Environmental Science
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This article can be cited before page numbers have been issued, to do this please use: N. Kerebba, P. Ssebugere, J. Justus Kwetegyeka, K. Arinaitwe and J. Wasswa, *Environ. Sci.: Processes Impacts*, 2017, DOI: 10.1039/C7EM00017K.

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View Article Online
DOI: 10.1039/C7EM00017K

Environmental impact statement

This research gives some new, interesting data about the PAHs in a lake system which is not well studied yet. Increasing presence of industrial, urban and agricultural activities that produce these contaminants is threatening this ecosystem some of which are considered 'priority' PAHs according to US EPA. The report could therefore provide helpful information for understanding the contamination status of PAHs in Uganda side of Lake Victoria to stakeholders.

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DOI: 10.1039/C7EM00017K

Concentrations and sources apportionment of polycyclic aromatic hydrocarbons in sediments from the Uganda side of Lake Victoria

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Abstract: This paper presents the levels and possible sources of selected polycyclic aromatic hydrocarbons (PAHs) in surface sediments from Napoleon Gulf and Murchison Bay of Lake Victoria. Sediment samples were extracted and cleaned up for PAHs using UNEP, 1992 and EPA method 3630C protocols, respectively. The analysis of sample extracts was done using a gas chromatograph coupled to a mass spectrometer. Fifteen congeners, mostly the high molecular weight PAHs (HPAHs) (4-6 rings) were detected. Total (Σ) concentrations varied from 44.2 to 80.2 ng g^{-1} dry weight (d.w.) at Napoleon Gulf while those at the Murchison Bay ranged from 17.0 to 55.0 ng g^{-1} d.w. Statistical analysis showed no significant difference in the concentrations of PAHs among sites ($p < 0.05$, ANOVA). It was noted that the concentrations for most sampling sites were far below the lowest effect levels based on the Sediment Quality Guidelines except for one station at the Napoleon Gulf. Principal component analysis and diagonistic ratios indicated that PAHs of combustion and petroleum origin were dominant and brought mainly by atmospheric deposition.

***Key words*:** PAH concentrations; sediments; sources; Lake Victoria

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1. Introduction

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Polycyclic aromatic hydrocarbons (PAHs) are wide spread contaminants with two or more fused aromatic rings.[1-2] Sixteen PAHs have been included on the list of priority pollutants by United States Environmental Protection Agency (US EPA) because of their toxic, mutagenic and carcinogenic nature.[3-4] Quality guidelines such as probable effect level (PEL), threshold effect concentration (TEC) are used to assess the ecological toxicity of individual PAHs in sediments.[5]

The major PAH sources include combustion of petroleum and fossil fuels, discharges from industrial and waste water treatment plants, municipal and industrial waste incineration.[6] Some PAHs undergo atmospheric transport from point sources and end up being deposited in the environment.[7] In the environment, these pollutants may find their way into water bodies via run off.[8]

Despite reports about PAHs in matrices from various water bodies in the world[9-13] , little is known about the levels and sources of PAHs in the sediments of Lake Victoria. The lake is a receiver end for industrial and urban waste discharges from Kampala city, Uganda's capital via the Nakivubo Channel[14] and Jinja Municipality, Uganda's second largest city.[15]The aim of this study was to determine the concentration magnitude of PAHs in sediments from Lake Victoria and to identify their sources.

2. Materials and methods

2.1 Study area

Two embayments located in the northern waters of Lake Victoria namely the Napoleon Gulf (located on (0° 24′ 34″ N, 33° 14′ 50″ E) and Murchison Bay (0° 15′ 71″ N, 32° 45′ 55″ E) were chosen for this study (Figure. 1). The Gulf was chosen because it is located near industries such as Nyanza textile industries, Steel Rolling Mills Uganda Limited, Tembo Steel Mills Uganda Limited, a water treatment plant, soap and oil company (BIDCO), a copper smelting plant and, a paper and pulp industry. These industries could be potential sources of PAHs. Furthermore, Jinja town is highly urbanized with a population of over 72,000

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people in its catchment.[16] The Murchison Bay was chosen because it is a receiver end of sewage effluents, industrial and municipal waste from Kampala capital city. Further to this the Bay is located in vicinity of Port bell where ships and motor boats anchor on their way to and from Kisumu in Kenya and Mwanza in Tanzania.

