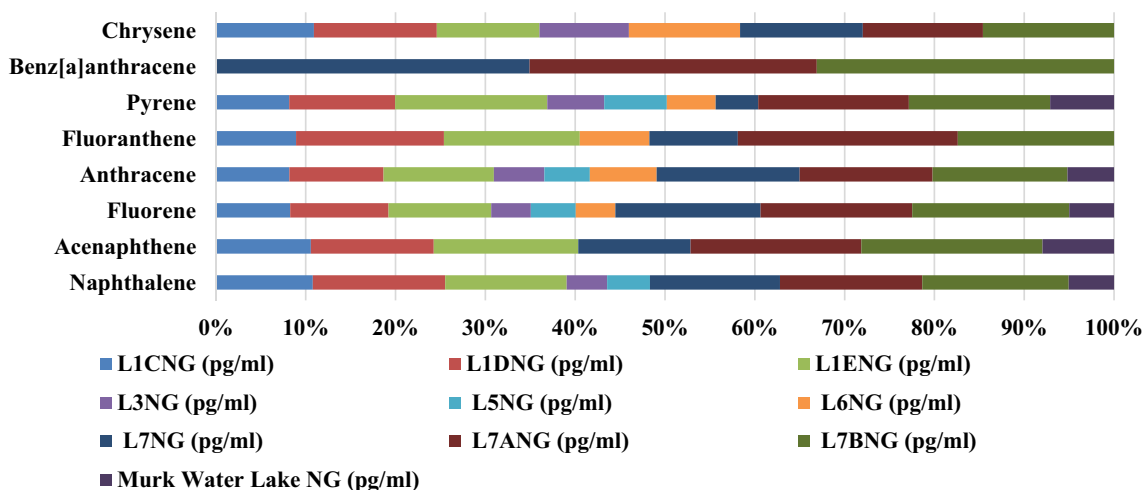
### 3.1.2 L1DNG Lake

Naphthalene was the main pollutant with a high concentration of  $36.00 \pm 2.00$  pg ml<sup>-1</sup>, followed by fluorene

$27.77 \pm 2.25$  pg ml<sup>-1</sup>, pyrene  $26.00 \pm 2.00$  pg ml<sup>-1</sup>, fluoranthene  $24.00 \pm 3.61$  pg ml<sup>-1</sup>, anthracene  $23.03 \pm 0.99$  pg ml<sup>-1</sup>, acenaphthene  $19.00 \pm 1.00$  pg ml<sup>-1</sup>, chrysene  $14.36 \pm 1.52$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.3 L1ENG Lake

Pyrene was the main pollutant with a high concentration of  $37.34 \pm 3.05$  pg ml<sup>-1</sup>, followed by naphthalene  $33.00 \pm 1.00$  pg ml<sup>-1</sup>, fluorene  $29.00 \pm 3.61$  pg ml<sup>-1</sup>, anthracene  $27.00 \pm 2.00$  pg ml<sup>-1</sup>, acenaphthene  $22.33 \pm 1.53$  pg ml<sup>-1</sup>, fluoranthene  $22.03 \pm 4.38$  pg ml<sup>-1</sup>,



