International Journal of Basic and Applied Sciences, 14 (6) (2025) 444-452

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/zk9a3751
Research paper

Heavy Metals and PAHs in Mollusks from The Sangomar Marine Protected Area in Senegal: A Baseline Study

Issa BA.[1] *, Ousmane Diankha [2], Bamol Ali Sow [1]

[1] *Laboratoire d'Océanographie, des Sciences de l'Environnement et du Climat (LOSEC), Université Assane seck de Ziguinchor (UASZ), Ziguinchor, Sénégal.; BP 523*
[2] *Département Hydrosciences et environnement, UFR Sciences et Technologies, Université Iba Der Thiam, Thiès, Sénégal.*
**Corresponding author E-mail: issabaa1@gmail.com*

Received: August 19, 2025, Accepted: October 1, 2025, Published: October 20, 2025

Abstract

This study provides the first baseline evaluation of heavy metals (Pb, Cd, Hg) and polycyclic aromatic hydrocarbons (PAHs) in the bivalves Senilia senilis and Crassostrea gasar from the Sangomar Marine Protected Area (Senegal), prior to offshore oil exploitation. Sampling was conducted during the dry and rainy seasons of 2023-2024. Plomb and Hg concentrations remained well below international safety limits, whereas Cd frequently exceeded the permissible threshold, reaching 2.36 mg/kg dry weight in S. senilis. PAH contamination, dominated by pyrogenic four-ring compounds (fluoranthene, pyrene), peaked in S. senilis during the rainy season (190 µg/kg). Health risk assessment indicated that target hazard quotients for Cd approached the critical value of 1 in S. senilis, suggesting possible long-term risks to consumers. These results reveal high Cd exposure and seasonal PAH inputs likely linked to runoff, providing essential reference data for environmental monitoring and informing adaptive management strategies in the face of industrial expansion.

Keywords: *Health Risk Assessment; Heavy Metals; PAHs; Crassostrea Gasar; Sangomar MPA; Senegal; Senilia Senilis.*

1. Introduction

Coastal ecosystems are among the most dynamic, productive, and sensitive environments on the planet. Located at the interface between terrestrial and marine systems, they play a fundamental ecological role by supporting a variety of functions, including biogeochemical cycle regulation, natural water purification, climate change mitigation, and biodiversity maintenance (Barbier et al., 2011). However, this ecological wealth is increasingly threatened by growing anthropogenic pressures, notably urban, agricultural, industrial, and, more recently, oil-related discharges. These multiple inputs introduce a wide range of persistent chemical contaminants into the marine environment, among which trace metals (TMs) and polycyclic aromatic hydrocarbons (PAHs) are of major concern (Rainbow, 2002; Neff, 1979).

Trace metals (TMs) such as lead (Pb), cadmium (Cd), and mercury (Hg) are known for their toxicity even at low concentrations, their persistence in sediments, and their ability to bioaccumulate throughout the food chain (Blackmore, 2000; Aranguren et al., 2008). Their accumulation in organisms can cause various physiological effects, including oxidative stress, enzymatic alterations, and reproductive impairment (Wang & Rainbow, 2008). PAHs, on the other hand, are hydrophobic compounds mainly derived from the incomplete combustion of organic matter (coal, biomass, fossil fuels), but also from leaks or discharges of crude or refined petroleum (Yunker et al., 2002). Due to their affinity for suspended particles, they preferentially accumulate in fine sediments. Some, particularly high-molecular weight compounds such as benzo[a] pyrene, are classified as carcinogenic, mutagenic, or toxic to reproduction (CMR) by the International Agency for Research on Cancer (IARC, 2010). Determining PAH sources often relies on molecular diagnostic ratios such as Flu/(Flu + Pyr) or Ant/(Ant + Phe), which help distinguish pyrogenic (combustion-related) from petrogenic (petroleum-derived) origins (Yunker et al., 2002; Tobiszewski & Namieśnik, 2012).

In an integrated environmental monitoring approach, abiotic analyses (water, sediments) should be complemented by biomonitoring, which assesses the fraction of pollutants that is truly bioavailable (Pan et al., 2012). This approach relies on the use of bioindicator organisms capable of accumulating contaminants from their environment and reflecting the chemical state of the habitat. Filter-feeding bivalves, such as Senilia senilis and Crassostrea gasar, are frequently used for this purpose. Their sessile lifestyle, high filtration capacity, and central ecological position make them relevant bioindicators of chemical contamination (Widdows et al., 2002; Matozzo et al., 2010; Chalghmi et al., 2015).

The Sangomar Marine Protected Area (MPA), located at the mouth of the Saloum Delta (Senegal), is a coastal ecosystem of major ecological and socio-economic importance. It is characterized by remarkable biodiversity and plays a crucial role in local fisheries.

However, the recent installation of offshore oil infrastructure near this protected area has raised increasing concerns about potential chronic contamination by TMs and PAHs. While previous studies have characterized baseline sediment and water quality (Ba et al., 2025a; Ba et al., 2025b), bioaccumulation of these contaminants in marine organisms remains poorly documented.

This study aims to establish a biological reference for metal and organic contamination in the Sangomar MPA by quantifying TM and PAH concentrations in the soft tissues of Senilia senilis and Crassostrea gasar. Conducted prior to the onset of oil exploitation, this assessment is part of a long-term environmental monitoring strategy. It will contribute to anticipating ecotoxicological risks, strengthening environmental management capacity, and supporting the sustainable preservation of Senegal's coastal ecosystems in the face of growing extractive pressures.

2. Materials and Methods

2.1. Study area

The Sangomar Marine Protected Area (MPA) is located within the Saloum Delta Biosphere Reserve and was designated as a UNESCO World Heritage site in 2011. Covering an area of 87,437 hectares, it is one of the largest MPAs in Senegal (DAMCP, 2013). Established by Decree No. 2014-338 of March 25, 2014, at the request of local communities, the MPA lies between the municipalities of Palmarin and Dionewar, in the Fatick region. This area hosts high biodiversity, including marine turtles, dolphins, manatees, more than 90 fish species, and numerous seabirds. Key habitats such as mangroves, seagrass beds, and coastal forests provide essential ecological functions for the region (Anonymous, 2020).

