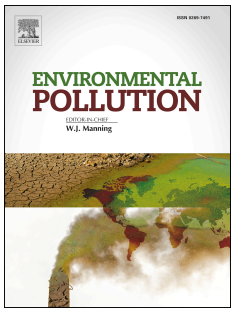
Accepted Manuscript



Sedimentary archive of Polycyclic Aromatic Hydrocarbons and perylene sources in the northern part of Taihu Lake, China

Aili Li, Tim aus der Beek, Michael Schubert, Zhenyang Yu, Thomas Schiedek, Christoph Schüth

PII: S0269-7491(18)32465-5

DOI: https://doi.org/10.1016/j.envpol.2018.11.112

Reference: ENPO 11939

To appear in: *Environmental Pollution*

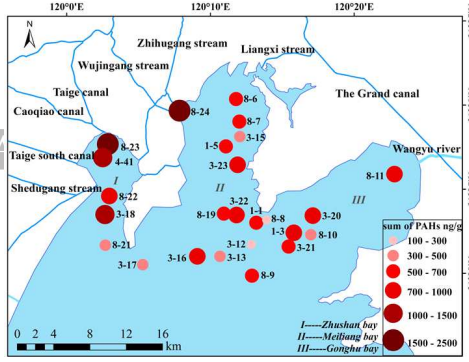
Received Date: 15 July 2018

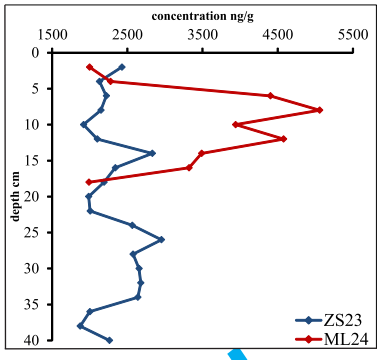
Revised Date: 30 November 2018

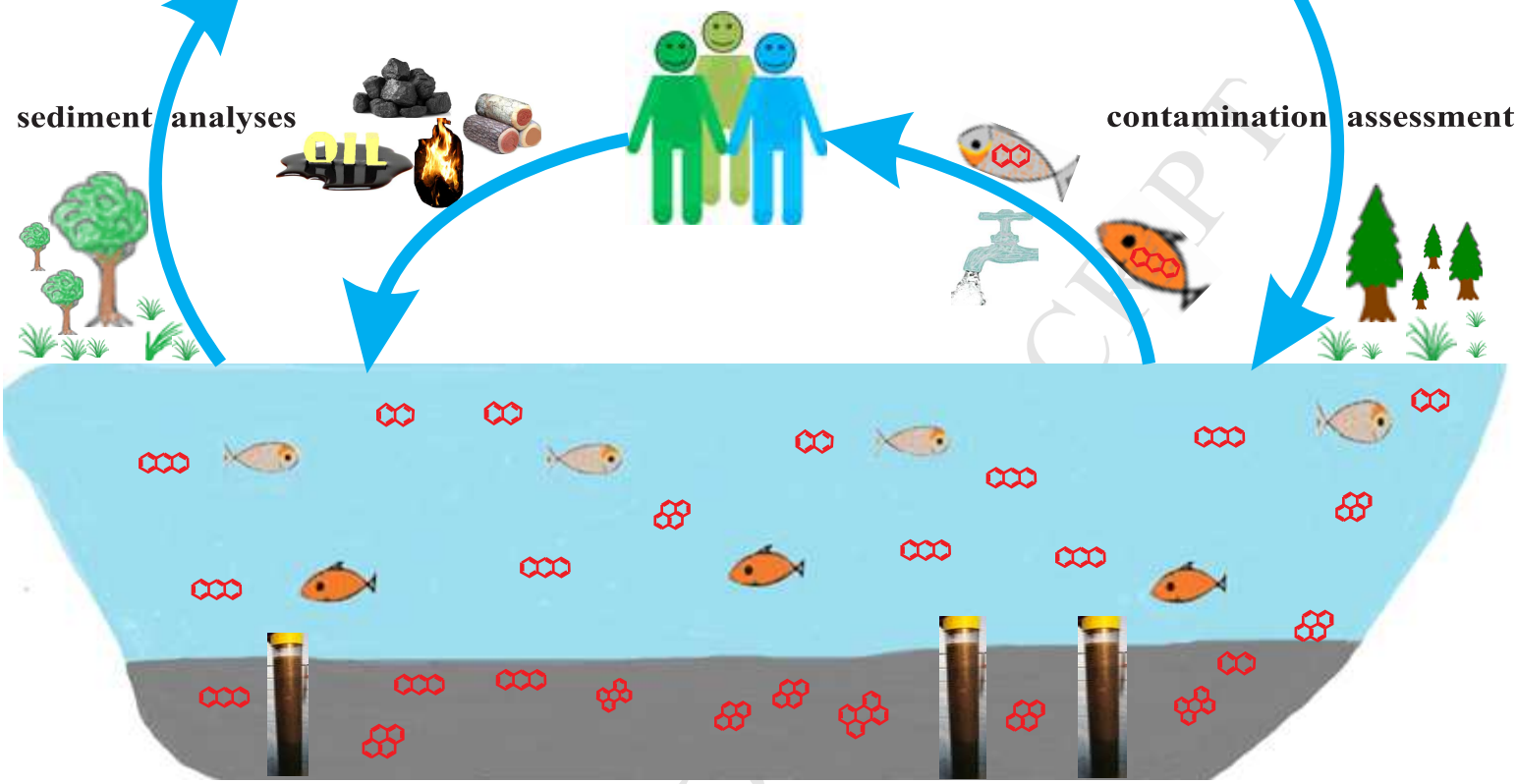
Accepted Date: 30 November 2018

Please cite this article as: Li, A., Beek, T.a.d., Schubert, M., Yu, Z., Schiedek, T., Schüth, C., Sedimentary archive of Polycyclic Aromatic Hydrocarbons and perylene sources in the northern part of Taihu Lake, China, *Environmental Pollution* (2019), doi: https://doi.org/10.1016/j.envpol.2018.11.112.


9-4-12
9-4-11


120°0'E
120°10'E
120°20'E
31°35'N
31°30'N
31°25'N
31°20'N
N
Zhihugang stream
Liangxi stream
Wujingang stream
Taige canal
The Grand canal
Caoqiao canal
Taige south canal
Wangyu river
Shedugang stream
I
II
III
8-24
8-6
8-7
3-15
1-5
3-23
8-23
4-41
8-11
8-22
3-18
3-22
8-19
1-1
8-8
3-20
1-3
8-10
3-21
8-21
3-12
3-16
3-13
3-17
8-9
sum of PAHs ng/g
100 - 300
300 - 500
500 - 700
700 - 1000
1000 - 1500
1500 - 2500
0 2 4 8 12 16
km
I-----Zhushan bay
II-----Meiliang bay
III-----Gonghu bay


concentration ng/g
1500
2500
3500
4500
5500
depth cm
0
5
10
15
20
25
30
35
40
ZS23
ML24


sediment analyses
OIL
contamination assessment

Sedimentary Archive of Polycyclic Aromatic Hydrocarbons and Perylene Sources in the Northern Part of Taihu Lake, China

Aili Li[a,*], Tim aus der Beek[b], Michael Schubert[c], Zhenyang Yu[d], Thomas Schiedek[a], Christoph Schüth[a,b]

[a] Institute of Applied Geosciences, Technical University of Darmstadt, Schnittspahnstrasse 9, 64287 Darmstadt, Germany

[b] IWW Water Centre, Moritzstrasse 26, 45476 Mülheim an der Ruhr, Germany

[c] UFZ - Helmholtz Centre for Environmental Research, Permoserstrasse 15, 04318 Leipzig, Germany

[d] State Key Laboratory of Pollution Control and Resource Reuse, Key Laboratory of Yangtze River Water Environment, Ministry of Education, College of Environmental Science and Engineering, Tongji University, 200092 Shanghai, P. R. China

Aili Li (aili@geo.tu-darmstadt.de)

Tim aus der Beek (t.ausderbeek@iww-online.de)

Michael Schubert (michael.schubert@ufz.de)

Zhenyang Yu (yuzhenyang3227@tongji.edu.cn)

Thomas Schiedek (schiedek@geo.tu-darmstadt.de)

Christoph Schüth (schueth@geo.tu-darmstadt.de)

Abstract: In the present work, we analyzed the concentration patterns of 20 Polycyclic Aromatic Hydrocarbons (PAHs) in 25 surface sediments and 11 sediment cores from the northern part of Taihu Lake, China. Three of the cores were dated based on ^{137}Cs activity for the deposition age of the sediment. The spatial distributions of the PAH concentrations show that the inflow rivers into Zhushan Bay and Meiliang Bay were the main pathway for PAHs and sediment input to the northern part of the lake. This results in substantially higher PAH concentrations (up to 5000 ng/g) and sedimentation rates (higher than the average of 3 – 4 mm/a) in the area close to the river outlets. In addition, results also show that PAH concentrations in the sediments considerably increased from the early 1960s, but the decreasing concentrations in the upper layers of the sediment could be attributed to the introduction of measures on environmental improvement from ca. 2000. There were both anthropogenic and biogenic origins of perylene in the lake sediments, which were distinguished based on spatial distribution patterns and also the concentration proportions of perylene to the sum of the 20 PAHs. In the cores collected close to river outlets, the concentration proportions of perylene typically range from 0.02 to 0.18 and there are significant positive linear correlations between the concentration of perylene and three anthropogenic PAHs (Benzo[a]pyrene, Benzo[e]pyrene, Pyrene), suggesting that perylene was dominated by anthropogenic input. However, the cores collected further away from the river outlets show the concentration proportions between 0.13 and 0.96, and present significant negative correlations or no correlations between perylene and the three PAHs, suggesting that perylene was mainly formed by biogenic activities. Furthermore, the different perylene sources accompanied with the location distributions imply that anthropogenic activities could inhibit its biogenic formation.

