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RESEARCH ARTICLE

ASSESSMENT OF THE CONCENTRATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN THE SURFACE WATERS OF THE EBRIE LAGOON ESTUARY

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Abstract

The Ebrie Lagoon estuary, located in the heart of the city of Abidjan, is under severe anthropogenic pressure due to industrial and domestic waste and port activities. Despite several studies on the overall quality of lagoon waters, little research has specially quantified PAHs in the estuary. Thirty (30) samples were collected at different stations and then analysed in the laboratory using High Performance Liquid Chroma tography (HPLC)by equipped with a C18 column and a fluorescence detector. The results reveal the presence of eight polycyclic aromatic hydrocarbons (PAHs), namely fluoranthene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)anthracene, pyrene, benzo(a)pyrene, benzo(g,h,i)pyrene, and indeno(1,2,3-cd)pyrene. The concentrations range from 0,01 to 24,54 µg/L for fluoranthene, 0,06 to 79,60 µg/L for pyrene, 0,10 to 18,59 µg/L for benzo(k)fluoranthene, for benzo(a)pyren e between 0,01 and 19.48 µg/L, for indeno(1,2,3-cd) pyrene from 0.19 to 85.83 µg/L, for benzo (g,h,i)pyrene between 0,11 and 5,52 µg/L, for Benzo(a)anthracene between 0,01 and 3,03 µg/L and for Benzo(b)fluor anthene between 0,01 and 15,53 µg/L. These concentrations could be due to urban and industrial discharges, leaks from motorboats, and the hydrodynamics of the lagoon waters.The results of this study demonstr ate that the Ebrie Lagoon estuary is a highly fragile environment. It is therefore necessary to strengthen environmental monitoring, implement wastewater treatment systems, and raise awareness among the population and industry in order to protect this ecosystem in the long term.

Introduction:-

Population growth and rapid industrialization in African coastal areas are putting increasing pressure on aquatic environments, leading to a deterioration in their ecological quality (Abraham, 2010). In Ivory Coast, the Ebrie

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lagoon, the largest in the country, suffers from multiple forms of pollution linked to domestic, industrial, and port discharges (Coulibaly et al., 2019). The lack of functional wastewater treatment plants in the municipalities of Abidjan (Cocody, Yopougon, Riviera, Bingerville) encourages the direct discharge of wastewater into the lagoon (Adingra and Kouassi, 2011). The estuarine area of the Ebrie lagoon is highly exposed to increasing organic pollution. This is linked to domestic, industrial, and port discharges (Toure et al., 2018).These discharges have a high toxic and bioaccumulative potential, as well as significant toxicity to benthic marine organisms (Iwegbe et al., 2019; Oura, 2022). These inputs are causing increasing eutrophication, mortality of aquatic fauna, and bioaccumulation of chemical contaminants such as Polycyclic Aromatic Hydrocarbons (PAHs). Polycyclic Aromatic Hydrocarbons (PAHs) are persistent organic pollutants found in various aquatic environments. They are produced by natural processes such as forest fires, but mainly by anthropogenic activities such as fossil fuel combustion, oil spills, and industrial discharges. They are lipophilic, accumulate in sediments and organisms, and several of them are proven carcinogens (IARC, 2012). Research on Polycyclic Aromatic Hydrocarbons in the Ebrie lagoon has focused mainly on sediments (Affian et al., 2009; Irie et al., 2024). The objective of this study is therefore to assess the concentration of PAHs in the waters of the Ebrie Lagoon estuary.

Materials and Methods:-

Sampling and analysis methods:-

The study was conducted in the Ebrie lagoon estuary located in South-Eastern Ivory Coast between the Vridi canal and the bays surrounding Abidjan. This area receives domestic, industrial and port effluents. In the field, thirty (30) water samples (500 mL) were collected using a Niskin bottle and then placed in vials. They were wrapped in aluminium foil and stored in a cooler for laboratory processing. In the laboratory, PAHs were extracted from the water samples using 100 ml of dichloromethane with a liquid-liquid separation system. The volume of the extracts was reduced using a rotary shaker and then filtered through Whatman paper. The liquid obtained was transferred to a 2-litre separating funnel. The organic phase, after being filtered through anhydrous sodium sulphate, was recovered for concentration. The concentrated extract obtained was evaporated to 0.5 mL under a nitrogen stream at a temperature of 40 °C. The extract was purified in a purification column filled with 5 g of deactivated alumina and 1 ml of anhydrous sodium sulphate. The column was rinsed with approximately 10 mL of cyclohexane. When the solvent meniscus reached, the surface of the sodium sulphate, The flow was stopped, and the extract was addedto the column to begin elution. The PAHs were eluted with 40 ml of hexane and concentrated under nitrogen to 0.5 mL, then transferred to 1.5 mL vials for analysis by High Performance Liquid Chromatography (HPLC). The injection volume was 20 µl with a flow rate of 1.5 mL/min and the column temperature was 20 ± 0.5 °C (ISSeP, 2014).