**Fig. 4** Occurrence of PAHs in the Samples of Northern Grovnes Peninsula

**Table 4** Concentration of Different PAHs in the Samples of Northern Grovnes Peninsula

| S. No | Compound Name               | LICNG                        |      | LIDNG                        |      | LIENG                        |      | L3NG                         |      | L5NG                         |      |
|-------|-----------------------------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|
|       |                             | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   |
| 1     | Naphthalene                 | 26.33                        | 1.53 | 36.00                        | 2.00 | 33.00                        | 1.00 | 11.00                        | 1.00 | 11.67                        | 0.58 |
| 2     | Acenaphthylene              | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 3     | Acenaphthene                | 14.68                        | 1.54 | 19.00                        | 1.00 | 22.33                        | 1.53 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 4     | Fluorene                    | 21.00                        | 1.00 | 27.77                        | 2.25 | 29.00                        | 3.61 | 11.17                        | 0.85 | 12.69                        | 1.53 |
| 5     | Phenanthrene                | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 6     | Anthracene                  | 18.00                        | 4.58 | 23.03                        | 0.99 | 27.00                        | 2.00 | 12.33                        | 2.08 | 11.13                        | 0.85 |
| 7     | Fluoranthene                | 13.01                        | 1.72 | 24.00                        | 3.61 | 22.03                        | 4.38 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 8     | Pyrene                      | 18.00                        | 2.65 | 26.00                        | 2.00 | 37.34                        | 3.05 | 14.00                        | 1.73 | 15.35                        | 2.51 |
| 9     | Benz[a]anthracene           | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 10    | Chrysene                    | 11.47                        | 0.80 | 14.36                        | 1.52 | 12.00                        | 2.00 | 10.45                        | 0.50 | <10.00                       | 0.00 |
| 11    | Benzo[b]fluoranthene        | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 12    | Benzo[k]fluoranthene        | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 13    | Benzo[a]pyrene              | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 14    | Indeno[1,2,3-cd] pyrene     | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 15    | Dibenz[a,h]anthracene       | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 16    | Benzo[g,h,i]perylene        | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
|       | <b>Total PAHs (Σ16PAHs)</b> | 122.49                       |      | 170.16                       |      | 182.70                       |      | 58.95                        |      | 50.84                        |      |

\*SD Standard Deviation

**Table 5** Concentration of Different PAHs in the Samples of Northern Grovnes Peninsula

| S. No | Compound Name           | L6NG                         |      | L7NG                         |      | L7ANG                        |      | L7BNG                        |      | Murk Water Lake NG           |      |
|-------|-------------------------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|
|       |                         | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   |
| 1     | Naphthalene             | <10.00                       | 0.00 | 35.33                        | 3.06 | 38.67                        | 1.53 | 39.80                        | 1.59 | 12.33                        | 2.08 |
| 2     | Acenaphthylene          | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 3     | Acenaphthene            | <10.00                       | 0.00 | 17.36                        | 1.54 | 26.38                        | 0.56 | 28.00                        | 2.00 | 11.07                        | 0.90 |
| 4     | Fluorene                | 11.20                        | 0.80 | 41.00                        | 4.00 | 42.80                        | 0.72 | 44.35                        | 3.07 | 12.67                        | 1.53 |
| 5     | Phenanthrene            | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 6     | Anthracene              | 16.35                        | 2.50 | 35.00                        | 4.36 | 32.53                        | 2.55 | 33.00                        | 5.57 | 11.40                        | 1.51 |
| 7     | Fluoranthene            | 11.30                        | 0.82 | 14.35                        | 1.52 | 35.69                        | 2.50 | 25.36                        | 0.60 | <10.00                       | 0.00 |
| 8     | Pyrene                  | 12.00                        | 2.00 | 10.43                        | 0.51 | 37.00                        | 2.65 | 34.67                        | 2.52 | 15.70                        | 1.50 |
| 9     | Benz[a]anthracene       | <10.00                       | 0.00 | 12.53                        | 2.25 | 11.47                        | 0.50 | 11.87                        | 1.20 | <10.00                       | 0.00 |
| 10    | Chrysene                | 13.00                        | 2.65 | 14.35                        | 1.51 | 14.04                        | 0.05 | 15.33                        | 2.08 | <10.00                       | 0.00 |
| 11    | Benzo[b]fluoranthene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 12    | Benzo[k]fluoranthene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 13    | Benzo[a]pyrene          | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 14    | Indeno[1,2,3-cd] pyrene | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 15    | Dibenz[a,h]anthracene   | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 16    | Benzo[g,h,i]perylene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
|       | Total PAHs (Σ16PAHs)    | 63.85                        |      | 180.35                       |      | 238.58                       |      | 232.38                       |      | 63.17                        |      |

\*SD = Standard Deviation



chrysene  $12.00 \pm 2.00$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.4 L3NG Lake

Pyrene was the main pollutant with a high concentration of  $14.00 \pm 1.73$  pg ml<sup>-1</sup>, followed by anthracene  $12.33 \pm 2.08$  pg ml<sup>-1</sup>, fluorene  $11.17 \pm 0.85$  pg ml<sup>-1</sup>, naphthalene  $11.00 \pm 1.00$  pg ml<sup>-1</sup>, chrysene  $10.45 \pm 0.50$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.5 L5NG Lake