2.2 Sample collection and preparation

A total of 53 surface sediments (<13 cm depth) were collected in July 2014 from the Napoleon Gulf (stations A and B) and Murchison Bay (stations C and D) using a pre-cleaned sediment grab sampler. The sediment collection size was as follows 17, 9, 15 and 12 from stations A, B, C and D, respectively. Within each station, samples were collected at distances of approximately 100 m from one another. The samples were transferred into polyethene bags with zip locks and transferred in cooling boxes containing ice packs to the Pesticide laboratory at Makerere University. In the laboratory, the samples were kept in a freezer at -18 ^{o}C to avoid microbial biodegradation.

2.3 Analytical procedure

2.3.1 Extraction and clean-up

Prior to extraction, sediment samples were allowed to thaw. The samples were homogenized and freeze dried. The freeze dried samples were then sieved using a <2.3 mm screen to remove gravel and any detritus material. The extraction of samples was done according to protocols set by UNEP, (1992)[17] with minor modification. Briefly, 5g of the freeze dried sample was spiked with standards (phenanthrene-d_{10} (Phe-d_{10}) and chrysene-d_{12} (Chr-d_{12}), and carefully transferred into the soxhlet apparatus. The spiked sample was then extracted for 18 hours using a mixture of dichloromethane (DCM) and *n*-hexane (50:50 v/v). The resulting extracts were evaporated to 1 mL using a rotary evaporator and kept for clean-up.

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The clean-up of extracts was done following the procedure described in method 3630C of the United States Environmental Protection Agency[18] (US EPA, 1996) with minor modifications. Clean-up involved two sequential stages: an alumina column (packed from bottom to top with glass wool, 6 g of basic alumina, 1g of activated copper powder layer on top and 2 g of anhydrous sodium sulfate) followed by a silica gel column (packed from bottom to top with glass wool, 5 g of activated silica gel, 1g of activated copper powder layer and 2 g of anhydrous sodium sulfate). The extract was added to the column (that had been conditioned with a 10:90 v/v of dichloromethane (DCM)/ *n*-hexane) and then eluted with a mixture of DCM and *n*-hexane (50:50 v/v). The resulting eluate was concentrated to 1mL using a rotary evaporator. The concentrated eluate was transferred to glass vials and further reduced to 20 µL using a gentle stream of nitrogen. The *n*-hexane/DCM solvent mixture in the vials was exchanged for iso-octane and kept for instrumental analysis. .

2.3.2 Gas chromatographic analysis

Analysis of PAHs was done on an Agilent 6890N series gas chromatograph (GC) equipped with a mass spectrometer (MS) (Agilent 5975 inert XL Duadrupole, Palo Alto, CA, USA). Chromatographic separation was achieved on a capillary column (30 m length × 0.25 mm i.d. × 0.25 µm film thickness). An aliquot of 1 µL extract was introduced into the injector port. The GC oven temperature was initially set at 90 °C for 1 min, increased to 180 °C for 4.5 min at 20 ^{o}C min^{-1}, raised to 240 °C at 10 °C min^{-1}, then held for 1 min and finally increased to 310 °C at 24 °C min^{-1}. The mass spectrometer was operated at 70eV in electron impact ionization mode. The injector and detector were kept at temperatures of 250 °C and 300 °C, respectively. Helium (99.99% purity) as the carrier gas at a flow rate of 1.0 mL min^{-1}. The GC-MS was operated in a splitless mode with a purge-off of 1 min and each injection volume was 1 µL. The MS solvent delay time was 3.57 min. The selected ion monitoring (SIM) mode was used for PAH determination. Data acquisition and processing was achieved using GC-MSD Chemstation Software. Identification of analytes was based on

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comparison of the retention times of peaks from the standards with those obtained from the sample extracts. After confirmation, quantification was done using external calibration method (absolute calibration method). Four levels of PAH mixture standards ranging from 1 to 100 ppb were injected into the GC-MS, run on the same day of the sample analysis and regression equations obtained by plotting peak areas; obtained from the integrated areas of specific parent ions obtained in SIM mode, against the concentration levels used to calculate the amount of the individual PAHs.