Keywords

Taihu Lake in China; Lake sediment; PAH distribution; Perylene source

Capsule

This study provides an insight of anthropogenic impacts on PAH deposition in the sediment of Taihu Lake and also clearly distinguishes biogenic and anthropogenic origins of perylene in the sediment.

1. Introduction

Taihu Lake, located in the Yangtze River Delta plain, is a large and shallow freshwater lake with an area of 2338 km^2. The lake plays an important role for flood control in the region and also for tourism, shipping, aquaculture, and as a raw source for drinking water supply in the neighboring cities of Shanghai, Suzhou, Wuxi and Huzhou (Qin et al., 2007) (Fig. 1a). However, decades of rapid development of industrialization and urbanization in this area caused serious pollution in the lake ecosystems, especially the northern part of the lake (Wang et al., 2003; Wilhelm et al., 2011; Jiang et al., 2012; Xu et al., 2014; Tao et al., 2018). This is due to the discharge of large amounts of industrial effluents and improperly treated municipal sewage into the lake, the diffuse pollution from agriculture and aquaculture, or the wet and dry atmospheric deposition of dissolved and particulate matter from traffic and biomass burning. In 2007, e.g., excessive nutrient input into the lake caused a massive cyanobacterial bloom with the formation of volatile sulfide compounds, resulting in a serious drinking water crisis in Wuxi City (Zhang et al., 2010).

Lake ecosystems are particularly sensitive to anthropogenic impacts as they can act as repositories for contaminants in the aquatic environment. Especially hydrophobic persistent organic pollutants (POPs) can easily bind to organic matter and then deposit in sediments. After deposition, such contaminants are less susceptible to microbial degradation due to their strong sorption and ageing, which reduces contaminant bioavailability (Erickson et al., 1993; Hatzinger and Alexander 1995). Lake sediments therefore may contain continuous archives of such inputs with an annual to decadal resolution. With this, the analyses of lake sediments that may have accumulated over decades or centuries can provide insights into background conditions, and into historical, present and potentially future anthropogenic impacts (Hollert et al., 2018).

Polycyclic Aromatic Hydrocarbons (PAHs) are such a group of POPs and ubiquitously distributed in ecosystems. They have been emitted since prehistoric time through e.g. wild fires (Vila-Escalé et al., 2007) and volcanos (Kozak et al., 2017). They are also indicators for anthropogenic activities resulting from incomplete combustion of fossil fuels and biomass (Zhang et al., 2008; Shen et al., 2012; Wu et al., 2017) and from various industrial processes (Yang et al., 2002), substantially raising PAH

abundance in the environment. Some of the PAHs such as benzo[a]pyrene, dibenzo[a,h]anthracene, benzo[a]anthracene are classified as mutagenic and carcinogenic and are listed as priority pollutants by US EPA (EPA US, 1993; Boffetta et al., 1997; Kim et al., 2013). Consequently, once these PAHs accumulate in the environment and biomagnify in food chains, they ultimately pose considerable threats to human and ecosystem health (Geffard et al., 2003). A specific PAH, perylene, can also be formed biogenically in sediments after deposition, e.g. probably from diatom (Louda and Baker, 1984), fungi (Suzuki et al., 2010), crinoids (Wolkensein et al., 2006), plants (Marynowski et al., 2013; Grice et al., 2009) or microbial transformations (Silliman et al., 2000). Therefore, its occurrence in sediments may indicate anthropogenic PAH input and also biogenic formation.

A certain amount of studies on PAHs in the sediment of Taihu Lake has been conducted (Qu et al., 2002; Peng et al., 2005; Qiao et al., 2006; Lei et al., 2014; Tang et al., 2015; Lei et al., 2016), which conclude that main PAH input are from the densely populated and industrialized region in the north of the lake. However, the historical PAH inputs and transport patterns in the lake are still not well known. In addition, perylene sources and formation have not yet been studied in Taihu Lake. In the present work, we analyzed 25 surface sediment samples and 11 sediment cores from the northern part of Taihu Lake for a more detailed investigation of PAH contents and patterns in this region of the lake. PAH concentrations in the surface sediments were used to delineate current PAH input into the lake, and PAH concentrations in the cores to record the temporal changes of PAH input. Specific attention is paid to the concentrations of perylene in relation to the other PAHs to potentially distinguish the anthropogenic sources and biogenic formations of perylene in the environment.

2. Materials and methods

With a mean depth of 1.9 m and a maximum depth of 2.6 m, Taihu Lake is a characterized by a rather flat lake bed. There are around 120 inflows and outflows around the lake, with the inflows mostly located in the northern and western part and the outflows in the eastern and southern part of the lake (Qin, 2008). Some are occasionally reversing in flow direction, depending on the lake water level. The shallowness of the lake and the hydraulic conditions result in complex flow patterns, and the spatial and temporal current patterns in the lake are not fully understood (Qin et al., 2007).

These complex flow conditions have an influence on the spatial distribution and deposition rates of sediment in the lake. Sediment thickness varies between 0.5 and 2 m in most parts of the lake with the greater in the northern and western parts and lesser sediment thickness in the central parts, reflecting the prevailing wind and resulting water circulation patterns (Luo et al., 2004). In the upper layers, sediment textures are dominated by clayey silt and clay (Jin et al., 2006; Qin et al., 2004). It is, however, likely that during strong winds or floods sediment scouring and resuspension can alter the sediment stratigraphy (Qin et al., 2004), complicating the interpretation of dating results and contaminant profiles.

2.1 Sample collection

During five sampling campaigns (May 2015, November 2015, June 2016, February 2017, September 2017) a total of 25 grab surface sediment samples and 11 sediment cores ranging between 12 cm and 40 cm in length, were collected from the northern part of Taihu Lake, covering Gonghu Bay, Meiliang Bay and Zhushan Bay. The surface sediment samples were stored in polyethylene bags. The cores were taken using a gravity corer with a core loss preventer (uwitec, Austria), and they were subsequently sliced into 2 cm segments (147 in total) and stored in aluminum screw top jars. Before further analyses, the samples were stored at –20 °C, except during the air shipping from China to Germany.

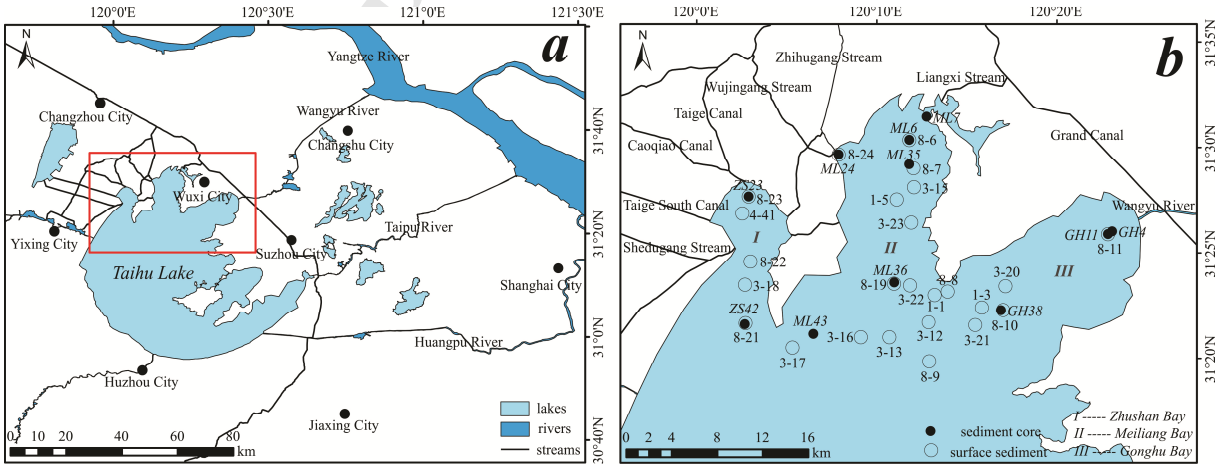


Fig. 1 a Overview of the area surrounding Taihu Lake; b Sampling sites for surface sediments and sediment cores. Exact coordinates of the samples and the sampling time are listed in S Tab. 1. The rivers and canals around the sampling area are generally only inflows into the lake. The Wangyu River connecting Taihu Lake and the Yangtze River, however, can act as an outflow in the rainy season.