Pyrene was the main pollutant with a high concentration of  $15.35 \pm 2.51$  pg ml<sup>-1</sup>, followed by fluorene  $12.69 \pm 1.53$  pg ml<sup>-1</sup>, naphthalene  $11.67 \pm 0.58$  pg ml<sup>-1</sup>, anthracene  $11.13 \pm 0.85$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.6 L6NG Lake

Anthracene was the main pollutant with a high concentration of  $16.35 \pm 2.50$  pg ml<sup>-1</sup>, followed by chrysene  $13.00 \pm 2.65$  pg ml<sup>-1</sup>, pyrene  $12.00 \pm 2.00$  pg ml<sup>-1</sup>, fluoranthene  $11.30 \pm 0.82$  pg ml<sup>-1</sup>, fluorene  $11.20 \pm 0.80$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.7 L7NG Lake

Fluorene was the main pollutant with a high concentration of  $41.00 \pm 4.00$  pg ml<sup>-1</sup>, followed by naphthalene  $35.33 \pm 3.06$  pg ml<sup>-1</sup>, anthracene  $35.00 \pm 4.36$  pg ml<sup>-1</sup>, acenaphthene  $17.36 \pm 1.54$  pg ml<sup>-1</sup>, fluoranthene  $14.35 \pm 1.52$  pg ml<sup>-1</sup>, chrysene  $14.35 \pm 1.51$  pg ml<sup>-1</sup>, benz[a]anthracene  $12.53 \pm 2.25$  pg ml<sup>-1</sup>, pyrene  $10.43 \pm 0.51$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.8 L7ANG Lake

Fluorene was the main pollutant with a high concentration of  $42.80 \pm 0.72$  pg ml<sup>-1</sup>, followed by naphthalene  $38.67 \pm 1.53$  pg ml<sup>-1</sup>, pyrene  $37.00 \pm 2.65$  pg ml<sup>-1</sup>, fluoranthene  $35.69 \pm 2.50$  pg ml<sup>-1</sup>, anthracene  $32.53 \pm 2.55$  pg ml<sup>-1</sup>, acenaphthene  $26.38 \pm 0.56$  pg ml<sup>-1</sup>, chrysene  $14.04 \pm 0.05$  pg ml<sup>-1</sup>, benz[a]anthracene  $11.47 \pm 0.50$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.9 L7BNG Lake

Fluorene was the main pollutant with a high concentration of  $44.35 \pm 3.07$  pg ml<sup>-1</sup>, followed by naphthalene

$39.80 \pm 1.59$  pg ml<sup>-1</sup>, pyrene  $34.67 \pm 2.52$  pg ml<sup>-1</sup>, anthracene  $33.00 \pm 5.57$  pg ml<sup>-1</sup>, acenaphthene  $28.00 \pm 2.00$  pg ml<sup>-1</sup>, fluoranthene  $25.36 \pm 0.60$  pg ml<sup>-1</sup>, chrysene  $15.33 \pm 2.08$  pg ml<sup>-1</sup>, benz[a]anthracene  $11.87 \pm 1.20$  pg ml<sup>-1</sup> while other compounds were found in BDL.

### 3.1.10 Murk Water Lake

Pyrene was the main pollutant with a high concentration of  $15.70 \pm 1.50$  pg ml<sup>-1</sup>, followed by fluorene  $12.67 \pm 1.53$  pg ml<sup>-1</sup>, naphthalene  $12.33 \pm 2.08$  pg ml<sup>-1</sup>, anthracene  $11.40 \pm 1.51$  pg ml<sup>-1</sup>, acenaphthene  $11.07 \pm 0.90$  pg ml<sup>-1</sup> while other compounds were found in BDL.

## 3.2 Estimation of PAHs in the Samples of the Southern Grovnes Peninsula

The concentration of PAHs was found from  $10.33$  pg ml<sup>-1</sup> to  $41.00$  pg ml<sup>-1</sup> in the five lakes of the Southern Grovnes peninsula. The concentrations of PAHs compounds are shown in Fig. 5 and Table 6.

### 3.2.1 L1SG Lake

Anthracene was the main pollutant with a high concentration of  $13.69 \pm 2.05$  pg ml<sup>-1</sup>, followed by fluorene  $11.68 \pm 1.53$  pg ml<sup>-1</sup>, pyrene  $11.13 \pm 1.10$  pg ml<sup>-1</sup>, acenaphthene  $10.53 \pm 0.42$  pg ml<sup>-1</sup> and other compounds were found in BDL.