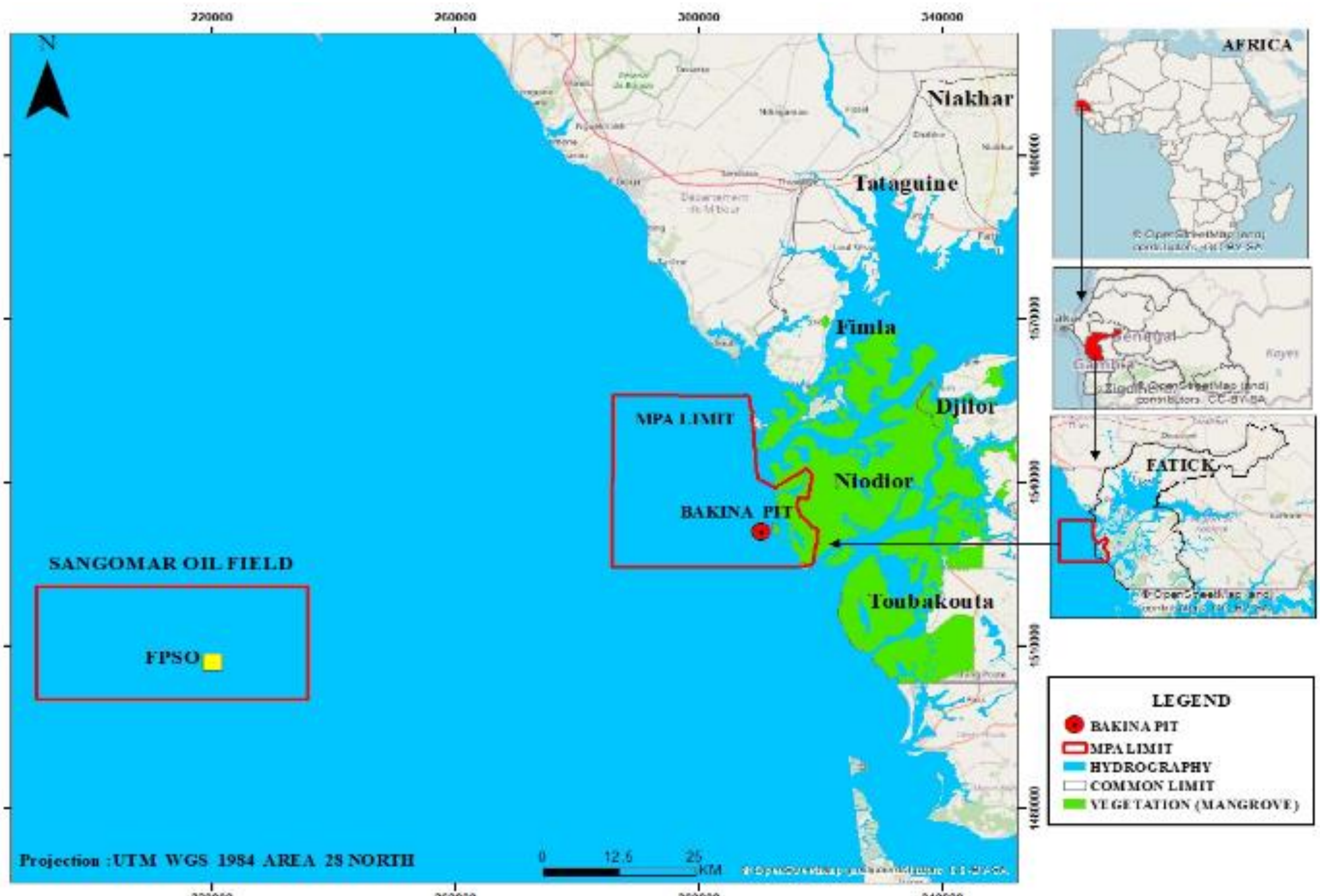

Fig. 1: Location of the Sangomar Marine Protected Area.

2.2. Sample collection

Four sampling campaigns were carried out in 2023 and 2024, during dry and rainy seasons. Samples were collected from Bakina, the main breeding and concentration areas for the bivalves Senilia senilis and Crassostrea gasar (DAMCP, 2013). Sampling was conducted at low tide. During each campaign, 10 individuals per species were collected. Specimens were immediately placed in ice-cooled containers to prevent post-harvest degradation and transported to the laboratory for analysis.

2.3. Trace metal analysis

For atomic absorption spectrometry (AAS110) calibration, analytical standards of Pb, Cd, and Hg were used. For each sample (fish muscles), 0.5 g was digested using 15 mL of 65% nitric acid, 3 mL of hydrochloric acid, and 0.5 mL of perchloric acid in Pyrex volumetric flasks, along with 6 mL of 1% nitric acid. The digested solutions were diluted to 50 mL with acidified water (0.1 N), and metal concentrations were measured using graphite furnace AAS (AAS110). Mercury was quantified using cold vapor atomic absorption spectrometry (CV-AAS110). Calibration solutions were prepared for each metal, and fortified sample were used to calculate recovery rates, with spike concentrations within the calibration range. All concentrations are expressed in mg/kg. La limite de quantification (LOQ) pour le Pb, le Cd, et le Hg est respectivement of 0.05, 0.005, and 0.01 mg/kg.

2.4. PAH analysis

The priority PAHs identified by the US EPA were extracted from homogenized fish muscles using a modified QuEChERS protocol (AOAC), as described by Pule et al. (2012). Extracts were analyzed using gas chromatography-mass spectrometry (GC/MS) on a Varian model 1200 system, with a DB-5MS capillary column (30 m × 0.25 mm × 0.25 µm). Injections were performed in splitless mode (1 µL), with injector and source temperatures set at 295 °C and 280 °C, respectively. Mass scanning was conducted from 50 to 500 m/z, using helium as the carrier gas at a constant flow of 1 mL/min. PAH quantification was performed using selective reaction monitoring (SRM). All reagents and standards were provided by Sigma-Aldrich.

2.5. Quality assurance and quality control

A strict QA/QC protocol was applied to ensure the accuracy and reliability of Pb, Cd, Hg and PAH analyses. For PAHs, three test samples were prepared from a homogenized reference material to assess analytical accuracy. One sample was spiked with 1 µL of a PAH standard solution at 2000 µg/mL (including all EPA priority PAHs), while the two others remained unspiked. Recovery rates were calculated accordingly and ranged from 78% to 97%. The detection limit for PAHs was set at 40 ng/g dry weight. For ETMs, multi-element calibration was performed using single-element standard solutions (SCP Sciences). To ensure instrument stability and analytical precision, standard solutions were injected after every three samples during analysis.

2.6. Human health risk assessment and statistical analysis

2.6.1. Target hazard quotient (THQ)

Non-carcinogenic health risks from daily consumption of contaminated oysters and ark clams were assessed using the Target Hazard Quotient (THQ) following Diop et al. (2017) and Diankha et al. (2020). The THQ integrates exposure frequency, duration, daily seafood intake (80 g/day), contaminant concentration, reference dose, and average body weight (60 kg for adults in Senegal; ANSD, 2017). A THQ below 1 indicates negligible risk, whereas values above 1 suggest potential adverse effects. The THQ is defined by the following equation:

$$THQ = \frac{EFrx * EDtot * Wfood\ X\ Ci}{RFdox * Bwx * ATn} * 10^{-3} \quad (1)$$

Where,
EFr is the exposure frequency (365 days);
EDtot is the lifetime expectancy (65 years in Senegal: ANSD, 2017);
Wfood is the daily consumption quantity (g), corresponding to 29 kg / 365 days = 80 g/day;
Ci is the metal concentration (mg/kg);
RFdox is the oral reference dose (3×10^{-4} mg/kg/day, USEPA, 2008);
Bwx is the average body weight (60 kg);
Atn is the exposure duration (365 days × lifetime expectancy);

If THQ < 1, it indicates a negligible effect on human health.
If THQ > 1, it indicates an adverse effect on human health (Diop et al., 2017).