2.2 Sample preparation and PAH analysis

All sediment samples were silty-clayey and therefore whole samples were freeze-dried and milled in a vibratory disc mill. Between 7 and 12 g of each sample was then extracted with 35 ml of acetone for 30 min using Accelerated Solvent Extraction (Dionex ASE 300) in static conditions (100 °C and 10 MPa). After extraction, 100 µL of an internal standard was spiked to each sample extract. Extracts were then cleaned using a glass column filled with glass wool, 2 g silica gel, 2 g Al_2O_3 and 0.5 g Na_2SO_4 to remove the residual water and interfering compounds. After clean-up, the column was eluted with 15 mL of n-hexane, followed by 5 mL of a 9:1 (v/v) mixture of n-hexane and dichloromethane, and 20 mL of a 4:1 (v/v) mixture of n-hexane and dichloromethane. The eluate was concentrated to around 2 mL using an automatic evaporation-dryer with nitrogen. Then 1 µL of the concentrated eluate was injected into a GC-MS (Agilent 7890A/5975C) in pulsed splitless mode and detected in the SIM mode of the MS.

For quantification, PAH standards (PAH-mix 14, PAH-mix 45 and deuterated PAH-mix 31) were obtained from Dr. Ehrenstorfer Augsburg, Germany. The standards were diluted together in cyclohexane to four different concentrations for external calibration and response factors calculation. The internal standard (dilution of deuterated PAH-mix 31) with 5 deuterated PAHs was then used to quantify the analytes. All solvents and cleanup chemicals were purchased from Carl Roth GmbH + Co.KG, Germany.

Including 16 EPA PAHs, a total of 20 PAHs were analyzed (2-ring: naphthalene, 2-methyl-naphthalene, 1-methyl-naphthalene; 3-ring: acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene; 4-ring: fluoranthene, pyrene, benzo[a]anthracene, chrysene; 5-ring: benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene (BeP), benzo[a]pyrene (BaP), perylene; 6-ring: dibenzo[a,h]anthracene, benzo[g,h,i]perylene, indeno[1,2,3-cd]pyrene).

2.3 Quality control

For testing the reliability of this method, a certified soil from a gas works site (European Reference Material ERM-CC013a) was purchased from the Federal Institute for Materials Research and Testing BAM (Berlin, Germany). The reported uncertainties for the concentrations of the different PAHs in

the certified soil were between 5% and 20%. The certified soil was extracted and measured identically to the field samples. Average recovery rates (9 replicates) in our tests were typically between 95% and 130%, indicating good recoveries.

The quantification limit for the GC-MS analysis was between 10 and 25 pg of injected mass, depending on the PAH. This limit corresponds to 3 – 7 ng/g of individual PAHs in the soil samples, depending on the amount of soil extracted and the volume of the eluates concentrated.

2.4 Dating methods

Three of the cores, located in the northern part of Meiliang Bay (ML35), southern part of Meiliang Bay (ML36) and Zhushan Bay (ZS42) were dated using the thermonuclear by-product ^{137}Cs that has a half-life of 30.17 years. Since a certain mass was required for the determination of ^{137}Cs activities, some adjacent layers of core samples were combined and each dating sample ranges between 2 and 8 cm in length and between 15.1 and 29.9 g in weight. ^{137}Cs activity measurements were carried out with low-level gamma-spectroscopy based on the distinct ^{137}Cs gamma emission energy of 661 keV, using a n-type coaxial Low-Energy HPGe detector (ORTEC) with an active volume of 39 cm^3 and a 0.5 mm Be window. The detector efficiency and measuring geometry were calibrated with the certified reference material "IAEA-375 SOIL". Each of the samples was measured at least 24 hours in 32 cm^3 cylindrical capsules. Spectra analysis was performed with the software GAMMA-W®.

3. Results and discussion

Riverine runoff and atmospheric deposition are the two main pathways responsible for PAHs and sediment input to a lake (Ferrey et al., 2018; Zakaria et al., 2002). Riverine runoff may potentially contribute more significant pollutant and particle loads, as rivers typically receive treated or untreated domestic wastewater, industrial effluents, and surface runoff (Wolf et al. 2013; Pal et al., 2010). These factors may lead to higher deposition rates and PAH concentrations in the sediment close to river inflows.

3.1 Dating of the cores

The presence of anthropogenic ^{137}Cs in the environment of the northern hemisphere can be traced both to the atmospheric testing of nuclear weapons in the late 1950s and early 1960s and to major accidents in nuclear power stations, i.e. the Chernobyl accident in 1986. The latter produced a less uniform and laterally more limited pattern since the fallout was associated with complex short-term weather patterns (in particular rain). Whereas (for this reason) no Chernobyl fallout is known for the southern hemisphere, the nuclear weapon testing fallout is traceable in both the north and the south, appearing in the south about two years later (Rowntree and Foster, 2012).

Sediment deposition rates for the three locations were measured based on ^{137}Cs activities in the cores taken from that locations. Fig. 2 shows that the ^{137}Cs activities are rather low and only detectable in the upper around 20 cm of the three cores, which is comparable to the results reported by others (Xue and Yao, 2011; Liu et al., 2004). Although the detected ^{137}Cs activities in the cores do not show any distinct peak related to any of the events, the deepest layer (at ca. 20 cm depth) at which ^{137}Cs was detected can be consequently dated to around 1960. This would indicate that an average sedimentation rate at these three locations is around 3 – 4 mm/a, which is similar to the rates reported by Xue and Yao (2011) and Liu et al. (2009), and is also reasonably consistent with the chronological results of spheroidal carbonaceous particles (Cao et al., 2013; Liu et al., 2012). These three locations are some km away from the lakefront and also away from the inflows into the lake. The sedimentation rates therefore represent most likely the average rate in the northern part of the lake, but might not be representative for the areas close to the lakefront and river outlets due to more intense sediment input.

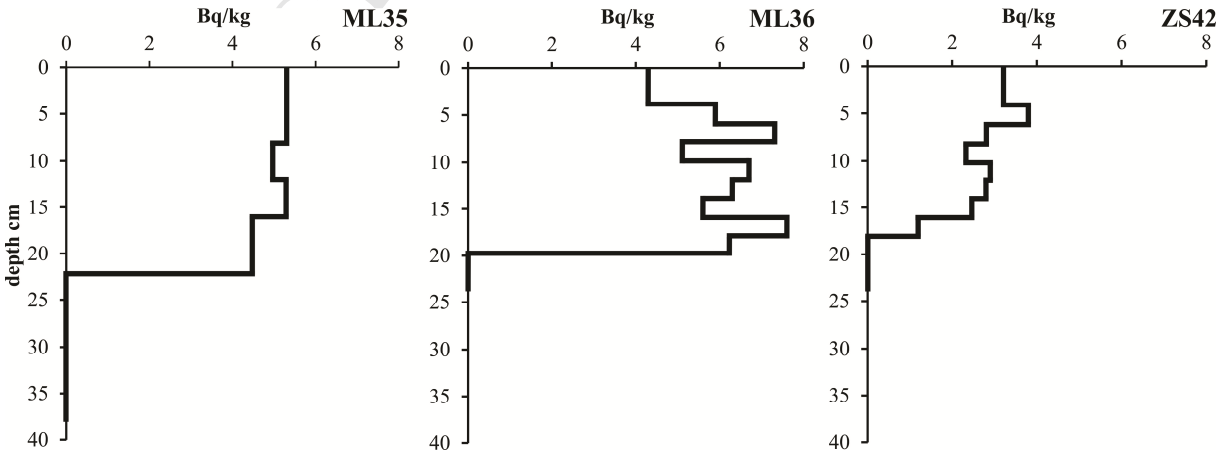


Fig. 2 Distribution of ^{137}Cs activities in the three dated cores

3.2 PAH in the surface sediments and the cores

Fig. 3a shows the spatial distribution of the total PAH concentrations, without considering perylene, in the surface sediments. The concentrations range from around 150 ng/g to around 2300 ng/g. The higher concentrations (above 1000 ng/g) are found close to the inflow in Zhushan Bay (locations 8-23, 4-41 and 3-18) and in the northwestern part of Meiliang Bay (location 8-24). The concentrations at the other locations are typically below 1000 ng/g. These distribution patterns, with the higher concentrations located close to the inflows, reveal that the inflow rivers are the major current pathways for PAH input.