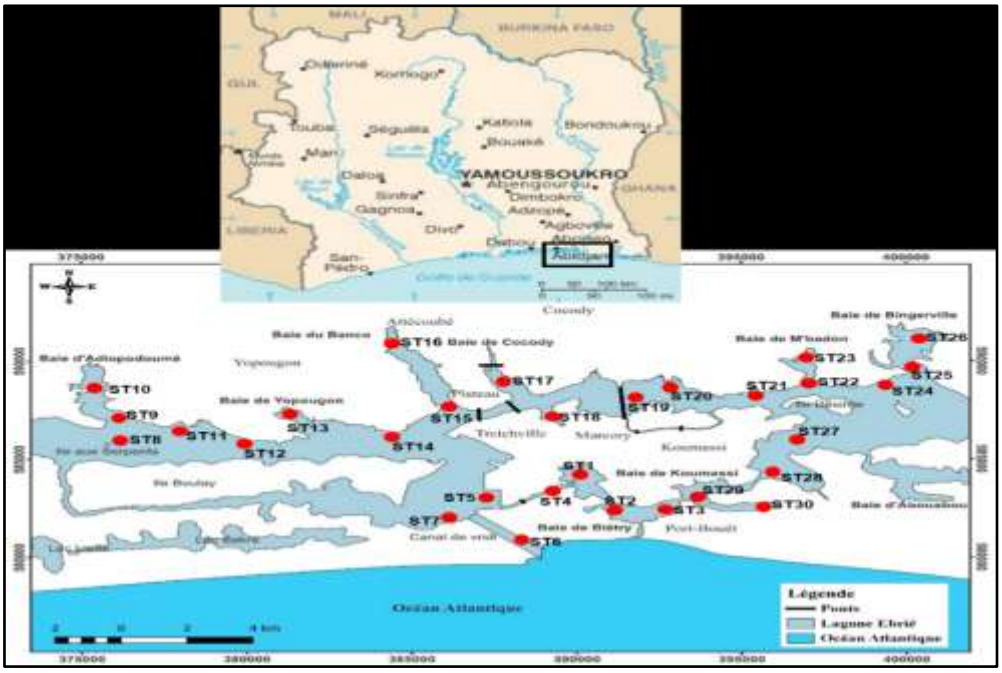

Figure 1: Location of the study area and sampling points

Results:-

Types of PAHs in estuary waters:-

Eight (08) PAHs were identified. These are: fluoranthene (Fla), benzo(k)fluoranthene (BkF), benzo(b)fluoranthene (BbF), benzo(a)anthracene (BaA), pyrene (Pyr), benzo(a)pyrene (BaP), benzo(g,h,i)pyrene (BghiP) and indeno(1,2,3-cd)pyrene (IND). Their minimum and maximum concentrations are recorded in Table 1:

Table 1: Characteristic concentrations of PAHs in the estuary in µg/L

PAHs	Minimum Concentration	Maximum Concentration	Average
Fluoranthène	0.01	24.54	1.29
Benzo(k)fluoranthene	0.1	18.59	1.67
Benzo(b)fluoranthene	0.01	15.53	1.08
Benzo(a)anthracene	0.01	3.03	0.19
Pyrene	0.06	79.6	9.11
Benzo(a)pyrene	0.01	19.48	1.88
Benzo(g,h,i)pyrene	0.11	5.52	0.32
Indeno(1,2,3-cd)pyrene	0.19	85.83	5.86
Total	**0.5**	**252.12**	**21.4**

Spatial variation in PAH concentrations in estuary waters:-

The PAHs with high concentrations in the waters of the Ebrie lagoon estuary are indeno(1,2,3-cd)pyrene (85.83 µg/L) and pyrene (79.6 µg/L), whereas the PAHs with low concentrations are benzo (g,h,i)pyrene (5.52 µg/L) and benzo(a)anthracene (3.03 µg/L). The concentrations of the various PAHs are shown in the following graphs:

- **Fluoranthene**

Fluoranthene concentrations range from 0.01 to 24.54 µg/L, with an average concentration of 1.29 µg/L (Fig. 2). No fluoranthene was detected at stations ST1, ST3, ST5, ST9, ST13, ST22, ST23, ST26, ST28, ST29 and ST30. However, at station ST8 (Adiopodoume Bay), the fluoranthene concentration was very high (24.54 µg/L) and low (0.01 µg/L) at station ST14 (Banco Bay).