2.4 Source identification and apportionment

Diagonistic ratios and principal component analysis (PCA) in conjunction with source markers were used to identify the possible sources of PAHs in the Lake Victoria environment. Multiple linear regression (MLR) was used to apportion the sources identified by PCA. Principal component analysis was done to extract significant components, following 1/3 root standardization on combined data from Napoleon gulf and Murchison Bay. Transformation was performed to remove differences in ranges of variables as well as giving variables the same importance during data analysis. Only samples that could give at least 40% of the detects were used during PCA analysis. The number of significant components was chosen by the broken stick model criterion. Observed eigen values in this model were only interpreted in cases where they exceeded the expected generated values. Factor scores and loadings were obtained and used in the analysis. Multiple regression of the absolute PCA scores (independent variable) was then completed against the dependent PAH levels.

2.5 Quality assurance and quality control

To ensure the quality of data, PAH standards and replicates were included in the analysis. A procedural blank was also run after every five samples. Blank samples were separately spiked with 0.2 and 0.4 μg kg^{-1} of a standard PAH mixture. The recovery assays were replicated three times. The recovery ranges at 0. 2 and 0.4 μg kg^{-1} were 51-75 and 65-99%, respectively. Since most recoveries were within the acceptable US EPA

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range (60-120%), the reported data was not corrected for recovery. Method detection limit (MDL) was calculated as three times standard deviations of the detected concentrations in the blank matrix. The MLDs were between 0.3 and 2.7 ng g^{-1} dry weight (d.w.).

2.6 Statistical data analysis

Statistical analysis was performed using SIRIUS 8.1 software. Descriptive statistics such as mean and standard deviation were calculated from the generated data. In computing the mean concentrations, analytes that were below the limit of detection were taken to be half the detection limit. One-way analysis of variance (ANOVA) was used to assess differences in PAH levels between sampling stations. The students't-test was used to assess differences between the concentrations of the high molecular weight polycyclic aromatic hydrocarbons (HPAH) and low molecular weight polycyclic aromatic hydrocarbons (LPAHs). Regression analysis was used to study the significance of principal components. In all cases, the level of significance was taken to be $p < 0.05$.

3. Results and discussion

3.1 Concentration of PAHs in sediments

The concentrations of PAHs in surface sediments from Napoleon Gulf and Murchison Bay are presented in Table 1. Total (Σ_{16}) PAH levels at the study sites varied from 17 to 80 ng g^{-1} d.w.. The concentrations were in the same range of data as that reported in the surface sediments from the Winam Gulf on the Kenya side of Lake Victoria (0.04 to 32 ng g^{-1} d.w)[19], and Ibadan River in Nigeria; where Σ_{14}PAHs varied from 1.68 to 919 ng g^{-1} d.w.[12] The PAH levels in the present study were lower than those reported from sediments of the Fosu Lagoon, along coastal belt of Ghana (254 to 558 ng g^{-1} d.w)[20] and those of sediments of a creek in the Niger Delta region (5583 to 9326 ng g^{-1} d.w).[21] The PAH levels were also lower than some of those reported from other parts of the world, namely the Jakarta Bay in Indonesia (Σ_{26}PAHs was 257-1511 ng g^{-1} d.w.)[11],

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Langat Estuary in Malaysia(Σ_{17}PAHs 322-2480 ng g^{-1} d.w.)[9], and Tokyo Bay in Japan (Σ_{26}PAHs was 1372-1615 ng g^{-1} d.w.)[11] . The Σ_{16}PAHs at Napoleon Gulf ranged from 44 to 80 ng g^{-1} d.w. It was observed that the PAH concentrations in sediments from station B were statistically greater ($p < 0.05$, ANOVA) than those from station A. The high levels at the former site than the later could be due to release of PAH related compounds from oil spillages of car oil garages and washing bays which are located not that far from it. Also, in vicinity of Site B is a soap and oil industry (BIDCO) which could be a potential source to these PAHs. The Σ_{16}PAHs in the sediments from the Murchison Bay were between 17 and 55 ng g^{-1} d.w. Statistically the PAH levels at station C of the Bay were significantly higher than those from station D ($p < 0.05$, ANOVA). One possible reason for the high levels at station C could be that it receives industrial and municipal waste via the Nakivubo channel. It should be noted that station C is located near the mouth of the channel which carries all sorts of waste from Kampala capital city. No significant difference in the concentrations of PAHs among sites ($p < 0.05$, ANOVA).