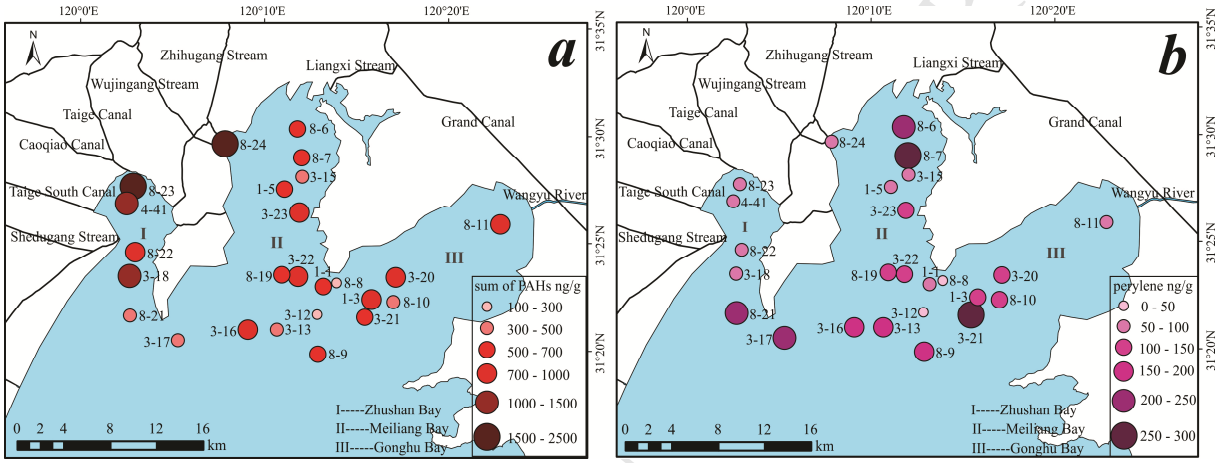


Fig. 3 Concentrations of the sum of the 19 PAHs (without perylene) (a) and of perylene (b) in the surface sediments

Three sediment cores were also taken close to the inflows in Zhushan Bay (ZS23), and in the northwestern and northeastern part of Meiliang Bay (ML7, ML24) (Fig. 1b). In line with the results of the surface sediments, the three cores show the by far highest PAH concentrations (without perylene), reaching up to 5000 ng/g in core ML24 (Fig. 4). These three cores have a length of 40 cm (ZS23), 35 cm (ML7) and 18 cm (ML24), respectively, and their concentrations remain high throughout the cores. The other cores (ML6, ML35, ML36, ML43, ZS42) collected further away from the inflows in the two bays, however, show consistently low background concentrations (below around 150 ng/g) in the deeper parts and comparably high concentrations only in the upper 10 – 20 cm. These results suggest that the sedimentation rates in the area close to the inflows are substantially higher than the average rate of 3 – 4 mm/a in the other locations, and that the rivers connected to the northern part of these two bays are the main pathway for PAHs and sediment input into the lake.

These general findings are also reflected in the three cores (ML6, ML35 and ML36) located with increasing distances from the river outlets in Meiliang Bay (Fig. 1b). These cores present similar concentration profiles, with background concentrations in the deeper layers and higher concentrations in the upper layers (Fig. 4). The concentrations increase from a depth of 28 cm (ML6), 26 cm (ML35) and 22 cm (ML36), respectively, which indicate that the sedimentation rates in the three locations decrease with increasing distances from the river outlets. In addition, core ML36 has lower concentrations in the upper layers compared to the other two cores, in line with the greater distance from river inflows. The two cores located in the south of Zhushan Bay and Meiliang Bay (ZS42 and ML43) show even lower sedimentation rates and also lower PAH concentrations (350 – 450 ng/g) in their upper layers.

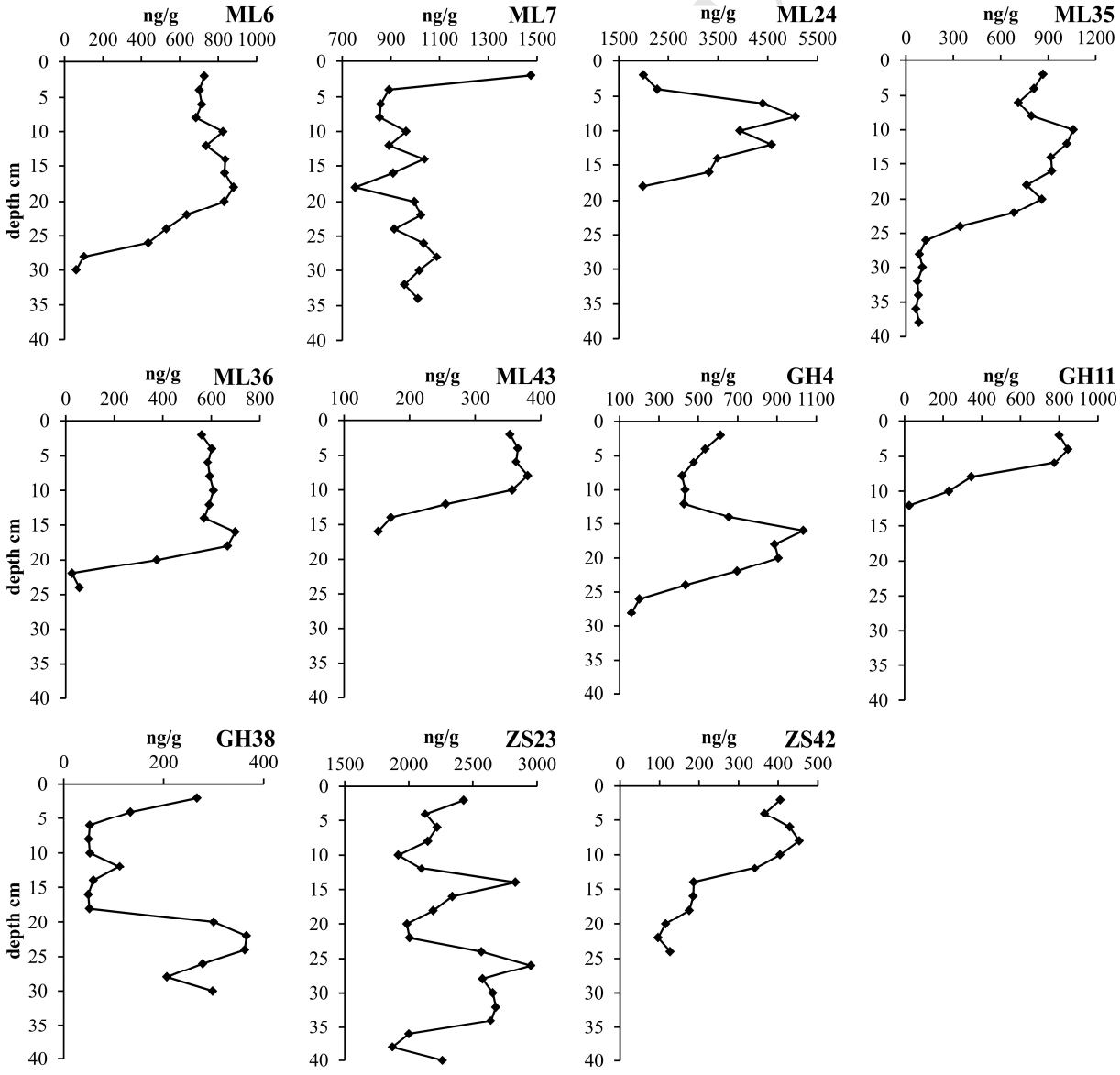


Fig. 4 Concentration profiles of the sum of the 19 PAHs (without perylene) in the cores (different x axis scale)

Three cores (GH4, GH38 and GH11) were taken from Gonghu Bay (Fig. 1b). Taihu Lake is a crucial drinking water source in this region, especially Gonghu Bay provides water to 4 major water treatment works covering 80% of drinking water supply in Wuxi City (Qin et al. 2010; Tao et al., 2010). Gonghu Bay is connected to the Yangtze River through the Wangyu River. In order to alleviate algae blooms in Taihu Lake, a project (WTYT project) was started in 2002 to transfer water from the comparatively low nutrient status Yangtze River to Taihu Lake through the Wangyu River (Zhai et al., 2010). In addition, sediment dredging was conducted around ten years ago to remove contaminated sediments from the bay (Liu et al., 2010; Liu et al., 2016; Chen et al., 2018). These activities likely had an impact on the contamination patterns and thickness of the sediments. The three cores show significantly different concentration profiles that consequently might be influenced by the activities in this bay and may not represent the original stratification.

In principal, the PAH concentration patterns together with the information on sedimentation rates can be used to reveal the historical input of PAHs into the sediments. Coal and oil are the major energy sources in China (Crompton and Wu, 2005; Wang and Feng, 2003), hence PAH abundance in the sediments is a crucial indicator of energy consumption and industrial and economic development. After the People's Republic of China was established in 1949, China started intensifying the development of industry and economy, particularly in coastal areas (Li, 2009; Fan, 1995), which was accompanied with a considerable increase in consumption of coal and oil (Liu, 2008; Jiang and Zhang, 2005). Furthermore, the reform and opening-up Policy in China, implemented in 1978, was associated with rapidly growing urbanization and industrialization (Yeh et al., 2011; Chen et al., 2013). Therefore, combining the PAH concentration profiles and the dating results with an average sedimentation rate of 3 – 4 mm/a in the sediments away from inflows, the significant increases of the PAH concentrations documented in cores ML6, ML35, ML36, ML43, and ZS42 would start from the early 1960s.