2.6.2. Maximum safe consumption (MSC)

The MSC was calculated to determine the maximum daily intake of oysters and ark clams that does not exceed provisional tolerable daily intake limits for Cd and Pb (FAO, 2007; 2022), based on contaminant concentration and body weight (Diop et al., 2017; Diankha et al., 2020; Badji et al., 2025).

$$MSCi = \frac{JLi\ x\ Bw}{Ci} \quad (2)$$

Where,
JLi is the provisional maximum tolerable daily intake: $7*10^{-3}$ mg/kg for cadmium and $25*10^{-3}$ mg/kg for lead (FAO, 2007, 2022);
Bw is the body weight (60 kg);
Ci is the metal concentration (mg/kg).

2.6.3. Statistical analysis

A Student's t-test was performed to assess differences in trace metal (TM) concentrations between the two bivalve species, as well as across seasons and sampling years. This statistical method allowed for precise comparison of means, enabling the identification of both significant and non-significant variations.

3. Results

3.1. Heavy metal concentrations

Lead, Cd, and Hg concentrations were measured in S. senilis (ark clam) and C. gasar (oyster) during the dry and rainy seasons of 2023 and 2024 (Figure 2). Lead concentrations indicated moderate contamination, generally below the European regulatory limit of 1.5 mg/kg dry weight. In 2023, the highest values were recorded in oysters during the dry season (1.15 mg/kg) and in ark clams during the rainy season

(0.54 mg/kg). In 2024, Pb levels in ark clams decreased to undetectable levels, while oysters still showed a notable concentration in the rainy season (0.7 mg/kg). Statistical tests revealed no significant seasonal (p = 0.45 for ark clams; p = 0.85 for oysters) or interannual variation (p = 0.36 for ark clams; p = 0.65 for oysters).

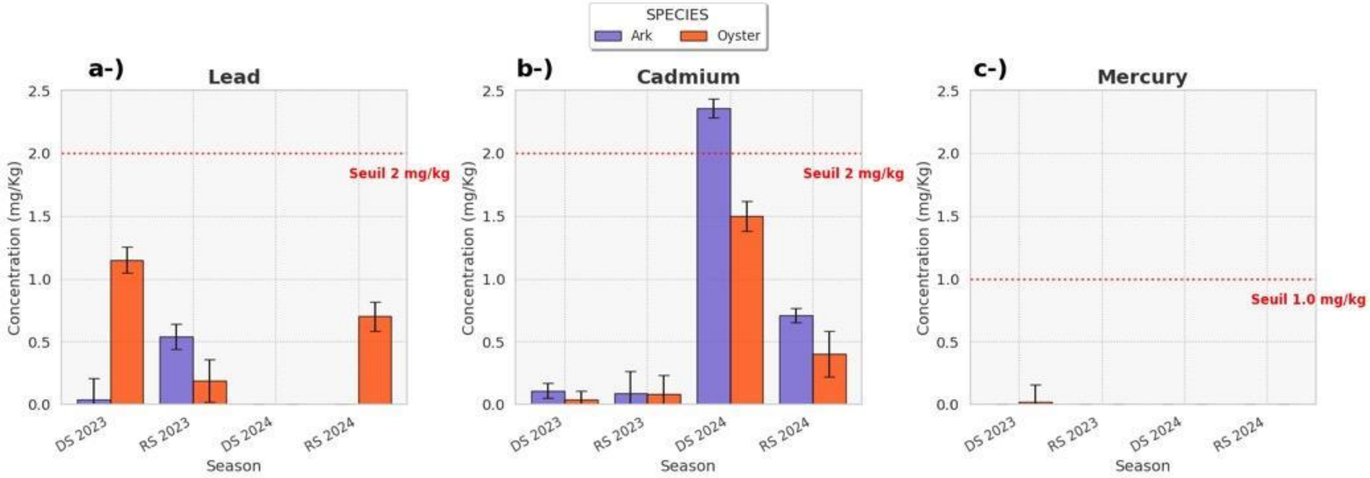

Fig. 2: Temporal Variation of Heavy Metal Concentrations in S. Senilis (Purple Bars) and C. Gasar (Orange Bars) in the Sangomar Marine Protected Area (MPA). The Red Dashed Line Represents the Reference Threshold Values.

Cadmium exhibited a more concerning profile, with concentrations exceeding the regulatory limit of 1.0 mg/kg in 2024. In the dry season, Cd reached 2.36 mg/kg in ark clams and 1.5 mg/kg in oysters. Although values decreased during the rainy season (0.71 mg/kg in ark clams; 0.4 mg/kg in oysters), they remained relatively high. In comparison, 2023 levels were much lower (≤ 0.11 mg/kg in ark clams; ≤ 0.08 mg/kg in oysters). Statistical analysis showed no significant differences between seasons (ark clams: p = 0.54; oysters: p = 0.55), years (ark clams: p = 0.22; oysters: p = 0.24), or species (p = 0.64). Mercury concentrations were negligible or undetectable across all sampling periods and species. The only measurable value (0.018 mg/kg) was found in oysters during the dry season of 2023, far below the regulatory limit of 1.0 mg/kg.

3.2. Human health risk assessment

The THQ and MSC were calculated for Pb and Cd in the two species (Figure 3 and Table 1). For Pb, THQ values were 0.29 for ark clams and 0.51 for oysters, suggesting moderate exposure below the critical threshold of 1. MSC values were 5.172 kg/day for ark clams and 2.941 kg/day for oysters. For Cd, THQ values reached 0.82 for ark clams and 0.51 for oysters. MSC values were low, at 0.513 kg/day for ark clams and 0.831 kg/day for oysters. Hg showed no measurable health risk, with THQ values equal to zero.