It was observed that the high molecular polycyclic aromatic hydrocarbons (HPAHs) were statistically greater than the low molecular weight polycyclic aromatic hydrocarbons (LPAHs) ($p<0.05$, students't-test). The high abundance of the HPAHs (benzo[b]fluoranthene, pyrene, chrysene, benzo[k]fluoranthene, benzo(a) anthracene, benzo[a]pyrene, benzo[g,h,i]perylene) is associated with their high octanol-water partition coefficient (K_{oc}) compared to the LPAHs and are thus more likely to adsorb onto the sediments for longer periods.[22] These PAHs therefore undergo long term accumulation resulting from runoff, municipal and industrial discharges and aerial deposition. The Leakages and spills would remain a float on the lake for some time before biodegradation and photo degradation allowing time for adsorption on the sediments. Shor et al., (2003) further noted that phenanthrene and anthracene (3-ring LPAHs) were readily desorbed onto the sediments and that their desorption rates correlated positively with low water–sediment partition (Log K_{oc}) more than HPAHs[22].

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In this study, ∑4-ring (chrysene and pyrene) was the most predominant HPAH congener in the sediments at 75% stations (Figure. 2). Naphthalene (∑2-ring) was the most predominant low molecular weight PAH in the sediments. In a related study, the two congeners, ∑4-ring (pyr and Chr) and ∑2-ring (naphthalene) congeners were the most dominant in air samples collected at Kakira and Entebbe in the Lake Victoria water shade[23] consequently atmospheric deposition was a great contributor to PAHs levels. The abundance of chrysene could also be attributed to its low water solubility and high resistance to degradation.[24]

Evaluation of ecological toxicity was done by comparing the concentration of the PAH congeners against three sets of effect-based Sediment Quality Guidelines (SQGs) (Interim sediment quality guidelines (ISQGs), probable effect level (PEL), and threshold effect concentration (TEC) or levels (TEL)). The ISQGs, TEL and PEL values of individual PAHs for the fresh lake are provided in Table 1. The PAH concentrations in the sediments from all the sampling stations except at station B of Napoleon Gulf were far below the lowest effect levels set by the Canadian Council of Ministers of the Environment (1999).[8]In addition, reports of adverse biological effects due to PAHs are considered to occur rarely when the concentration values <TEL, occasionally when ≥TEL and/or <PEL and frequently when the values are >PEL[25]. A study by Canadian Council of Ministers of the Environment (1999) noted that toxicity of PAHs can occur at concentrations higher than ISQG values[8]. Based on the ISQG values, the results of our study indicate no risk to living organisms except at one station (station B) of the Napoleon Gulf.

3.2 Source identification and apportionment of PAHs in the sediments of Lake Victoria

3.2.1 Using diagonistic ratios

Diagonistic ratios are used to distinguish sources of PAHs originating from petroleum products, petroleum combustion and biomass or coal burning.[26] Normally, the PAH compounds involved in each ratio have the same molar mass, aqueous solubilities and octanol-water partition coefficients, thus, they have similar

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physicochemical and stability properties in the environment. In this respect, the use of paired PAH constituents as "diagnostic source ratios" suggests that PAHs with similar properties typically retain the same relative concentration in residues as in their sources.

The ratios of Flt/(Flt+Pyr), Ant/(Ant+Phe), IcP/(IcP+BgP) , BaA/(BaA+Chr) and LPAHs/ HPAHs were used to predict the sources of PAHs in this study. Studies have previously used these ratios since they are highly consistent.[26-27] The ratio of Ant/(Ant+Phe) was 0.54 at C, (Table 2), suggesting that pollution was due to combustion. The ratio of IcP/(IcP+BgP) at station A (0.33) indicates that sources of PAHs were pyrolytic. Yunker et al. (2002) reported that if the ratio of IcP/(IcP+BgP) is between 0.2 and 0.5, then the PAH source could be combustion[26]. Station A is located near industries like Uganda leather tannery, a soap and oil company (BIDCO), copper smelting plant, and paper and pulp industries. These industries use firewood and gas as sources of energy and could therefore be emitting PAH related compounds. At station C, the ratios of Ant/(Ant+Phe) , IcP/(IcP+BgP) and Phe/Ant were >0.1, >0.2,<10, respectively. According to Budzinski et al. (1997) and Yunker et al. (2002), these ratios suggest pyrolytic sources[26,28]. The ratio of Flt to (Flt+Pyr) was less than 0.4; suggesting that PAH emissions were due to combustion petroleum products. The ratio of the LPAHs to the HPAHs was greater than 1 and this was attributed to sources of petrogenic origin[29]. For station D, the ratio IcP/(IcP+BgP) was greater than 0.2, suggesting that the PAH sources were combustion based. The ratio of LPAHs/ HPAHs at all stations were less than 1 implying that PAHs were partly pyrolytic. Typical combustion origin PAHs can be represented by the sum of major combustion specific compounds (∑COMB) which are fluoranthene, pyrene, benzo[a]anthracene, chrysene,benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene and benzo[g,h,i]perylene.[30] In this study, the ratio ∑COMB/ ∑PAHs were 0.84, 0.95, 0.85, and 0.56 for stations A, B, C and D, respectively. Stations A, B and C had higher ratios than stations D, implying that they had more combustion related activities.