### 3.2.2 L2SG Lake

Fluorene was the main pollutant with a high concentration of  $36.00 \pm 3.61$  pg ml<sup>-1</sup>, followed by pyrene  $30.53 \pm 0.50$  pg ml<sup>-1</sup>, acenaphthene  $23.35 \pm 2.05$  pg ml<sup>-1</sup>, naphthalene  $15.67 \pm 2.52$  pg ml<sup>-1</sup> and other compounds were found in BDL.

### 3.2.3 L3SG Lake

Fluorene was the main pollutant with a high concentration of  $12.00 \pm 1.00$  pg ml<sup>-1</sup>, followed by pyrene  $11.73 \pm 2.05$  pg ml<sup>-1</sup>, naphthalene  $11.00 \pm 1.00$  pg ml<sup>-1</sup> and other compounds were found in BDL.

### 3.2.4 L4SG Lake

Fluorene was the main pollutant with a high concentration of  $41.00 \pm 1.00$  pg ml<sup>-1</sup>, followed by naphthalene  $29.73 \pm 1.55$  pg ml<sup>-1</sup>, anthracene  $20.00 \pm 4.58$  pg ml<sup>-1</sup>, acenaphthene  $13.69 \pm 2.06$  pg ml<sup>-1</sup>, chrysene

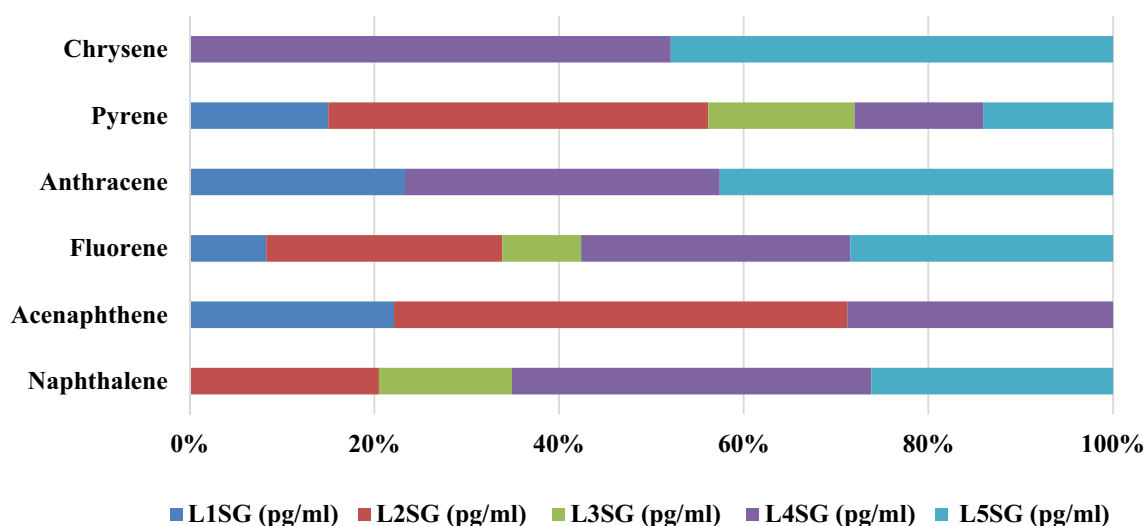


Fig. 5 Occurrence of PAHs in the Samples of Southern Grovnes Peninsula

$11.97 \pm 1.05 \text{ pg ml}^{-1}$ , pyrene  $10.33 \pm 0.58 \text{ pg ml}^{-1}$  and other compounds were found in BDL.

### 3.2.5 L5SG Lake

Fluorene was the main pollutant with a high concentration of  $40.07 \pm 2.00 \text{ pg ml}^{-1}$ , followed by anthracene  $25.00 \pm 2.65 \text{ pg ml}^{-1}$ , naphthalene  $20.00 \pm 1.00 \text{ pg ml}^{-1}$ , chrysene  $11.00 \pm 1.00 \text{ pg ml}^{-1}$ , pyrene  $10.43 \pm 0.12 \text{ pg ml}^{-1}$  and other compounds were found in BDL.