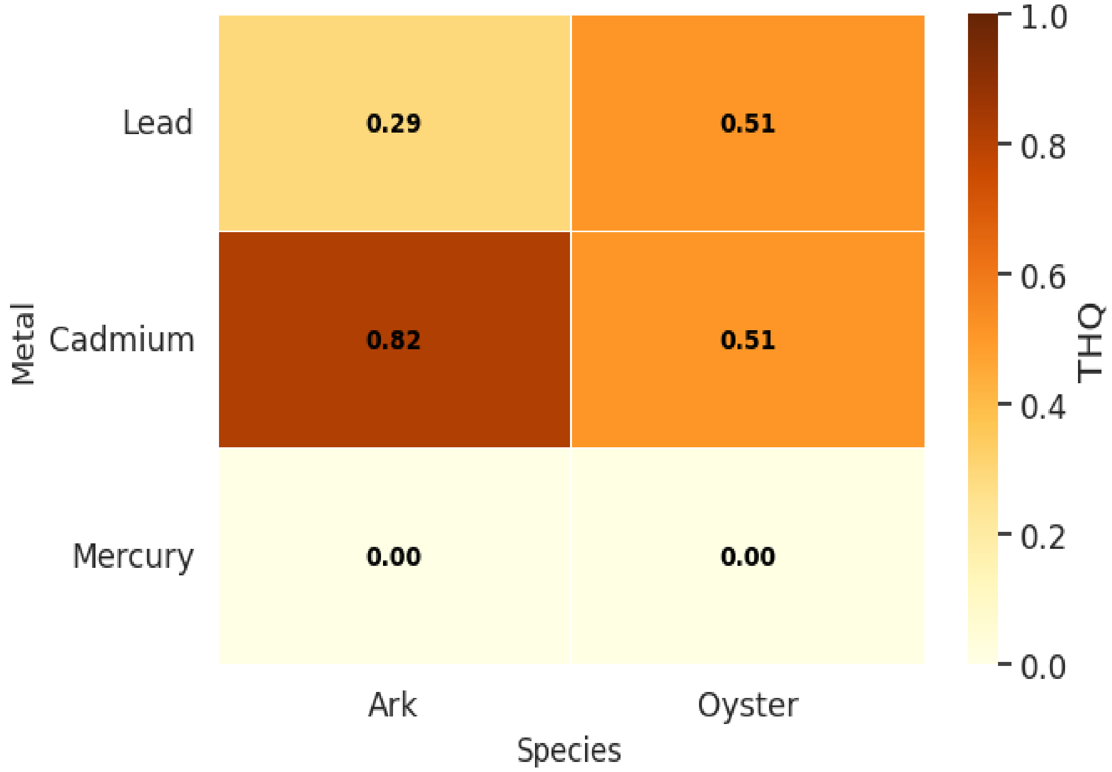

Fig. 3: Target Hazard Quotient (THQ) Values for Pb, Cd, And Hg in S. Senilis and C. Gasar from the Sangomar Marine Protected Area.

Table 1: Estimated Margin of Safety for Consumption (MSC) for Pb and Cd in Oysters and Ark Clams from the Sangomar Marine Protected Area

Species	Trace metal (TM)	Daily intake (µg/kg)	Mean concentration (mg/kg)	Body weight (kg)	MSC (kg/j)
C. gasar	Pb	25	0.500	60	2.941
	Cd	7	0.505		0.831
S. senilis	Pb	25	0.290		5.172
	Cd	7	0.818		0.513

3.3. PAH concentrations in ark clams and oysters

The analysis of PAHs revealed pronounced spatial and temporal variability, with distinct seasonal patterns and species-specific accumulation behaviors (Figure 4). The temporal trajectory showed a marked bioaccumulation peak during the 2023 rainy season, followed by a systematic decline in 2024. During the 2023 dry season, both species exhibited moderate levels of PAH contamination. S. senilis contained phenanthrene (8 µg/kg), anthracene (3 µg/kg), benzo(a)anthracene (6 µg/kg), and chrysene (6 µg/kg). Oysters (C. gasar) displayed comparable levels of phenanthrene (7 µg/kg) but consistently lower concentrations of the other compounds: anthracene (2 µg/kg), benzo(a)anthracene (2 µg/kg), and chrysene (2 µg/kg), suggesting differential bioaccumulation capacities between the two species.The 2023 rainy season was marked by a dramatic contamination peak, particularly in S. senilis, which exhibited sharp increases in high molecular weight PAHs: fluoranthene (190 µg/kg), pyrene (190 µg/kg), benzo(a)anthracene (60 µg/kg), and chrysene (45 µg/kg). This 10- to 30-fold increase suggests enhanced terrestrial runoff and intensified urban discharges during the wet season. Ark clams demonstrated markedly higher bioaccumulation efficiency compared to oysters, which maintained lower or undetectable levels for the same compounds.In 2024, PAH concentrations showed a marked decline across both seasons, indicating either reduced pollution inputs or enhanced environmental remediation processes. During the 2024 dry season, S. senilis contained only phenanthrene (4 µg/kg) and anthracene (2 µg/kg), representing 50–75% reductions compared to 2023 levels, while no PAHs were detected in oysters. The complete absence of quantifiable PAHs in both species during the 2024 rainy season suggests a significant improvement in water quality or enhanced metabolic clearance rates.Throughout the study period, S. senilis consistently exhibited higher detectable PAH concentrations than C. gasar, particularly for four-ring compounds (fluoranthene and pyrene). This interspecific differentiation likely reflects distinct feeding behaviors, metabolic rates, and habitat preferences, with ark clams potentially experiencing greater exposure to sediment-associated contaminants and possessing reduced biotransformation capacities compared to oysters.