3.2.2 Source apportionment using principal component analysis (PCA)

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Principal component analysis was done to compare the percent congener profiles with known PAH sources reported in literature[31-36] by Harrison et al. (1996); Li and Kamens (1993); Khalili et al. (1995); Nasher et al. (2013); Rogge et al. (1997); and Peters et al. (1999). All the two principal components extracted explained 61.6% of the total variance (Figure. 3). PC1 explained 36.3% of the total variance. This component had high contribution from benzo[g,h,i]perylene, benzo[a]pyrene, indeno(1,2,3-cd)pyrene and chrysene, with medium loading for pyrene and benzo[b]fluoranthene. A Study by Nasher et al. (2013) showed that these PAHs are associated with combustion of heavy gasoline oils, lubrication oils and used motor oils.[34] Diesel emissions are similar to gasoline emissions (PAH markers are indeno(1,2,3-cd)pyrene, corone and benzo[g,h,i]perylene) however the latter has more loading from benzo[b]fluoranthene and benzo[k]fluoranthene.[31] PC1 would be a diesel emission source category since they are characterized by high concentrations of benzo[g,h,i]perylene[32] but due to absence of benzo[k]fluoranthene and corone; the component has been tagged a 'heavier oil combustion' factor that may include gasoline and diesel. PC2 explained 25.3% of the variance. It had high loading from benzo[b]fluoranthene, indeno(1,2,3-cd)pyrene and pyrene with presence of naphthalene and benzo[g,h,i]perylene. No clear source is associated with this composition; however benzo[a]pyrene and naphthalene are well researched examples of coal tar PAHs.[37]It should be noted that indeno[1,2,3-cd]pyrene and naphthalene are present in coke during its production.[33] The presence of benzo[b]fluoranthene, indeno(1,2,3-cd)pyrene, benzo[a]pyrene and benzo[g,h,i]perylene which are similar to the PAH compositions of engine emission.[36](petrogenic origin). Therefore PC2, can be tagged a 'mixed factor' of petroleum and combustion factor. In vicinity of stations B and A of the Napoleon Gulf , biomass based fuel such as wood and petroleum are used in addition to fossil fuels burnt to generate energy for the oil and soap company (BIDCO). The wastes of the industry therefore could be channeled to these sites via runoff.

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Multiple linear regression (MLR) of the elements in the factor score matrix was done against the total PAH levels for the data set to estimate the contribution of each PAH source on total PAH level of the sample. Significance of the regression coefficients (R^2 = 0.81, observations; N= 19) were at 95% confidence level ($p < 0.05$). The regression results based on 2 factor scores showed that component 2 (p= 0.642) did not significantly influence the ΣPAH values. Therefore, the components were reduced to 1 factor which explained 36.3% of the total variance. The MLR equation (R^2 = 0.81, ANOVA significance $f < 1.56\times10^{-7}$, p-value for SC1 = 1.56×10^{-7}) was: Σ PAH = 31.39 SC1 + 56.14; where SC1 are factor scores for samples on component 1 (heavier oil combustion). Multiple linear regressions apportion heavier oil combustion as the major source of PAHs. These are petrogenic inputs though some pyrolytic sources like combustion of biomass could not be ruled out. The sources were also in agreement with those from diagonistic ratios source apportionment approach in this study and those reported by Arinaitwe, et al., (2012) in the air samples around the water shade of L. Victoria that is; Combustion of petroleum, biomass and mixed sources among others. This would therefore indicate that atmospheric deposition of PAHs in sediments was possible.