### 3.3 PAHs Diagnostic Ratio in the Samples of the Northern Grovnes Peninsula

PAHs diagnostic ratio is based on the parent PAHs and is applicable to the determination of PAHs in water, air, soil, and sediment. Different PAHs diagnostic ratios were calculated in the samples on the basis of the concentration of PAHs. They were found in the range of 0.76 to 3.02 for  $\sum\text{LMW}/\sum\text{HMW}$ , 0.44–0.80 for  $\text{FL}/(\text{FL} + \text{PYR})$ , 1.00 for  $\text{ANT}/(\text{ANT} + \text{PHE})$ , 0.37–0.58 for  $\text{FLA}/(\text{FLA} + \text{PYR})$ , 0.44–0.47 for  $\text{BaA}/(\text{BaA} + \text{CHR})$  in the ten different lakes of the Northern Grovnes peninsula. PAHs diagnostic ratios are shown in Table 7.

### 3.4 PAHs Diagnostic Ratio in the Samples of the Southern Grovnes Peninsula

Different PAHs diagnostic ratios were calculated in the samples on the basis of the concentration of PAHs. They were found in the range of 1.96–4.68 for  $\sum\text{LMW}/\sum\text{HMW}$ , 0.51–0.80 for  $\text{FL}/(\text{FL} + \text{PYR})$ , 1.00 for  $\text{ANT}/(\text{ANT} + \text{PHE})$  in the five different lakes of the Southern Grovnes peninsula. PAHs diagnostic ratios are shown in Table 8.

## 4 Discussion

The result of the present study indicates that lakes in the vicinity of the Bharati research station on Grovnes peninsula have been polluted with traces of PAHs. We found that the lakes close to the research station, such as L1CNG, L1DNG, L1ENG, L7NG, L7ANG & L7BNG had relatively high PAHs concentration while lakes far from the research stations such as L3NG, L5NG, L6NG, L1SG, L2SG, L3SG, L4SG & L5SG had low PAHs concentration. This contamination may be due to the discharge from the research station and the influence of anthropogenic activities such as the use of carbon-based fuels for household activities, power generation, and transportation. Lenihan et al. [39] & Cripps [20] also stated in their study that the presence of PAHs levels was due to anthropogenic activities, which came from the research station and tourism while Wania and Mackay [40] supported the theory of migration of PAHs from world to pole. The discharge from the McMurdo research station was affecting the lakes near the research station [41].

Human activities such as oil spills from transportation or even oil spills from vehicles or the use of oil or gasoline, which burns at high temperatures in light-duty gasoline vehicles, as well as fossil-fuel combustion, were responsible for the low PAHs in the lakes far from the research station [42–44]. Most of the locations in Antarctica at which PAHs have been reported by researchers for example- Western Antarctica Dickhut [45], Gerlache Inlet, Ross Sea & Teranova Bay [46]. These locations have a relatively long history of human activities such as improper disposal of old electrical equipment and incineration of wastes generated by the research stations. The presence of PAH concentration near to the different research stations (McMurdo station 621–5024 ng g<sup>-1</sup>; Jubany station 28–1908 ng g<sup>-1</sup>; James

**Table 6** Concentration of Different PAHs in the Samples of Southern Grovnes Peninsula

| S. No | Compound Name           | L1SG                         |      | L2SG                         |      | L3SG                         |      | L4SG                         |      | L5SG                         |      |
|-------|-------------------------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|------|
|       |                         | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   | Conc. (pg ml <sup>-1</sup> ) | SD   |
| 1     | Naphthalene             | <10.00                       | 0.00 | 15.67                        | 2.52 | 11.00                        | 1.00 | 29.73                        | 1.55 | 20.00                        | 1.00 |
| 2     | Acenaphthylene          | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 3     | Acenaphthene            | 10.53                        | 0.42 | 23.35                        | 2.05 | <10.00                       | 0.00 | 13.69                        | 2.06 | <10.00                       | 0.00 |
| 4     | Fluorene                | 11.68                        | 1.53 | 36.00                        | 3.61 | 12.00                        | 1.00 | 41.00                        | 1.00 | 40.07                        | 2.00 |
| 5     | Phenanthrene            | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 6     | Anthracene              | 13.69                        | 2.05 | <10.00                       | 0.00 | <10.00                       | 0.00 | 20.00                        | 4.58 | 25.00                        | 2.65 |
| 7     | Fluoranthene            | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 8     | Pyrene                  | 11.13                        | 1.10 | 30.53                        | 0.50 | 11.73                        | 2.05 | 10.33                        | 0.58 | 10.43                        | 0.12 |
| 9     | Benz[a]anthracene       | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 10    | Chrysene                | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | 11.97                        | 1.05 | 11.00                        | 1.00 |
| 11    | Benzo[b]fluoranthene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 12    | Benzo[k]fluoranthene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 13    | Benzo[a]pyrene          | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 14    | Indeno[1,2,3-cd] pyrene | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 15    | Dibenz[a,h]anthracene   | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
| 16    | Benzo[g,h,i]perylene    | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 | <10.00                       | 0.00 |
|       | Total PAHs (Σ16PAHs)    | 47.03                        |      | 105.55                       |      | 34.73                        |      | 126.72                       |      | 106.50                       |      |