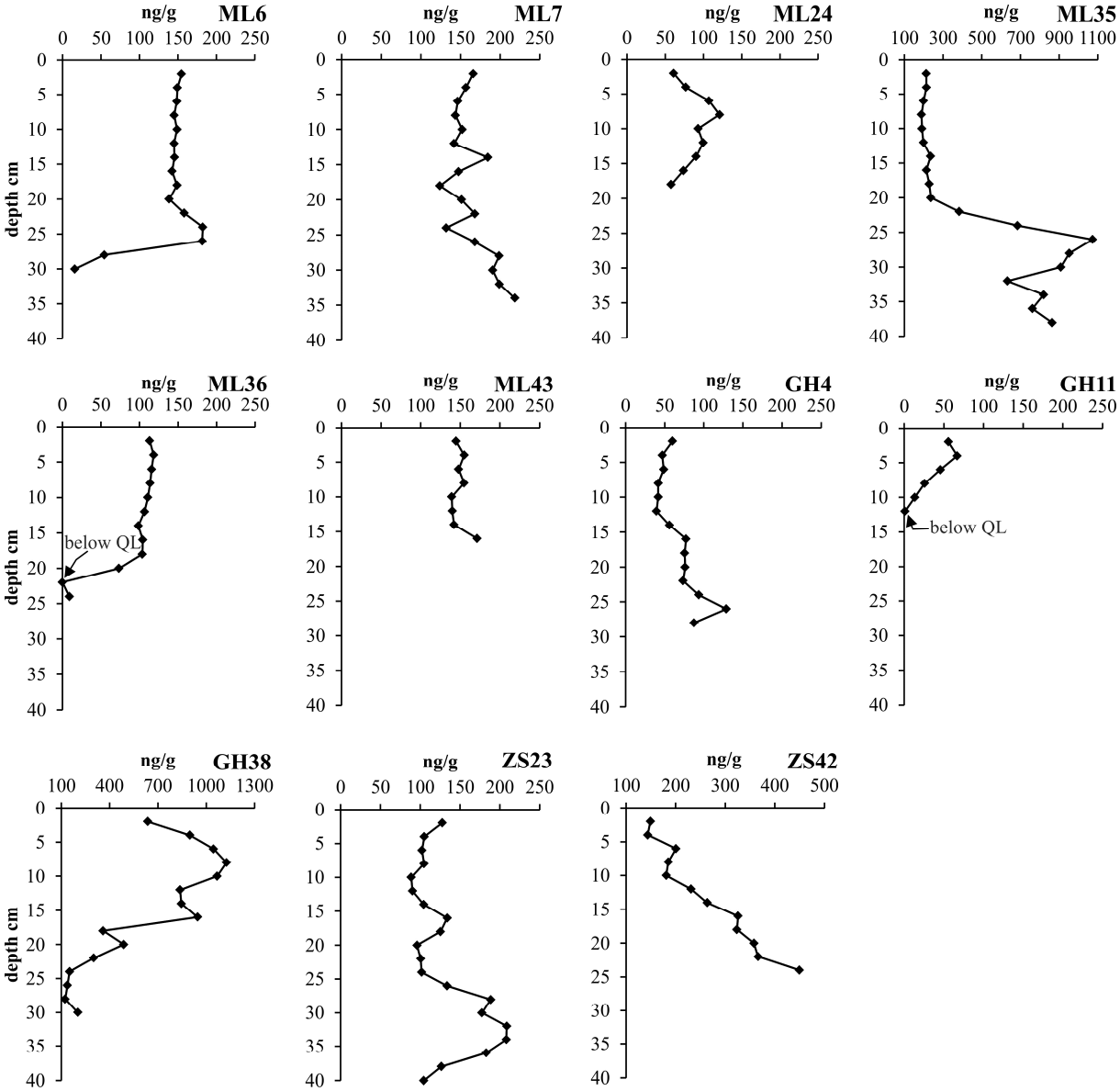
However, the concentrations are rather stable or somehow decreased in the upper layers of the cores compared to the peak concentration in each of the cores. In contrast, energy consumptions in the catchment are still increasing after 2000. Therefore, the inconsistent PAH concentration distributions

with energy consumption could be accounted for by the fact that the Chinese government has enacted and enforced a series of laws and regulations regarding ecologically sustainable development and resources conservation since the 9th Five-Year Plan (1996 – 2000). From the 10th Five-Year Plan (2001 – 2005), in particular, multiple measures for environmental improvement were introduced (Schreifels et al., 2012; Chen and Xu, 2010; Zhou et al., 2010; Crompton and Wu, 2005). Especially, Taihu Lake is one of the prioritized regions for pollution control and treatment.

3.3 Perylene in the surface sediments and the cores

Perylene concentrations in the surface sediments are typically below 200 ng/g, except in the five locations 8-6, 8-7, 8-21, 3-17 and 3-21 with higher concentrations (200 – 300 ng/g) (Fig. 3b). Compared to the other PAHs (Fig. 3a), perylene concentrations are relatively high in most of the sampling locations and the higher concentrations are generally located in the area close to the central part of the lake. The spatial distribution of perylene concentrations is somewhat inverse to the distribution of the other PAHs, which is especially obvious in Zhushan Bay.

As in the case of the surface sediments, perylene concentrations in the cores are generally below 200 ng/g, except cores ML35, GH38 and ZS42 (Fig. 5). In some sections of cores ML35 and GH38, perylene concentrations reach over 1000 ng/g, accounting for up to 96% of the sum of the 20 PAH concentrations. Concentration patterns, however, in the three cores are different. In core ML35, the high concentrations occur in the deeper layers and the relatively low and stable ones (around 200 ng/g) in the upper layers, while in core GH38 perylene concentrations generally increase from the deeper to the upper layer of the core with the highest concentration at 8 cm. In addition, the concentrations in core ZS42 decrease linearly from the deeper layer (around 450 ng/g) to the upper one (around 150 ng/g). Nevertheless, in the other cores, perylene concentrations are low and vary slightly, particularly in the upper 15 – 20 cm.



277

278 Fig. 5 Concentration profiles of perylene in the cores (below QL: below the quantification limit)

279 Compared to the other PAHs, the concentration profiles of perylene are specific in each core, which
280 might result from two potential sources, anthropogenic input together with the other PAHs and
281 biogenic formation in the sediments after deposition. Three anthropogenic PAHs (BaP, BeP and
282 pyrene) were selected as references to distinguish between these two sources (Venkatesan, 1988). The
283 five cores (ZS23, ML24, ML7, GH11 and GH4) collected close to the river outlets show significant
284 positive linear correlations between the concentration of perylene and the three PAHs (Fig. 6a), while
285 the other six cores (ZS42, ML6, ML35, ML36, ML43 and GH38) collected far from the river outlets
286 show significant negative correlations (Fig. 6b) or no correlations (cores ML36 and ML43 shown in S
287 (supplementary material) Fig. 2). The significant positive linear correlations found close to the river

outlets might indicate that perylene was deposited at these locations together with the other PAHs originating from anthropogenic sources in the upstream areas. The detailed results and explanation of the correlation and regression calculations are presented in S Tab. 2 and its following text.

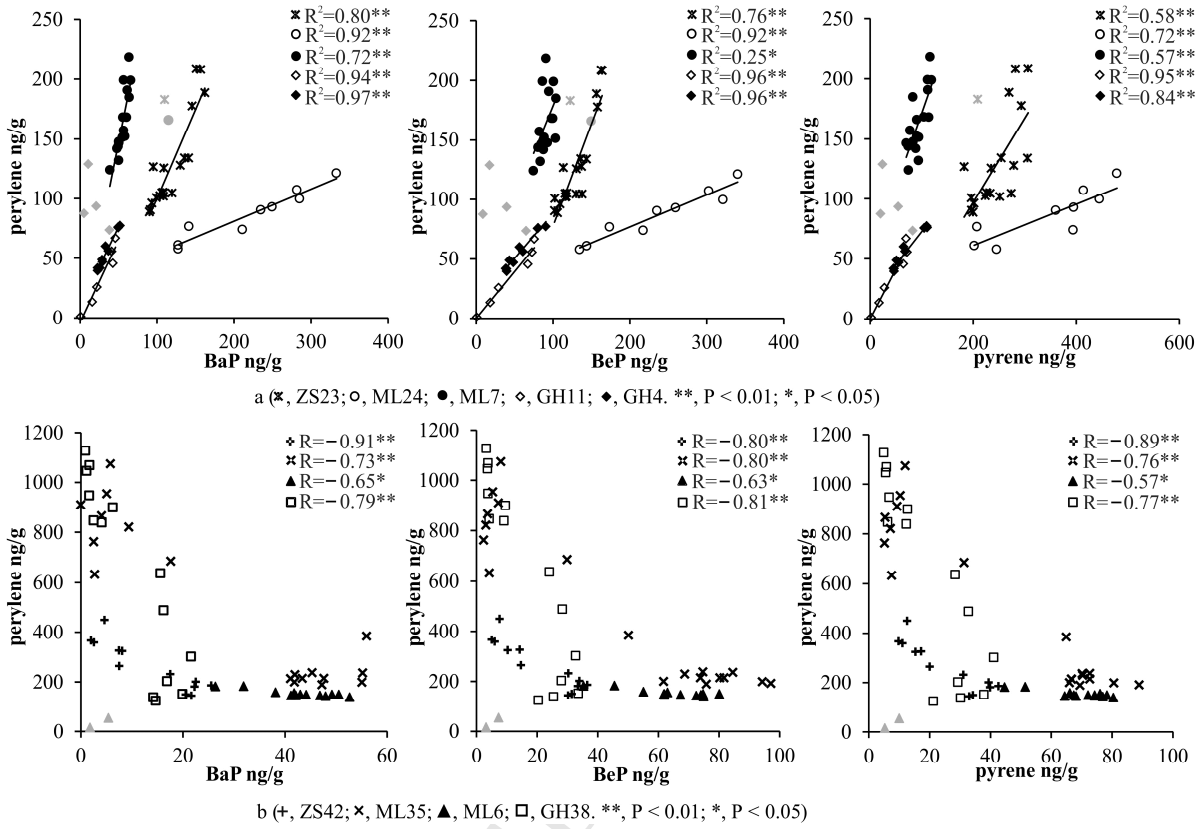


Fig. 6 Concentration correlations between perylene and the three anthropogenic PAHs (BaP, BeP and pyrene) with (a) significant positive linear correlations and (b) significant negative correlations. Four points from core GH4, one point from core ML7, one point from core ZS23 and two points from core ML6 (labelled with grey color) are outliers and are excluded from the correlation and regression calculations, the details about the outliers are explained in supplementary material (below S Tab. 1).