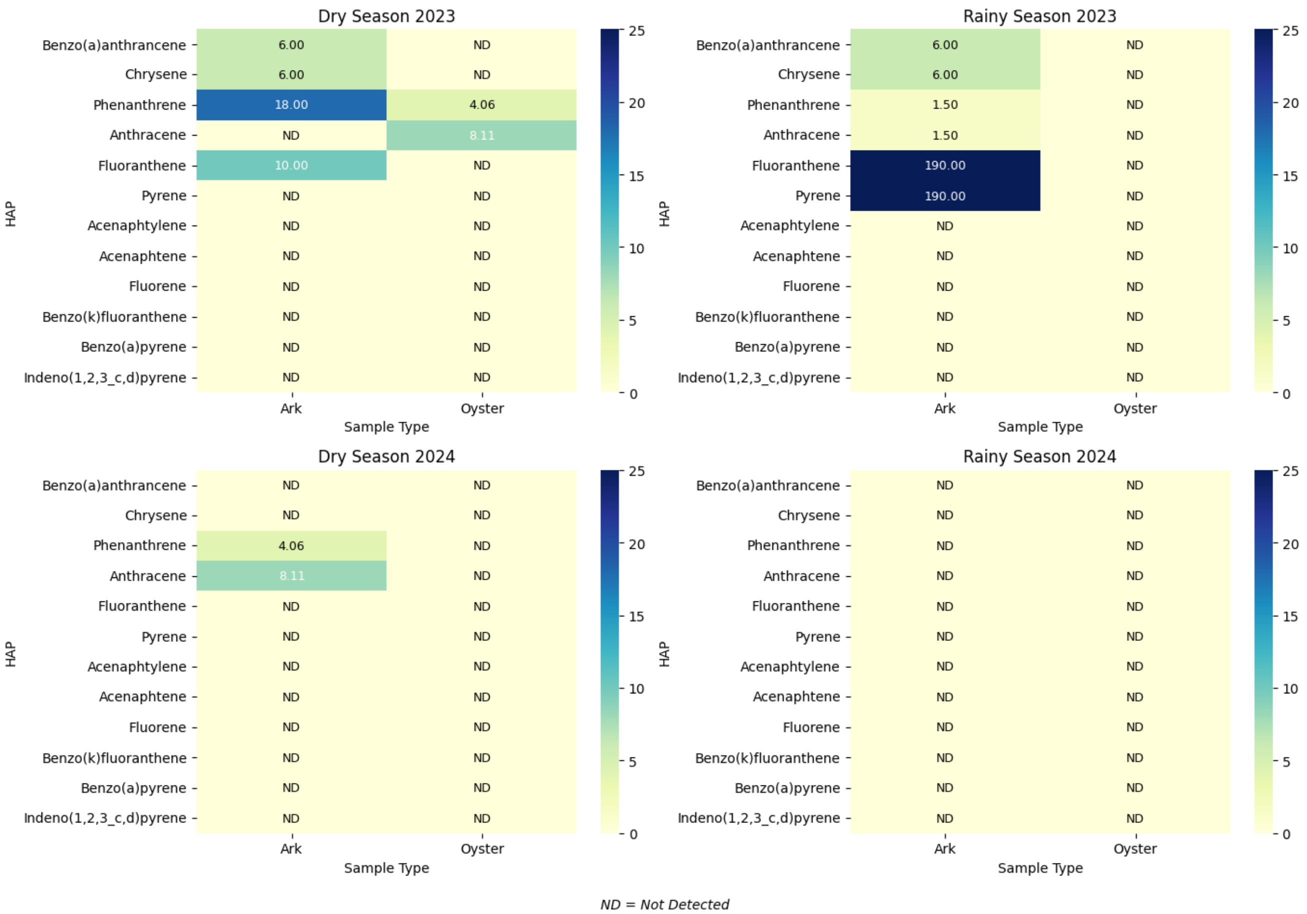

Fig. 4: Temporal Variations in Polycyclic Aromatic Hydrocarbon (PAH) Concentrations in Ark Clams and Oysters Collected from the Sangomar Marine Protected Area (MPA).

3.4. PAH source identification

Molecular diagnostic ratios were applied to determine the origin of PAHs in the two bivalve species studied. The Flu/(Flu + Pyr) ratio reached 0.513 in S. senilis, which is above the conventional threshold of 0.5 and therefore points to a predominantly pyrogenic source of contamination, most likely linked to incomplete combustion processes (e.g., biomass burning, petroleum combustion). By contrast, this ratio was zero in C. gasar, suggesting either the absence of detectable fluoranthene and pyrene in its tissues or that this species was exposed to negligible concentrations of these compounds during the sampling period. This discrepancy between species may reflect differences in habitat, filtration behavior, or bioaccumulation capacity.The Ant/(Ant + Phe) ratio provided additional evidence, with values of 0.71 in S. senilis and 0.33 in C. gasar. Both values exceed the threshold of 0.1, further supporting a pyrogenic origin for the PAHs detected. However, the much higher ratio in S. senilis suggests that this species was more directly exposed to, or more efficient at accumulating, combustion-related PAHs than C. gasar.Other diagnostic ratios, such as BaA/(BaA + Chry) and IcdP/(IcdP + BghiP), could not be calculated due to the non-detection of the respective parent compounds. This limitation highlights the low to moderate level of contamination in the study area, which restricts the full application of molecular ratio-based source apportionment. Nevertheless, the available ratios consistently point towards pyrogenic sources as the dominant input pathway.

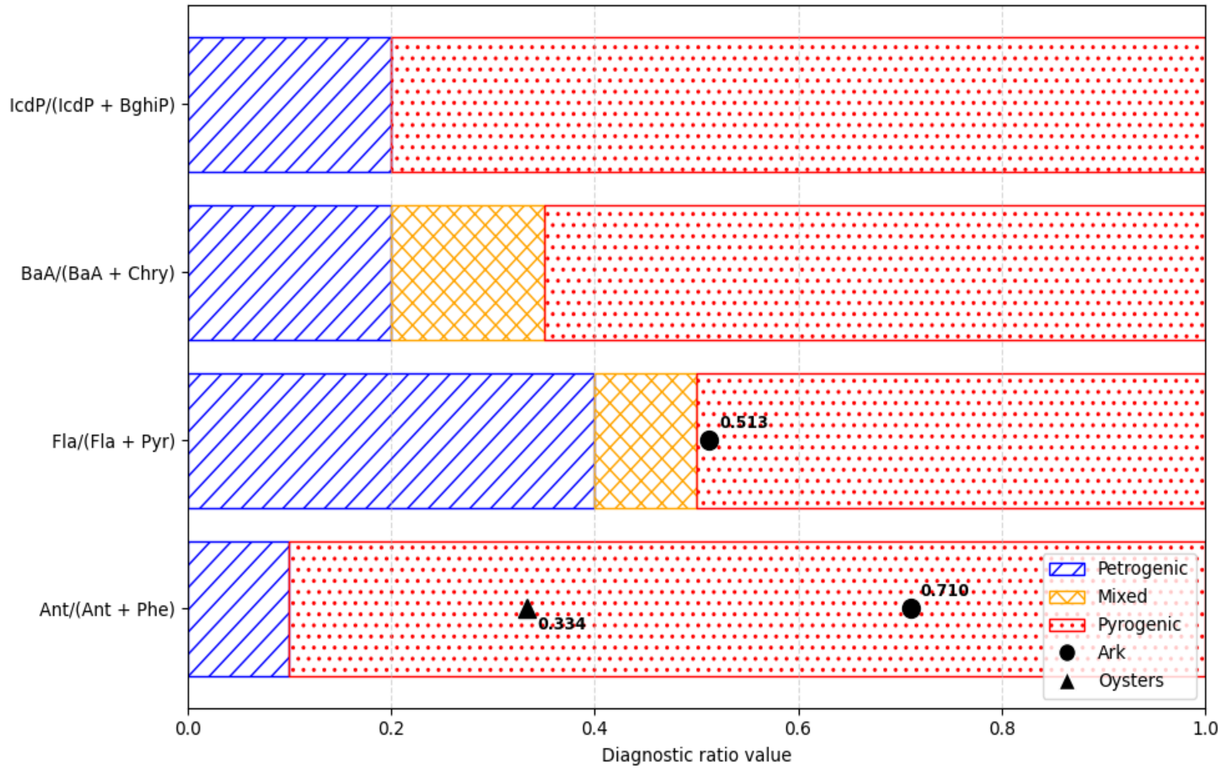

Fig. 5: Diagnostic Ratio Plots of Polycyclic Aromatic Hydrocarbons (PAHs) in Oysters (Black Triangles) and Ark Clams (Black Dots). the Colored Areas Indicate the Interpretation Ranges for Sources: Red for Pyrogenic-Origin PAHs, Blue for Petrogenic-Origin PAHs, and Yellow for Mixed Origin.

4. Discussion

This study represents the first systematic assessment of contamination by heavy metals (HMs) and polycyclic aromatic hydrocarbons (PAHs) in the bivalves S. senilis and C. gasar within the Sangomar Marine Protected Area (MPA), conducted before the offshore oil exploitation of the Sangomar field. It therefore provides an essential baseline for future environmental monitoring and sustainable management of local fishery resources.