Conclusion

Fifteen PAHs of the 16 'priority PAHs' were detected in sediment samples collected from four sampling stations at the Napoleon Gulf and Murchison Bay of Lake Victoria. The concentrations varied from 17.0 to 80.2 ng g^{-1} d.w.. The PAH levels in the sediments from Lake Victoria were low to pose risk to living organisms based on the ISQG values except at one station of the Napoleon Gulf. The results from PCA and diagnostic ratios showed that the major PAH sources were petrogenic. However, we would not rule out atmospheric deposition as a major source of PAHs in the Lake Victoria environment. Therefore, regulatory controls for monitoring and mitigating wastewater emissions into Lake Victoria need to be implemented and emphasized by the relevant government organs.

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Acknowledgement

The financial support from the Swedish International Development Agency (SIDA) is gratefully acknowledged.

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Figure 1: Location of the sampling stations in Murchison Bay and Napoleon Gulf of Lake Victoria.

Figure 2: Percentage contribution of PAH congeners to total PAH concentration per station.

Figure 3: Component loadings of the principal components (PCs) for PAH composition in the sediments of Napoleon Gulf and Murchison Bay.

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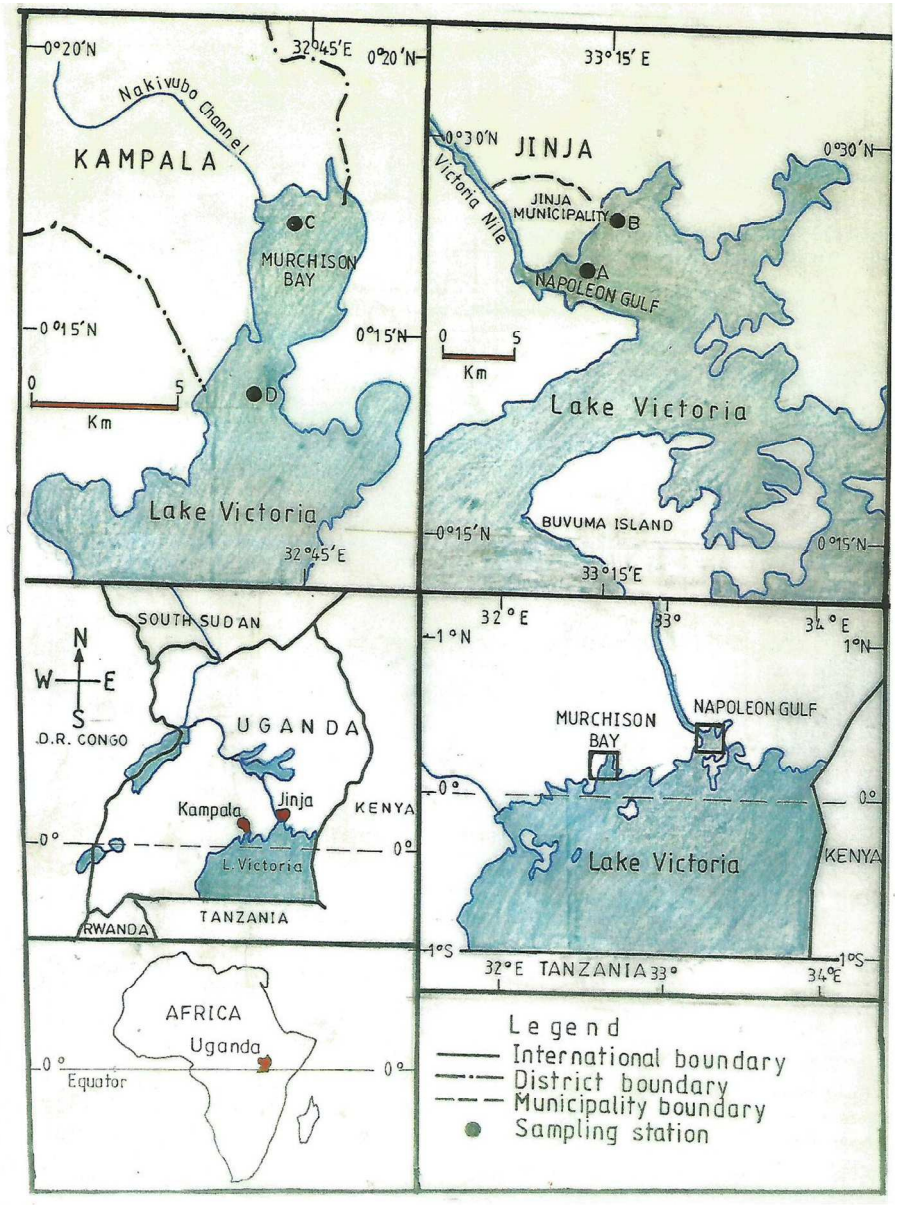