Furthermore, lower perylene abundance relative to other PAHs suggests that perylene mainly originates from pyrolytic processes instead of diagenetic processes (Readman et al., 2002; Baumard et al., 1998). In this study, the concentration proportions of perylene to the sum of the 20 PAHs (S Fig. 1) are typically lower (0.02 to 0.18) in the five cores with significant positive linear correlations compared to the other six cores (0.13 to 0.96) with significant negative correlations or without correlations. This can be also supported by the perylene concentration distributions in the surface sediment (Fig. 3b) where the lower concentrations are generally located in the areas near the river outlets.

Consequently, these three aspects, the positive linear concentration correlations, the lower concentration proportions and the locations with short distance from inflows, together strongly imply that perylene in these five locations originated mainly from anthropogenic activities and were input by river runoff. In addition, the different slopes of the regressions (Fig. 6a) and the different perylene proportions (S Fig. 1) in the five cores might suggest that there were different anthropogenic PAH sources in the inflow rivers.

However, in the other six locations ML6, ML35, ML36, ML43, GH38 and ZS42, perylene could be mainly formed in situ by biogenic activities without obvious spatial transportation and interaction. This is supported by the negative or no correlations between the PAH concentrations and also the higher perylene concentration proportions on one hand, and on the other hand by the specific perylene concentration profiles.

Previous studies suggested that phytoplankton, particularly diatom, could be perylene precursors in deep aquatic sediments (Louda and Baker, 1984; Venkatesan and Kaplan1987; Soma et al., 1996). Massive nutrient inputs have resulted in the rapid proliferation of phytoplankton in Taihu Lake since the 1980s and the occurrence of phytoplankton bloom became more frequent and severe after ca. 2000 (Dong et al., 2008; Duan et al., 2009; 2015). However, perylene concentrations fluctuate slightly or even decrease in the upper layers of the cores. This implies that the distribution of perylene is not consistent with the accumulation of phytoplankton, which agrees with Silliman's report (1998) that there is poor correlation between the mass accumulation rates of perylene and biogenic silica (an indicator of diatom production) in Lake Ontario.

The results also indicate that biogenic formation of perylene might be inhibited in the sediments where anthropogenic impacts are stronger, which is close to the river inflows and in the upper layer of the sediments. Nutrients, organic matter and pollution levels can influence the diversity of microbial communities and mineralization in sediments (Zeng et al., 2005; Haller et al., 2011; Xu et al., 2018) and therefore could also affect biogenic formation of perylene in sediments.

4. Conclusions

Analyses of the spatial distribution of PAHs in the sediments in the northern part of Taihu Lake reveal that the main PAH input into the lake occurs through the inflowing rivers into Zhushan Bay and Meiliang Bay. This coincides with higher sediment deposition rates close to the river inflows. PAH concentrations in the sediments in Meiliang Bay are higher compared to the other two bays.

The temporal analyses of the cores show that increasing PAH input into the lake started from the 1960s due to rapid economic and industrial development. Over the years, PAH concentrations in the sediments increased by a factor of 10 or more compared to the background concentrations. However, the decreased or stable PAH concentrations in the upper layers of the sediments might show the effects of environmental measures implemented by the Chinese government from ca. 2000, although more data are needed to prove this.

The spatial distributions of perylene concentrations in the sediments and its concentrations in relation to the other PAHs suggest that Perylene originates from the same sources as the other anthropogenic PAHs in the locations close to the river inflows. However, it may result from biogenic processes in the locations far away from inflows. Consequently, this could imply that the biogenic formation of perylene is inhibited by anthropogenic activities.

Declaration of interest: none

Acknowledgements

This work was supported by BMBF-SIGN 02WCL1336C and by the International Science & Technology Cooperation Program of China (No. 2016YFE0123700). The author Aili Li sincerely thanks the Chinese Scholarship Council. The authors thank the Working Group of Environmental Mineralogy & Env. System Analysis (ENMINSA), Karlsruhe Institute of Technology (KIT) for supplying sediment core sampler and also give thanks to Dr. Andreas Holbach (KIT) and other field campaign partners. Meanwhile, we thank our lab technicians, Claudia Cosma and Stefanie Schmidt, in TU Darmstadt.

Reference

Baumard, P., Budzinski, H., Michon, Q., Garrigues, P., Burgeot, T. and Bellocq, J., 1998. Origin and bioavailability of PAHs in the Mediterranean Sea from mussel and sediment records. Estuarine, Coastal and Shelf Science, 47, pp.77-90. https://doi.org/10.1006/ecss.1998.0337

Boffetta, P., Jourenkova, N. and Gustavsson, P., 1997. Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons. Cancer Causes & Control, 8, pp.444-472.https://doi.org/10.1023/A:1018465507029

Cao, Y., Zhang, E., Langdon, P., Liu, E. and Shen, J., 2013. Spatially different nutrient histories recorded by multiple cores and implications for management in Taihu Lake, eastern China. Chinese geographical science, 23, pp.537-549. https://doi.org/10.1007/s11769-013-0625-6

Chen, M., Cui, J., Lin, J., Ding, S., Gong, M., Ren, M. and Tsang, D.C., 2018. Successful control of internal phosphorus loading after sediment dredging for 6 years: A field assessment using high-resolution sampling techniques. Science of The Total Environment, 616, pp.927-936. https://doi.org/10.1016/j.scitotenv.2017.10.227

Chen, M., Liu, W. and Tao, X., 2013. Evolution and assessment on China's urbanization 1960–2010: under-urbanization or over-urbanization?. Habitat International, 38, pp.25-33. https://doi.org/10.1016/j.habitatint.2012.09.007

Chen, W. and Xu, R., 2010. Clean coal technology development in China. Energy policy, 38, pp.2123-2130. https://doi.org/10.1016/j.enpol.2009.06.003

Crompton, P. and Wu, Y., 2005. Energy consumption in China: past trends and future directions. Energy economics, 27, pp.195-208. https://doi.org/10.1016/j.eneco.2004.10.006

Dong, X., Bennion, H., Battarbee, R., Yang, X., Yang, H. and Liu, E., 2008. Tracking eutrophication in Taihu Lake using the diatom record: potential and problems. Journal of Paleolimnology, 40, pp.413-429. https://doi.org/10.1007/s10933-007-9170-6

Duan, H., Ma, R., Xu, X., Kong, F., Zhang, S., Kong, W., Hao, J. and Shang, L., 2009. Two-decade reconstruction of algal blooms in China's Lake Taihu. Environmental Science & Technology, 43(10), pp.3522-3528. https://doi.org/10.1021/es8031852

Duan, H., Loiselle, S.A., Zhu, L., Feng, L., Zhang, Y. and Ma, R., 2015. Distribution and incidence of algal blooms in Lake Taihu. Aquatic Sciences, 77, pp.9-16. https://doi.org/10.1007/s00027-014-0367-2

EPA, US, 1993. Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. Development.