\*SD Standard Deviation

**Table 7** PAHs Diagnostic Ratio in the Samples of Northern Grovnes Peninsula

| S. No | PAHs Ratio          | L1CNG | L1DNG | L1ENG | L3NG | L5NG | L6NG | L7NG | L7ANG | L7BNG | Murk Water Lake NG |
|-------|---------------------|-------|-------|-------|------|------|------|------|-------|-------|--------------------|
| 1     | $\sum LMW/\sum HMW$ | 1.88  | 1.64  | 1.56  | 1.41 | 2.31 | 0.76 | 2.49 | 1.43  | 1.66  | 3.02               |
| 2     | FL/(FL + PYR)       | 0.54  | 0.52  | 0.44  | 0.44 | 0.45 | 0.48 | 0.80 | 0.54  | 0.56  | 0.45               |
| 3     | ANT/(ANT + PHE)     | 1.00  | 1.00  | 1.00  | 1.00 | 1.00 | 1.00 | 1.00 | 1.00  | 1.00  | 1.00               |
| 4     | FLA/(FLA + PYR)     | 0.42  | 0.48  | 0.37  | 0.00 | 0.00 | 0.48 | 0.58 | 0.49  | 0.42  | 0.00               |
| 5     | BaA/(BaA + CHR)     | 0.00  | 0.00  | 0.00  | 0.00 | 0.00 | 0.00 | 0.47 | 0.45  | 0.44  | 0.00               |
| 6     | BaP/(BaP + BeP)     | 0.00  | 0.00  | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00  | 0.00  | 0.00               |
| 7     | IcdP/(IcdP + BghiP) | 0.00  | 0.00  | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00  | 0.00  | 0.00               |

\* $\sum LMW$  sum of two and three ring PAHs,  $\sum HMW$  sum of four and five ring PAHs

**Table 8** PAHs Diagnostic Ratio in the Samples of Southern Grovnes Peninsula

| S. No | PAHs Ratio          | L1SG | L2SG | L3SG | L4SG | L5SG |
|-------|---------------------|------|------|------|------|------|
| 1     | $\sum LMW/\sum HMW$ | 3.23 | 2.46 | 1.96 | 4.68 | 3.97 |
| 2     | FL/(FL + PYR)       | 0.51 | 0.54 | 0.51 | 0.80 | 0.79 |
| 3     | ANT/(ANT + PHE)     | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 |
| 4     | FLA/(FLA + PYR)     | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5     | BaA/(BaA + CHR)     | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6     | BaP/(BaP + BeP)     | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7     | IcdP/(IcdP + BghiP) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

\* $\sum LMW$  sum of two and three ring PAHs;  $\sum HMW$  = sum of four and five ring PAHs

Ross Island 1–2005 ng g<sup>-1</sup>) [47–49] was due to oil spills or fuel combustion.

The highest total PAH concentrations ( $\sum 16$ PAHs) were observed in L7ANG followed by L7BNG, L1ENG, L7NG, L1DNG, L4SG, L1CNG, L5SG, L2SG, L6NG, Murk Water Lake NG, L3NG, L5NG, L1SG & L3SG. Phenanthrene, pyrene, and fluoranthene were reported as the most abundant PAHs on King George Island, Antarctica [50]. Alekseev and Abakumov [51] reported the PAHs (fluorene and acenaphthylene) in the soil of Larsemann Hills, Fulmar Island, Eastern Antarctica. Our study also reported a high concentration of fluorene and naphthalene. Apart from these two, pyrene, fluoranthene, anthracene, acenaphthene, chrysene, benz-ananthracene, etc. reported in trace quantities. While acenaphthylene, phenanthrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenz[a,h]anthracene, benzo[g,h,i]perylene were found below the detection limits.