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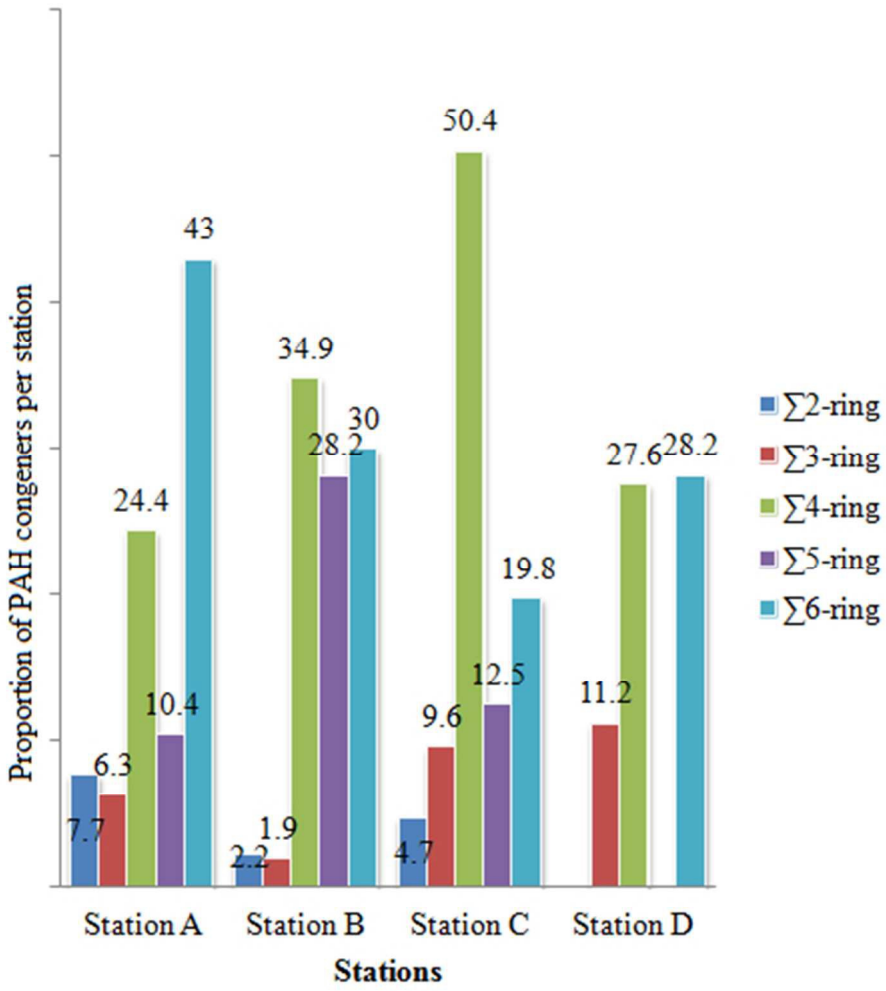

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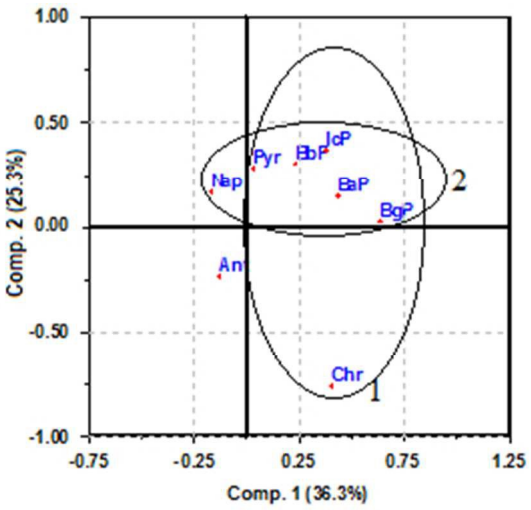