Erickson, D.C., Loehr, R.C. and Neuhauser, E.F., 1993. PAH loss during bioremediation of manufactured gas plant site soils. Water Research, 27, pp.911-919. https://doi.org/10.1016/0043-1354(93)90157-D

Fan, C.C., 1995. Of belts and ladders: state policy and uneven regional development in post-Mao China. Annals of the Association of American Geographers, 85, pp.421-449. https://doi.org/10.1111/j.1467-8306.1995.tb01807.x

Ferrey, M.L., Hamilton, M.C., Backe, W.J. and Anderson, K.E., 2018. Pharmaceuticals and other anthropogenic chemicals in atmospheric particulates and precipitation. Science of The Total Environment, 612, pp.1488-1497. https://doi.org/10.1016/j.scitotenv.2017.06.201

Geffard, O., Geffard, A., His, E. and Budzinski, H., 2003. Assessment of the bioavailability and toxicity of sediment-associated polycyclic aromatic hydrocarbons and heavy metals applied to Crassostrea gigas embryos and larvae. Marine Pollution Bulletin, 46, pp.481-490. https://doi.org/10.1016/S0025-326X(02)00451-4

Grice, K., Lu, H., Atahan, P., Asif, M., Hallmann, C., Greenwood, P., Maslen, E., Tulipani, S., Williford, K. and Dodson, J., 2009. New insights into the origin of perylene in geological samples. Geochimica et Cosmochimica Acta, 73, pp.6531-6543. https://doi.org/10.1016/j.gca.2009.07.029

Haller, L., Tonolla, M., Zopfi, J., Peduzzi, R., Wildi, W. and Pote, J., 2011. Composition of bacterial and archaeal communities in freshwater sediments with different contamination levels (Lake Geneva, Switzerland). Water research, 45, pp.1213-1228. https://doi.org/10.1016/j.watres.2010.11.018

Hatzinger, P.B. and Alexander, M., 1995. Effect of aging of chemicals in soil on their biodegradability and extractability. Environmental science & technology, 29, pp.537-545. https://doi.org/ 10.1021/es00002a033

Hollert, H., Crawford, S.E., Brack, W., Brinkmann, M., Fischer, E., Hartmann, K., Keiter, S., Ottermanns, R., Ouellet, J.D., Rinke, K. and Rösch, M., 2018. Looking back-Looking forward: A novel multi-time slice weight-of-evidence approach for defining reference conditions to assess the impact of human activities on lake systems. Science of The Total Environment, 626, pp.1036-1046. https://doi.org/10.1016/j.scitotenv.2018.01.113

Jiang, W. and Zhang, L., 2005. China energy consumption change and its spatial-temporal effect analysis. Journal of Liaoning Technical University, 24, pp. 612-615. (in Chinese)

Jiang, X., Wang, W., Wang, S., Zhang, B. and Hu, J., 2012. Initial identification of heavy metals contamination in Taihu Lake, a eutrophic lake in China. Journal of Environmental Sciences, 24, pp.1539-1548. https://doi.org/10.1016/S1001-0742(11)60986-8

Jin, X., Wang, S., Pang, Y. and Wu, F.C., 2006. Phosphorus fractions and the effect of pH on the phosphorus release of the sediments from different trophic areas in Taihu Lake, China. Environmental Pollution, 139, pp.288-295. https://doi.org/10.1016/j.envpol.2005.05.010

Kim, K.H., Jahan, S.A., Kabir, E. and Brown, R.J., 2013. A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. Environment international, 60, pp.71-80. https://doi.org/10.1016/j.envint.2013.07.019

Kozak, K., Ruman, M., Kosek, K., Karasiński, G., Stachnik, Ł. and Polkowska, Ż., 2017. Impact of volcanic eruptions on the occurrence of PAHs compounds in the aquatic ecosystem of the southern part of West Spitsbergen (Hornsund fjord, Svalbard). Water, 9, p.42. https://doi.org/10.3390/w9010042

Lei, B., Kang, J., Wang, X., Yu, Y., Zhang, X., Wen, Y. and Wang, Y., 2014. The levels of PAHs and aryl hydrocarbon receptor effects in sediments of Taihu Lake, China. Environmental Science and Pollution Research, 21, pp.6547-6557. https://doi.org/10.1007/s11356-014-2542-3

Lei, P., Zhang, H. and Shan, B., 2016. Vertical records of sedimentary PAHs and their freely dissolved fractions in porewater profiles from the northern bays of Taihu Lake, Eastern China. RSC Advances, 6, pp.98835-98844. https://doi.org/10.1039/C6RA11180G

Li, Y., 2009. Sixty Years' Finance in New China (Xin Zhongguo Jinrong 60 nian). China Financial & Economic Publishing House, Beijing. (in Chinese)

Liu, C., Zhong, J., Wang, J., Zhang, L. and Fan, C., 2016. Fifteen-year study of environmental dredging effect on variation of nitrogen and phosphorus exchange across the sediment-water interface of an urban lake. Environmental pollution, 219, pp.639-648. https://doi.org/10.1016/j.envpol.2016.06.040

Liu, E., Birch, G.F., Shen, J., Yuan, H., Zhang, E. and Cao, Y., 2012. Comprehensive evaluation of heavy metal contamination in surface and core sediments of Taihu Lake, the third largest freshwater lake in China. Environmental Earth Sciences, 67, pp.39-51. https://doi.org/10.1007/s12665-011-1478-x

Liu, E., Shen, J., Zhu, Y., Xia, W. and Zhu, G., 2004. Source analysis of heavy metals in surface sediments of Lake Taihu. Journal of Lake Sciences, 16, pp.113-119. (in Chinese).

Liu, G., Zhang, G., Jin, Z. and Li, J., 2009. Sedimentary record of hydrophobic organic compounds in relation to regional economic development: a study of Taihu Lake, East China. Environmental pollution, 157, pp.2994-3000. https://doi.org/10.1016/j.envpol.2009.05.056

Liu, G.F., Zhang, Z.Y., Liu, H.Q., Zhong, J.C., Yan, S.H. and Fan, C.X., 2010. Effects of sediment dredging on benthos community structure and water quality in The Zhushan Bay. Huan jing ke xue, 31, pp.2645-2651. (in Chinese)

Liu H., 2008. Time-dependent Analysis of Relation Between Oil Consumption and Economic Growth in China. Journal of Northeastern University (Social Science), 10, pp.121-126. (in Chinese)

Louda, J.W. and Baker, E.W., 1984. Perylene occurrence, alkylation and possible sources in deep-ocean sediments. Geochimica et Cosmochimica Acta, 48, pp.1043-1058. https://doi.org/10.1016/0016-7037(84)90195-9

Luo, L.C., Qin, B.Q. and Zhu, G.W., 2004. Sediment distribution pattern mapped from the combination of objective analysis and geostatistics in the large shallow Taihu Lake, China. Journal of Environmental Sciences-Amsterdam, 16, pp.908-911.

Marynowski, L., Smolarek, J., Bechtel, A., Philippe, M., Kurkiewicz, S. and Simoneit, B.R., 2013. Perylene as an indicator of conifer fossil wood degradation by wood-degrading fungi. Organic geochemistry, 59, pp.143-151. https://doi.org/10.1016/j.orggeochem.2013.04.006

Pal, A., Gin, K.Y.H., Lin, A.Y.C. and Reinhard, M., 2010. Impacts of emerging organic contaminants on freshwater resources: review of recent occurrences, sources, fate and effects. Science of the total environment, 408, pp.6062-6069. https://doi.org/10.1016/j.scitotenv.2010.09.026

Peng, X., Zhang, G., Zheng, L., Mai, B. and Zeng, S., 2005. The vertical variations of hydrocarbon pollutants and organochlorine pesticide residues in a sediment core in Lake Taihu, East China. Geochemistry: Exploration, Environment, Analysis, 5, pp.99-104. https://doi.org/10.1144/1467-7873/03-038

Qiao, M., Wang, C., Huang, S., Wang, D. and Wang, Z., 2006. Composition, sources, and potential toxicological significance of PAHs in the surface sediments of the Meiliang Bay, Taihu Lake, China. Environment International, 32, pp.28-33. https://doi.org/10.1016/j.envint.2005.04.005

Qin, B. ed., 2008. Lake Taihu, China: dynamics and environmental change (Vol. 87). Springer Science & Business Media.

Qin, B., Hu, W., Gao, G., Luo, L. and Zhang, J., 2004. Dynamics of sediment resuspension and the conceptual schema of nutrient release in the large shallow Lake Taihu, China. Chinese Science Bulletin, 49, pp.54-64. https://doi.org/10.1007/BF02901743

Qin, B., Xu, P., Wu, Q., Luo, L. and Zhang, Y., 2007. Environmental issues of lake Taihu, China. Hydrobiologia, 581, pp.3-14. https://doi.org/10.1007/s10750-006-0521-5

Qin, B., Zhu, G., Gao, G., Zhang, Y., Li, W., Paerl, H.W. and Carmichael, W.W., 2010. A drinking water crisis in Lake Taihu, China: linkage to climatic variability and lake management. Environmental management, 45, pp.105-112. https://doi.org/10.1007/s00267-009-9393-6

Qu, W., Dickman, M., Fan, C., Wang, S., Su, C., Zhang, L., Zou, H., 2002. Distribution, sources and potential toxicological significance of polycyclic aromatic hydrocarbons (PAHs) in Taihu Lake sediments, China. Hydrobiologia, 485, pp.163-171. https://doi.org/10.1023/A:1021301909296

Readman, J.W., Fillmann, G., Tolosa, I., Bartocci, J., Villeneuve, J.P., Catinni, C. and Mee, L.D., 2002. Petroleum and PAH contamination of the Black Sea. Marine Pollution Bulletin, 44, pp.48-62. https://doi.org/10.1016/S0025-326X(01)00189-8

Rowntree, K.M., Foster I.D.L., 2012. A reconstruction of historical changes in sediment sources, sediment transfer and sediment yield in a small, semi-arid Karoo catchment, South Africa. Zeitschrift für Geomorphology. 56, suppl. 1:87-https://doi.org/10.1127/0372-8854/2012/S-00074

Schreifels, J.J., Fu, Y. and Wilson, E.J., 2012. Sulfur dioxide control in China: policy evolution during the 10th and 11th Five-year Plans and lessons for the future. Energy Policy, 48, pp.779-789. https://doi.org/10.1016/j.enpol.2012.06.015