4.1. Metal contamination in S. senilis and C. gasar

Analysis of Pb, Cd, and Hg concentrations revealed distinct contamination patterns according to both the metal and the species. Overall, most measured concentrations were below the European Commission regulatory limits for seafood (EC, 2015), with the notable exception of Cd, which exceeded the permissible threshold in several cases. Pb concentrations, reaching up to 1.15 mg/kg in oysters, remained below the regulatory limit of 1.5 mg/kg. The recurrent presence of Pb, with no significant differences between species or seasons, suggests chronic exposure from diffuse sources. This is consistent with findings from Badji et al. (2025) in the Casamance estuary, where similar Pb concentrations were reported in bivalves. In contrast, higher Pb levels were recorded in the Niger Delta (Ihunwo et al., 2022), reflecting stronger anthropogenic pressure. Seasonal hydrological factors such as runoff and river inputs (Kantati et al., 2013), as well as abiotic (temperature, salinity) and biological parameters (reproductive cycle, food availability), may influence Pb bioaccumulation, as shown by Saha et al. (2006) and Giarratano et al. (2011). Cd contamination was more concerning. In 2024, levels reached 2.36 mg/kg in S. senilis and 1.5 mg/kg in C. gasar, well above the 1.0 mg/kg limit. Such contamination likely stems from local anthropogenic activities such as domestic and agricultural discharges, as previously reported in other West African coastal areas (Ihunwo et al., 2022; Góngora-Gómez et al., 2017). The higher Cd bioaccumulation in S. senilis may be linked to its sedentary, sediment-burrowing lifestyle, increasing exposure to sediment-bound contaminants. The absence of significant seasonal or interannual variation supports the hypothesis of persistent, chronic contamination (Yap et al., 2021). Mercury concentrations were negligible, with only one detected value (0.018 mg/kg), well below the 1.0 mg/kg limit. This suggests low local anthropogenic pressure and reduced bioavailability of methylated Hg, a pattern also observed in other less industrialized coastal environments (Góngora-Gómez et al., 2017). This aligns with Diankha et al. (2020), who reported slightly higher Hg levels in Soumbédioune Bay, though still below regulatory limits, indicating low health concern.

4.3. PAH contamination in S. senilis and C. gasar

The highest PAH concentrations were found in Senilia senilis during the 2023 rainy season, with fluoranthene and pyrene (both 190 µg/kg) dominating. These high–molecular–weight PAHs are typically associated with pyrogenic sources, particularly the incomplete combustion of organic matter or fossil fuels (Yunker et al., 2002; Tobiszewski & Namieśnik, 2012; Aamir, 2017). Their seasonal increase during the rainy season suggests substantial PAH input from watershed runoff, a well-documented phenomenon in tropical coastal zones (Baumard et al., 1999; Keshavarzifard et al., 2016). Conversely, concentrations during the 2023 dry season and throughout 2024 were significantly lower, likely due to reduced diffuse inputs in the absence of runoff and interannual variations in local human activities (navigation, combustion, domestic or industrial discharges). The absence of detectable PAHs in some samples, especially Crassostrea gasar, may reflect methodological detection limits, sample preservation conditions, or extraction efficiency (USEPA, 2000). Inter-species differences showed Senilia senilis more contaminated than Crassostrea gasar in all sampling periods. As a sediment-associated species, Senilia senilis is in direct contact with PAH-enriched substrates, whereas Crassostrea gasar, a suspension feeder, primarily filters seawater and may be less exposed to sediment-bound hydrophobic contaminants. Such bioaccumulation patterns have been reported in other tropical bivalves in the Mediterranean and West Africa (Perugini et al., 2007; Khedir-Ghenim, 2009). Similar trends have also been observed in the southern Mediterranean, where long-term assessments revealed the persistence of PAH contamination in sediments and benthic species of Monastir Bay, Tunisia (Ben Salem et al., 2021). Detected PAHs were mainly four-ring compounds (fluoranthene, pyrene, benzo(a)anthracene, chrysene), consistent with pyrogenic contamination from urban, industrial, and biomass combustion sources (Yunker et al., 2002). These pollutants are persistent and tend to concentrate in coastal sediments, serving as a long-term contamination source for benthic organisms.

4.4. Health risks assessment

The health risk assessment, based on the non-carcinogenic target hazard quotient (THQ) and the maximum safe consumption (MSC), highlights the need for close monitoring, particularly regarding cadmium. For lead, THQ values remained below 1 (0.29 in S. senilis and 0.51 in C. gasar), indicating moderate exposure. However, when combined with regular seafood consumption, these levels could pose a concern for vulnerable populations. These findings are consistent with Diop et al. (2019), who reported significant Pb bioaccumulation in estuarine mollusks from Senegal. Cadmium reached a THQ of 0.82 in S. senilis, approaching the critical threshold of 1. At the same time, the MSC dropped to 0.513 kg/day (Table 1), a level that is markedly lower than the average seafood consumption reported by the FAO (2005), estimated at 72 g/day in Senegal. This comparison suggests a potential risk of long-term chronic exposure for local consumers, particularly those with higher-than-average shellfish intake. This situation is particularly concerning given the well-established toxic effects of Cd on renal function and its documented links to certain cancers, notably kidney and prostate cancer (Pesch et al., 2000; Waalkes, 2000). For Hg, THQ values were zero, ruling out any immediate health risk for consumers. Nevertheless, this apparent absence should not overshadow the potential hazard posed by methylated Hg in more contaminated ecosystems.

4.5. PAH source identification

For S. senilis, the Flu/(Flu + Pyr) ratio was 0.513, slightly above the 0.50 threshold that marks the shift from petroleum-related to combustion-related sources. This suggests that the PAHs in this species mainly come from burning biomass, coal, or wood (Yunker et al., 2002; Katsoyiannis et al., 2007). In C. gasar, this ratio was zero, meaning either these two compounds (fluoranthene and pyrene) were absent or their levels were too low to detect, pointing to minimal or no exposure. A similar trend appeared with the Ant/(Ant + Phe) ratio, 0.71 in S. senilis and 0.33 in C. gasar. Both values are well above the 0.10 cut-off that indicates pyrogenic sources (Yunker et al., 2002; Zhang et al., 2008). The higher ratio in S. senilis suggests it is more exposed to PAHs from combustion. This could be due to its feeding strategy, closely linked to sediment, and its preference for habitats where particulate-bound contaminants are more available. Two other ratios, BaA/(BaA + Chry) and IcdP/(IcdP + BghiP), could not be calculated due to the non-detection of the required compounds. This limitation reduces the ability to cross-check the results and to more robustly confirm the sources. In contexts of low contamination levels, where several compounds remain below detection limits, it is recommended to apply alternative source apportionment approaches, such as compound-specific isotope analysis or statistical models like positive matrix factorization (Zhang et al., 2008). Overall, the dominance of pyrogenic signals in both species indicates that the Sangomar Marine Protected Area is receiving inputs from combustion processes. These likely include land-based biomass burning, exhaust from fishing boats, and other low-to-moderate temperature combustion activities. Such emissions can reach the marine environment through atmospheric fallout or river runoff (Ma et al., 2018; Bai et al., 2022). The stronger pyrogenic signature in S. senilis likely reflects differences in feeding behavior, habitat depth, and how each species meets contaminants.

5. Conclusion

This study represents the first systematic baseline assessment of contamination by heavy metals and polycyclic aromatic hydrocarbons (PAHs) in Senilia senilis and Crassostrea gasar within the Sangomar Marine Protected Area (Senegal), before the commencement of offshore oil exploitation. Lead (Pb) and mercury (Hg) concentrations were low and stable, whereas cadmium (Cd) levels frequently exceeded regulatory thresholds, revealing chronic local pollution and a potential health risk associated with the consumption of these bivalves. PAHs were more abundant in S. senilis, particularly during the rainy season, indicating enhanced inputs via watershed runoff. The profiles were dominated by four-ring pyrogenic compounds, such as fluoranthene and pyrene, highlighting persistent anthropogenic pressure linked to urban and industrial activities.