Several researchers have reported the presence of PAHs from the different parts of Antarctica such as, in penguins and seabirds [52], naphthalene, and acenaphthalene in the lake water samples of Sarah Tarn near the Law Base station of East Antarctica [53], in Inland Lake of Larsemann Hills from 14 to 360 ng l<sup>-1</sup> [54], in the wreck (up to 600  $\mu$ g kg<sup>-1</sup>) of the Bahia Paraiso near the USA Palmer research station, Anvers Island [16], in sewage effluents and small oil spillages [55], in the air (7134.49 pg m<sup>-3</sup>) and in

soil (61.09 ng g<sup>-1</sup>) from the Filds peninsula, King George Island [56], in oil exposed soil samples (0.9–30.8 mg kg<sup>-1</sup>) of King George Island [57], naphthalene, phenanthrene, and fluorene from the Fildes peninsula, King George Island [58]. Szopińska et al. [59] have studied the PAHs in Antarctic diesel-exposed soils or sediments (10–40 mg kg<sup>-1</sup>) and in non-exposed samples (10–100  $\mu$ g kg<sup>-1</sup>).

The occurrences of PAHs in the Antarctic lake water samples explain the transportation of contamination. Atmospheric transportation may be a possible source of PAHs. The presence of PAHs in the Antarctic residents is due to biomagnification [60] while in the lake water, soil and sediment is due to the activities of the Antarctic residents [61]. The presence of PAHs in the Antarctic lakes may constitute a potentially negative effect on the environment of Antarctica [62]. The accumulation of PAHs in the Antarctic organisms and its environment may cause mutagenicity, genotoxicity, reproductive disorders, and interference in the immune system.

#### 4.1 Identification of PAHs Sources by Diagnostic Ratio

Several scientists reported different PAHs emission sources based on the PAHs diagnostic ratio. Wang et al. [63] reported combustion and petroleum-related sources of PAH emission on the basis of ANT/(ANT + PHE) and

FLA/(PYR + FLA) in the water samples of the Yellow River Delta while Wang et al. [64] studied the mixed petrogenic and pyrogenic sources of PAHs in the samples of the Pearl River Delta. The combustion is a source of waterborne PAHs on the basis of BaA/(BaA + CHR), ANT/(ANT + PHE) and IcdP/(IcdP + BghiP), while petroleum combustion and coal/biomass burning are the sources of PAHs in Elelenwo Creek water of Nigeria on the basis of FLA/(PYR + FLA) [65].

The ratio FLA/(PYR + FLA) indicated sampling points affected by fuel combustion processes, unburnt petroleum products and biomass burning [66]. Riccardi et al. [67] reported the PAHs in the groundwater originated from fuel leaks on the basis of ANT/(ANT + PHE) and FLA/(PYR + FLA). Wang et al. [68] studied that coal combustion is the source of PAHs in the precipitation samples of Taisihan Mountain, China on the basis of PHE/(PHE + ANT), FLA/(FLA + PYR), and BaA/(BaA + CHR) ratios. The LMWPAHs/HMWPAHs ratio may be much higher for water samples than PM<sub>2.5</sub> and particulate matter samples [69]. Hwang and Foster [70] described that coal-burning as PAHs emission sources on the basis of high BbF/BkF and BaA/CHR. Jacobs et al. [71] stated that PAHs undergo photolysis in the aquatic environment which may alter the values of diagnostic ratios. The ratios FLA/(FLA + PYR), IcdP/(IcdP + BghiP) are more conservative than ANT/(ANT + PHE), BaA/(BaA + CHR), and are sensitive to photodegradation. The ratio ANT/(ANT + PHE) is sensitive to environmental changes. Tobiszewski and Namieśnik [72] have well presented the PAHs emission sources with the value of PAHs diagnostic ratios in Table 9.