Shen, G., Tao, S., Wei, S., Zhang, Y., Wang, R., Wang, B., Li, W., Shen, H., Huang, Y., Chen, Y. and Chen, H., 2012. Emissions of parent, nitro, and oxygenated polycyclic aromatic hydrocarbons from residential wood combustion in rural China. Environmental science & technology, 46, pp.8123-8130. https://doi.org/ 10.1021/es301146v

Silliman, J.E., Meyers, P.A. and Eadie, B.J., 1998. Perylene: an indicator of alteration processes or precursor materials?. Organic Geochemistry, 29, pp.1737-1744. https://doi.org/10.1016/S0146-6380(98)00056-4

Silliman, J.E., Meyers, P.A., Ostrom, P.H., Ostrom, N.E. and Eadie, B.J., 2000. Insights into the origin of perylene from isotopic analyses of sediments from Saanich Inlet, British Columbia. Organic Geochemistry, 31, pp.1133-1142. https://doi.org/10.1016/S0146-6380(00)00120-0

Soma, Y., Tanaka, A., Soma, M. and Kawai, T., 1996. Photosynthetic pigments and perylene in the sediments of southern basin of Lake Baikal. Organic geochemistry, 24, pp.553-561. https://doi.org/10.1016/0146-6380(96)00036-8

Suzuki, N., Yessalina, S. and Kikuchi, T., 2010. Probable fungal origin of perylene in Late Cretaceous to Paleogene terrestrial sedimentary rocks of northeastern Japan as indicated from stable carbon isotopes. Organic Geochemistry, 41, pp.234-241. https://doi.org/10.1016/j.orggeochem.2009.11.010

Tang, Z., Guo, J., Liao, H., Zhao, X., Wu, F., Zhu, Y., Zhang, L. and Giesy, J.P., 2015. Spatial and temporal distribution and sources of polycyclic aromatic hydrocarbons in sediments of Taihu Lake, eastern China. Environmental Science and Pollution Research, 22, pp.5350-5358. https://doi.org/10.1007/s11356-014-3746-2

493 Tao, Y., Yao, S., Xue, B., Deng, J., Wang, X., Feng, M. and Hu, W., 2010. Polycyclic aromatic hydrocarbons in surface
494 sediments from drinking water sources of Taihu Lake, China: sources, partitioning and toxicological risk. Journal of
495 Environmental Monitoring, 12, pp.2282-2289. https://doi.org/10.1039/C0EM00144A
496 Tao, Y., Dan, D., Kun, L., Chengda, H., Haibing, C., Guo, F., Qiujin, X., Fuhong, S. and Fengchang, W., 2018. δ 15 N and
497 nutrient stoichiometry of water, aquatic organisms and environmental implications in Taihu lake, China. Environmental
498 Pollution, 237, pp.166-173. https://doi.org/10.1016/j.envpol.2018.02.048
499 Venkatesan, M.I., 1988. Occurrence and possible sources of perylene in marine sediments-a review. Marine Chemistry, 25,
500 pp.1-27. https://doi.org/10.1016/0304-4203(88)90011-4
501 Venkatesan, M.I. and Kaplan, I.R., 1987. The lipid geochemistry of Antarctic marine sediments: Bransfield Strait. Marine
502 Chemistry, 21, pp.347-375. https://doi.org/10.1016/0304-4203(87)90056-9
503 Vila-Escalé, M., Vegas-Vilarrúbia, T. and Prat, N., 2007. Release of polycyclic aromatic compounds into a Mediterranean
504 creek (Catalonia, NE Spain) after a forest fire. Water Research, 41, pp.2171-2179.
505 https://doi.org/10.1016/j.watres.2006.07.029
506 Wang, H., Wang, C., Wu, W., Mo, Z. and Wang, Z., 2003. Persistent organic pollutants in water and surface sediments of
507 Taihu Lake, China and risk assessment. Chemosphere, 50, pp.557-562. https://doi.org/10.1016/S0045-6535(02)00484-8
508 Wang, X. and Feng, Z., 2003. Energy consumption with sustainable development in developing country: a case in Jiangsu,
509 China. Energy Policy, 31, pp.1679-1684. https://doi.org/10.1016/S0301-4215(02)00234-3
510 Wolf, A., Bergmann, A., Wilken, R.D., Gao, X., Bi, Y., Chen, H. and Schüth, C., 2013. Occurrence and distribution of
511 organic trace substances in waters from the Three Gorges Reservoir, China. Environmental Science and Pollution
512 Research, 20, pp.7124-7139. https://doi.org/10.1007/s11356-013-1929-x
513 Wilhelm, S.W., Farnsley, S.E., LeCleir, G.R., Layton, A.C., Satchwell, M.F., DeBruyn, J.M., Boyer, G.L., Zhu, G. and Paerl,
514 H.W., 2011. The relationships between nutrients, cyanobacterial toxins and the microbial community in Taihu (Lake
515 Tai), China. Harmful Algae, 10, pp.207-215. https://doi.org/10.1016/j.hal.2010.10.001
516 Wolkenstein, K., Gross, J.H., Falk, H. and Schöler, H.F., 2006. Preservation of hypericin and related polycyclic quinone
517 pigments in fossil crinoids. Proceedings of the Royal Society of London B: Biological Sciences, 273, pp.451-456.
518 https://doi.org/10.1098/rspb.2005.3358
519 Wu, D., Zhang, F., Lou, W., Li, D. and Chen, J., 2017. Chemical characterization and toxicity assessment of fine particulate
520 matters emitted from the combustion of petrol and diesel fuels. Science of The Total Environment, 605, pp.172-179.
521 https://doi.org/10.1016/j.scitotenv.2017.06.058
522 Xu, J., Zhang, Y., Zhou, C., Guo, C., Wang, D., Du, P., Luo, Y., Wan, J. and Meng, W., 2014. Distribution, sources and
523 composition of antibiotics in sediment, overlying water and pore water from Taihu Lake, China. Science of the Total
524 Environment, 497, pp.267-273. https://doi.org/10.1016/j.scitotenv.2014.07.114

Xu, Z., Wu, J., Li, H., Chen, Y., Xu, J., Xiong, L. and Zhang, J., 2018. Characterizing heavy metals in combined sewer overflows and its influence on microbial diversity. Science of the Total Environment, 625, pp.1272-1282. https://doi.org/10.1016/j.scitotenv.2017.12.338

Xue, B. and Yao, S., 2011. Recent sedimentation rates in lakes in lower Yangtze River basin. Quaternary international, 244, pp.248-253. https://doi.org/10.1016/j.quaint.2011.01.003

Yang, H.H., Lai, S.O., Hsieh, L.T., Hsueh, H.J. and Chi, T.W., 2002. Profiles of PAH emission from steel and iron industries. Chemosphere, 48, pp.1061-1074. https://doi.org/10.1016/S0045-6535(02)00175-3

Yeh, A.G., Xu, J. and Liu, K., 2011. China's Post-reform Urbanization: Retrospect, Policies and Trends (Vol. 5). IIED.

Zakaria, M.P., Takada, H., Tsutsumi, S., Ohno, K., Yamada, J., Kouno, E. and Kumata, H., 2002. Distribution of polycyclic aromatic hydrocarbons (PAHs) in rivers and estuaries in Malaysia: a widespread input of petrogenic PAHs. Environmental science & technology, 36, pp.1907-1918. https://doi.org/10.1021/es011278+

Zeng, R., Zhao, J., Zhang, R. and Lin, N., 2005. Bacterial community in sediment from the Western Pacific "Warm Pool" and its relationship to environment. Science in China Series D: Earth Sciences, 48, pp.282-290. https://doi.org/10.1360/03yd0531

Zhai, S., Hu, W. and Zhu, Z., 2010. Ecological impacts of water transfers on Lake Taihu from the Yangtze River, China. Ecological Engineering, 36, pp.406-420. https://doi.org/10.1016/j.ecoleng.2009.11.007

Zhang, X.J., Chen, C., Ding, J.Q., Hou, A., Li, Y., Niu, Z.B., Su, X.Y., Xu, Y.J. and Laws, E.A., 2010. The 2007 water crisis in Wuxi, China: analysis of the origin. Journal of Hazardous Materials, 182, pp.130-135. https://doi.org/10.1016/j.jhazmat.2010.06.006

Zhang, Y., Schauer, J.J., Zhang, Y., Zeng, L., Wei, Y., Liu, Y. and Shao, M., 2008. Characteristics of particulate carbon emissions from real-world Chinese coal combustion. Environmental science & technology, 42, pp.5068-5073. https://doi.org/10.1021/es7022576

Zhou, N., Levine, M.D. and Price, L., 2010. Overview of current energy-efficiency policies in China. Energy policy, 38, pp.6439-6452. https://doi.org/10.1016/j.enpol.2009.08.015

HIGHLIGHT

- River inflows are the main pathway for PAHs and particles input in the northern part of Taihu Lake
- Anthropogenic activities significantly influenced the PAH abundance in the lake sediment
- Perylene originated from anthropogenic and biogenic activities in different sampling areas