These results provide a critical reference point for the initial contamination status of the Sangomar MPA and underscore the need for regular, multidisciplinary, and multi-species environmental monitoring to detect early signs of anthropogenic impacts. Moreover, this study opens important research perspectives aimed at better understanding the effects of offshore oil exploitation on cadmium bioavailability and accumulation in S. senilis and C. gasar in the Saloum Delta. Such investigations will help strengthen evidence-based adaptive management and conservation strategies in this sensitive coastal area, while contributing to the protection of its biodiversity and the sustainability of local fisheries

References

[1] Aamir, M., Khan, S., Tang, M., et al. (2017). Congener-specific evaluation of biota-sediment accumulation factor model for HCHs and DDTs under small-scale in situ riverine condition. Journal of Soils and Sediments, 17, 525–535. https://doi.org/10.1007/s11368-016-1579-y.

[2] Agence Nationale de la Statistique et de la Démographie (ANSD). (2017/2018). Situation économique et sociale du Sénégal : Pêche et aquaculture.

[3] Aranguren, M. M. (2008). Contamination en métaux lourds des eaux de surface et des sédiments du Val de Mulluni (Andes boliviennes) par des déchets miniers : Approche géochimique, minéralogique et hydrochimique (Thèse de doctorat). Université Paul Sabatier — Toulouse III.

[4] Badji, Y., Diankha, O., & Sow, B. A. (2025). Study of heavy metal contamination of Sarotherodon melanotheron and Crassostrea gasar in Casamance River (Senegal). https://doi.org/10.4314/ijbcs.v19i1.4.

[5] Ba, I., Diankha, O., Ali Sow, B., and Ba, S. (2025). Assessment of Sediment Quality in the Sangomar Marine Protected Area in Senegal Prior to Oil Development. Open Journal of Marine Science, 15, 157-172. https://doi.org/10.4236/ojms.2025.153009.

[6] Ba, I., Diankha, O., Sow, B. A., & Ba, S. (2025). Assessment of physicochemical water quality in the Sangomar marine protected area before oil exploitation of the Sangomar offshore field, Senegal. African Journal of Environmental Science and Technology, 19(6), 180–190. https://doi.org/10.5897/AJEST2025.3341.

[7] Bai, Y., Shi, K., Yu, H., Shang, N., Hao, W., Wang, C., Huang, T., Yang, H., Huang, C. (2022). Source apportionment of polycyclic aromatic hydrocarbons (PAHs) in a sediment core from Lake Dagze Co, Tibetan Plateau, China: Comparison of three receptor models, Journal of Environmental Sciences, 121, 224-233. https://doi.org/10.1016/j.jes.2022.01.043.

[8] Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193. https://doi.org/10.1890/10-1510.1.

[9] Ben Salem, F., et al. (2021). *Southern Mediterranean coast pollution: Long-term assessment and evolution of PAH pollutants in Monastir Bay (Tunisia).* Environmental Pollution, 286, 117502.

[10] Blackmore, G. (2001). Interspecific variation in heavy metal body concentrations in Hong Kong marine invertebrates. Environmental Pollution, 114(3), 303–311. Cambridge University Press & Assessment. https://doi.org/10.1016/S0269-7491(01)00086-0.

[11] Chalghmi, H., Bourdineaud, J.-P., Haouas, Z., et al. (2015). Transcriptomic, biochemical, and histopathological responses of the clam Ruditapes decussatus from a metal-contaminated Tunis lagoon. Archives of Environmental Contamination and Toxicology, 70(2), 241–256. https://doi.org/10.1007/s00244-015-0185-0.

[12] Diankha, O., Ndiaye, T., Agbogba, C., & Sarr, A. (2020). Détermination des teneurs en mercure (Hg) total chez la moule Perna perna et l'oursin Echinometra lucunter de la baie de Soumbédioune (Région de Dakar, Sénégal) et évaluation des risques sanitaires. European Scientific Journal, 16, 15–26. https://doi.org/10.19044/esj.2020.v16n9p15.

[13] Diop, C., Diatta, A., Ndiaye, A., Cabral, M., Touré, A., & Fall, M. (2019). Teneurs en métaux traces des eaux et poissons de cinq étangs de Dakar et risques pour la santé humaine. Journal of Applied Biosciences, 137, 13931–13939. https://doi.org/10.4314/jab.v137i1.1.

[14] Diop, M., Net, S., Howsman, M., Lencel, P., Watier, D., Grard, T., Duflos, G., & Amara, R. (2017). Concentration and potential human health risks for regulated metals (Cd, Pb, Hg) and organic pollutants (PAHs, PCBs) in fish and seafood from the Senegalese coast. International Journal of Environmental Research, 11, 349–358. https://doi.org/10.1007/s41742-017-0032-4.

[15] European Commission. (2015). Commission Regulation (EU) 2015/1005 of 25 June 2015 amending Regulation No 1881/2006 as regards maximum levels of lead in certain foodstuffs. Official Journal of the European Union, L161/9. http://data.europa.eu/eli/reg/2015/1005/oj

[16] Fakayode, S. O. (2005). Impact assessment of industrial effluent on water quality of the receiving Alora River in Ibadan, Nigeria. African Journal of Environmental Assessment and Management, 10, 1–13.

[17] Förstner, U. (1981). Metal transfer between solid and aqueous phases. In U. Förstner & G. T. W. Wittmann (Eds.), Metal pollution in the aquatic environment (pp. 197–270). Springer. https://doi.org/10.1007/978-3-642-69385-4_5.

[18] Giarratano, E., Duarte, C. A., Amin, O. A., & Comoglio, L. I. (2011). Heavy metal concentrations and biomarkers of oxidative stress in native mussels (Mytilus edulis chilensis) from Beagle Channel coast (Tierra del Fuego, Argentina). Marine Pollution Bulletin, 62(8), 1895–1904. https://doi.org/10.1016/j.marpolbul.2011.05.031.

[19] Góngora-Gómez, A. M., García-Ulloa, M., Muñoz-Sevilla, N. P., Domínguez-Orozco, A. L., Villanueva-Fonseca, B. P., Hernández-Sepúlveda, J. A., & Ortega Izaguirre, R. (2017). Heavy-metal contents in oysters (Crassostrea gigas) cultivated on the southeastern coast of the Gulf of California, Mexico. Hidrobiológica, 27(2), 219–227. https://doi.org/10.24275/uam/izt/dcbs/hidro/2017v27n2/Garcia.

[20] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2010). Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 92). Lyon, France: International Agency for Research on Cancer.

[21] Ihunwo, O. C., Ibezim-Ezeani, M. U., Wekpe, V. O., Shahabinia, A. R., Bonnail, E., Mmom, P. C., & Horsfall, M. (2022). Risk assessment of human exposure to lead and cadmium in tissues of Blackchin Tilapia (Sarotherodon melanotheron) from an intertidal creek in the Niger Delta region of Nigeria. Environmental Research Communications, 4(7), 075007. https://doi.org/10.1088/2515-7620/ac7f14.