Our study reported the PAHs ratio  $\sum\text{LMW}/\sum\text{HMW} > 1$  for all lakes of the Grovnes peninsula except L6NG. The ratio FL/(FL + PYR) was found  $> 0.5$  for all lakes except L1ENG, L3NG, L5NG, L6NG & Murk Water Lake NG. The ratio ANT/(ANT + PHE) was found  $> 0.1$  for all lakes except L2SG & L3SG. The ratio FLA/(FLA + PYR) was found  $< 0.4$  for L1ENG, 0.4–0.5 for L1CNG, L1DNG, L6NG, L7ANG & L7BNG,  $> 0.5$  for L7NG. The ratio BaA/(BaA + CHR) was found  $> 0.35$  for L7NG, L7ANG & L7BNG.

In future research, recently emerging contaminants must be studied with the estimation of PAHs. Through a long time study, future research will diagnose different diseases and it will relate to the concentration of PAHs over a period [78]. The present study provides an idea about the concentration of PAHs and their harmful effect on the Antarctic environment. We can decrease or replace the usage of PAHs with the outcome of other alternates. But we should ensure that these alternatives may be other chemicals and cannot replace one toxic chemical with others.

### 5 Conclusions

In the present study, fifteen different lake water samples were examined for the estimation of PAHs and the result indicates that the Grovnes peninsula has been contaminated with trace amounts of PAHs. Fluorene was the most dominant pollutant and the highest concentration was found in L7BNG lake while other lakes were less polluted. This study confirms the presence of PAHs in

**Table 9** Different PAHs Ratio with their Values and Sources

| S. No | PAHs Ratio                      | Value Range | Sources                         | References |
|-------|---------------------------------|-------------|---------------------------------|------------|
| 1     | $\sum\text{LMW}/\sum\text{HMW}$ | $< 1$       | Pyrogenic                       | [73]       |
|       |                                 | $> 1$       | Petrogenic                      |            |
| 2     | FL/(FL + PYR)                   | $< 0.5$     | Petrol emission                 | [42]       |
|       |                                 | $> 0.5$     | Diesel emission                 |            |
| 3     | ANT/(ANT + PHE)                 | $< 0.1$     | Petrogenic                      | [74]       |
|       |                                 | $> 0.1$     | Pyrogenic                       |            |
| 4     | FLA/(FLA + PYR)                 | $< 0.4$     | Petrogenic                      | [75]       |
|       |                                 | 0.4–0.5     | Fossil fuel combustion          |            |
|       |                                 | $> 0.5$     | Grass, wood, coal combustion    |            |
| 5     | BaA/(BaA + CHR)                 | 0.2–0.35    | Coal combustion                 | [76]       |
|       |                                 | $> 0.35$    | Vehicular emissions             |            |
|       |                                 | $< 0.2$     | Petrogenic                      |            |
|       |                                 | $> 0.35$    | Combustion                      |            |
| 6     | BaP/(BaP + BeP)                 | $\sim 0.5$  | Fresh particles                 | [77]       |
|       |                                 | $< 0.5$     | Photolysis                      |            |
| 7     | IcdP/(IcdP + BghiP)             | $< 0.2$     | Petrogenic                      | [29]       |
|       |                                 | 0.2–0.5     | Petroleum combustion            |            |
|       |                                 | $> 0.5$     | Grass, wood and coal combustion |            |

another region of Antarctica as reported earlier. Several factors such as oil spills, fossil fuels, different transport resources, human activities, etc. may be the major cause of PAHs in the pristine environment of Antarctica. Long-range atmospheric transport is another cause which helps to carry the PAHs into the poles. PAHs diagnostic ratios have been used for the identification of PAHs sources. It should be used with caution, as PAHs ratio values may change during the environmental fate of these compounds. More than one diagnostic ratio should be used to confirm the results. LMWPAHs are emitted from different sources than HMWPAHs.

We can regulate and measure the emission of PAHs through an effective monitoring system. In the future, we can make stronger guidelines for the minimization of PAHs from the continent. Scientific support and tourist activities have increased over the last few decades. These activities are affecting the ecosystem of Antarctica. Due to the large size of the continent, PAHs do not evenly distribute in Antarctica but if not checked properly, they will leave the residue in the future. Monitoring of the PAHs plays a key role to control its emission and continental migration at the global level by which we can reduce PAHs contamination globally and protect the pristine ecosystem of Antarctica.

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## Declarations

**Conflict of interest** The authors declare that they have no competing interests.

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