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Table 1: Mean concentrations and ranges of PAHs (ng g^{-1} d.w.) in surface sediments from Napoleon Gulf and Murchison Bay

Compound	Rings	Napoleon Gulf		Murchision Bay		ISQG	PEL	TEC
		Station A	Station B	Station C	Station D			
Nap	2	3.4±3.3	1.82.3	2.6±4.4	n.d.	34.6	391	30
Acy	3	n.d.	n.d.	n.d.	n.d.	5.87	128	10
Ace	3	0.8±1.0	n.d.	n.d.	0.5±2.3	6.71	88.9	10
Phe	3	n.d.	0.6±0.7	2.1±6.4	n.d.	41.9	515	90
Ant	3	2.0±2.5	0.9±1.2	3.2±5.1	0.5±1.8	46.9	245	50
Flu	3	n.d.	n.d.	n.d.	0.9±0.8	21.2	144	20
∑LPAHs	(2&3 rings)	7.8±1.2	4.9±0.5	9.5±1.2	3.1±0.2			
Pyr	4	2.4±1.8	2.8±1.2	5.7±14.4	n.d.	53.0	875	150
Flt	4	n.d.	n.d.	1.5±1.4	n.d.	111	2355	110
BaA	4	n.d.	0.5±0.8	1.3±3.2	n.d.	31.7	385	70
Chr	4	8.4±5.6	25±24	19±15	4.7±0.7	57.1	862	110
BbF	5	2.7±1.5	9.3±10.3	4.0±3.2	n.d.			70
BaP	5	1.9±1.3	4.9±5.3	1.3±1.8	n.d.	31.9	782	90
BkF	5	n.d.	6.5±18.0	0.6±0.7	n.d.			60
BgP	6	15±17	14±17	7.7±4.4	3.1±0.2			
IcP	6	3.8±2.9	9.7±16.1	3.2±2.5	1.7±1.0			
DaA	5	n.d.	1.9±3.3	1.0±1.4	n.d.	6.22	135	
∑HPAHs	(4,5&6 rings)	36±4.7	75±7.5	46±5.6	14±1.5	53		
∑PAHs		**44±3.9**	**80±6.7**	**55±4.7**	**17±1.3**			
% OM		9.5±1.8	10.0±0.7	9.9±1.0	9.1 ±1.3			

Results are presented as mean values ±SD. Total number of samples per station for A, B, C and D were 17, 9, 15 and 12, respectively; n.d. means nondetectable levels (used as 0.5 dl in the mean of the station). The ∑LPAHs represent sum of low molecular weight PAHs (Nap, Acy, Ace, Phe, Ant and Flu) while the ∑HPAHs represent sum

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of high molecular weight PAHs (Pyr, Flt, BaA, Chr, BbF, BaP, BkF, BgP, IcP and DaA), ∑PAHs = ∑LPAH + ∑HPAH, OM = organic matter.

SD = Standard deviation, ISQGs = Interim sediment quality guidelines TEC = threshold effect concentration and PEL = probable effect level, for some PAHs in sediments from fresh lake

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Table 2: Diagnostic ratios of PAHs for the Murchison Bay and Napoleon Gulf

Diagnostic ratios	Petrogenic source	Pyrolytic source	Napoleon Gulf		Murchison Bay	
			A	B	C	D
Ant/(Ant+Phe)	<0.1	>0.1	-	-	0.54	-
BaA/Chr	<0.4	>0.9	-	-	1.68	-
BaA/(BaA+Ch)	<0.2	>0.35	-		0.63	-
IcP/(IcP+BgP)	<0.2	>0.2	0.33	0.29	0.28	0.28
Phe/Ant	>15	<10	-	0.40	0.59	-
Flt/(Flt+Pyr)	<0.4	>0.4	-	-	0.16	-
Flt/Pyr	<1.0	>1.0	-	-	0.16	-
LPAHs/ HPAHs	>1	<1	0.21	29.4	5.74	0.18
∑COMB/∑PAHs			0.84	0.95	0.85	0.56