[22] Kantati, Y. T., Kodjo, M. K., Gnandi, K., Ketoh, G. K., & Gbeassor, M. (2013). Effects of pollution on oxidative stress in aquatic species: Case of the fish Sarotherodon melanotheron in Bè Lagoon (Lomé). International Journal of Biological and Chemical Sciences, 7(2), 717–725. https://doi.org/10.4314/ijbcs.v7i2.26.

[23] Katsoyiannis A, Terzi E, Cai QY. (2007). On the use of PAH molecular diagnostic ratios in sewage sludge for the understanding of the PAH sources. Is this use appropriate? Chemosphere, 69(8):1337-9. https://doi.org/10.1016/j.chemosphere.2007.05.084.

[24] Khedir-Ghenim, Z., Zrafi-Nouira, I., Bahri, R., Belayouni, H., Hammami, M., Rouabhia, M., & Saidane-Mosbahi, D. (2009). Identification and distribution of petroleum hydrocarbons in sediments, seawater and Ruditapes decussatus collected from a Mediterranean Sea site. International Journal of Water, 5(1), 35–50. https://doi.org/10.1504/IJW.2009.023081.

[25] Ma, W-L., Liu, L-Y., Jia, H-L., Yang, M., Li, Y-F. (2028). PAHs in Chinese atmosphere Part I: Concentration, source and temperature dependence, Atmospheric Environment, Volume 173, 330-337. https://doi.org/10.1016/j.atmosenv.2017.11.029.

[26] Matozzo, V., & Marin, M. G. (2010). First evidence of gender-related differences in immune parameters of the clam Ruditapes philippinarum (Mollusca, Bivalvia). Marine Biology, 157(6), 1181–1189. https://doi.org/10.1007/s00227-010-1398-4.

[27] Mehrzad Keshavarzifard, Mohamad Pauzi Zakaria & Shahin Keshavarzifard (2016). Evaluation of Polycyclic Aromatic Hydrocarbons Contamination in the Sediments of the Johor Strait, Peninsular Malaysia, Polycyclic Aromatic Compounds. https://doi.org/10.1080/10406638.2016.1257997.

[28] Neff, J. M. (1979). Polycyclic Aromatic Hydrocarbons in the Aquatic Environment: Sources, Fates and Biological Effects. London: Applied Science Publishers, 262 p.

[29] Ogindo, B. A. (2001). Heavy metal pollutants and their concentrations in fish (Barbus species) in Sosiani River, Kenya. Discovery and Innovation, 13(3). https://doi.org/10.4314/dai.v13i3.15611.

[30] Pan, K., & Wang, W.-X. (2012). Trace metal contamination in estuarine and coastal environments in China. Science of the Total Environment, 421–422, 3–16. https://doi.org/10.1016/j.scitotenv.2011.03.013.

[31] Pesch, B., et al. (2000). Facteurs de risque professionnels du carcinome à cellules rénales : résultats spécifiques à l'agent d'une étude cas-témoins en Allemagne. International Journal of Epidemiology, 29, 1014–1024.

[32] Perugini, M., Visciano, P., Manera, M., Turno, G., Lucisano, A., & Amorena, M. (2007). Polycyclic aromatic hydrocarbons in marine organisms from the Gulf of Naples, Tyrrhenian Sea. Journal of Agricultural and Food Chemistry, 55(5), 2049–2054. https://doi.org/10.1021/jf0630926.

[33] Plan d'aménagement et de gestion des aires marines protégées. (2017). Ministère de l'Environnement et du Développement durable, Sénégal.

[34] Pule, B.O., Mmualefe, L.C., Torto, N. (2012). Analysis of polycyclic aromatic hydrocarbons in soil with Agilent bond elut HPLC-FLD. Agilent application note 5990–5452 EN.

[35] Rainbow, P. S. (2002). Trace metal concentrations in aquatic invertebrates: Why and so what?Environmental Pollution, 120(3), 497–507. https://doi.org/10.1016/S0269-7491(02)00238-5.

[36] Saha, A., Zhang, Y., Smith, C. L., Grill, S. W., Mihardja, S., Smith, S. B., Cairns, B. R., Peterson, C. L., & Bustamante, C. (2006). DNA translocation and loop formation mechanism of chromatin remodeling by SWI/SNF and RSC. Molecular Cell, 24(4), 559–568. https://doi.org/10.1016/j.molcel.2006.10.025.

[37] Tobiszewski, M., & Namieśnik, J. (2012). PAH diagnostic ratios for the identification of pollution emission sources. Environmental Pollution, 162, 110–119. https://doi.org/10.1016/j.envpol.2011.10.025.
[38] United States Environmental Protection Agency (USEPA). (2000). Guidance for assessing chemical contaminant data for use in fish advisories: Fish sampling and analysis (3rd ed.). EPA 823-R-95-007.
[39] Waalkes, M. P. (2000). Carcinogenèse du cadmium en revue. Journal of Inorganic Biochemistry, 79, 241–244. https://doi.org/10.1016/S0162-0134(00)00009-X.
[40] Wang, W.-X., & Rainbow, P. S. (2008). Comparative approaches to understand metal bioaccumulation in aquatic animals. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 148(4), 315–323. https://doi.org/10.1016/j.cbpc.2008.04.003.
[41] Widdows, J., & Brinsley, M. (2002). Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone. Journal of Sea Research, 48(2), 143–156. https://doi.org/10.1016/S1385-1101(02)00148-X.
[42] Yap, C. K., Wong, K. W., Al-Shami, S. A., Nulit, R., Cheng, W. H., Aris, A. Z., Sharifinia, M., Bakhtiari, A. R., Okamura, H., Saleem, M., Chew, W., Ismail, M. S., & Al-Mutairi, K. A. (2021). Human health risk assessments of trace metals on the clam Corbicula javanica in a tropical river in Peninsular Malaysia. International Journal of Environmental Research and Public Health, 18(1), 195. https://doi.org/10.3390/ijerph18010195.
[43] Yunker, M. B., Macdonald, R. W., Vingarzan, R., Mitchell, R. H., Goyette, D., & Sylvestre, S. (2002). PAHs in the Fraser River basin: A critical appraisal of PAH ratios as indicators of PAH source and composition. Organic Geochemistry, 33(4), 489–515. https://doi.org/10.1016/S0146-6380(02)00002-5.
[44] Zhang, Y., Tao, S., Wang, W., Li, B., & Wang, L. (2005). Source diagnostics of polycyclic aromatic hydrocarbons based on species ratios: A multimedia approach. Environmental Science & Technology, 39(23), 9109–9114. https://doi.org/10.1021/es0513741.
[45] Zhang, W., Zhang, S., Wan, C., Yue, D., Ye, Y., Wang, X. (2008). Source diagnostics of polycyclic aromatic hydrocarbons in urban road runoff, dust, rain and canopy throughfall. Environmental Pollution, 153(3), 594–601. https://doi.org/10.1016/j.envpol.2007.09.004.