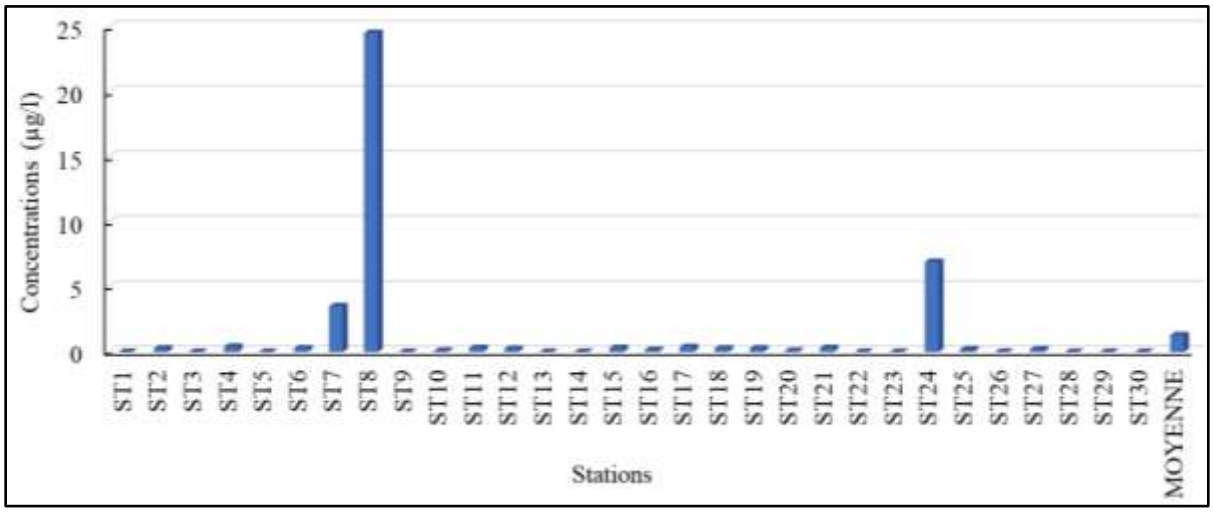

Figure 2: Concentrations of Fluoranthene in the estuary

- **Benzo(k)fluoranthene**

Benzo(k)fluoranthene concentrations range from 0.10 to 18.59 µg/L, with an average value of 1.67 µg/L (Fig. 3). Water samples taken at stations ST8, ST17, ST23, ST24 and ST30 showed no traces of benzo(k)fluoranthene. The

highest benzo(k)fluoranthene content (18.59 µg/L) was recorded at station ST5 in the Vridi Canal south of the estuary. The lowest content was obtained at station ST20 in Marcory (0.1µg/L) in the north.

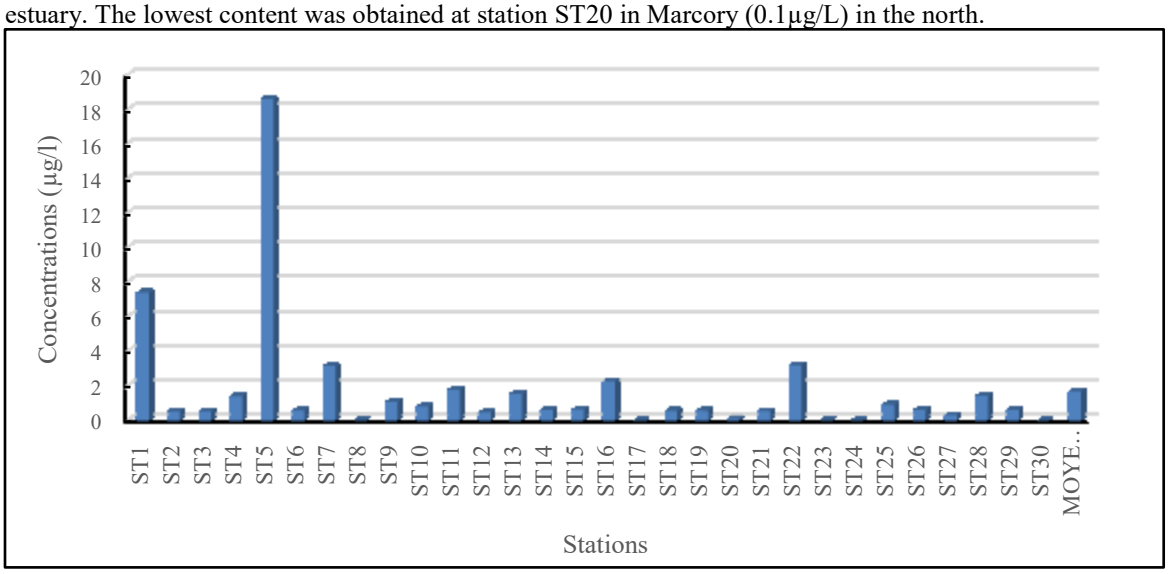

Figure 3: Concentrations of Benzo(k)fluoranthene in the estuary

- **Benzo(b)fluoranthene**

Benzo(b)fluoranthene concentrations range from 0.01 to 15.53 µg/L, with an average concentration of 1.37 µg/L (Fig. 4). Benzo(b)fkuoranthene concentrations are zero at stations ST22, ST27, ST28 and ST30. The highest concentration (15.53 µg/L) was recorded at station ST17 in Cocody Bay, north of the estuary, and the lowest (0.01 µg/L) at stations ST2 in Bietry Bay and ST6 in the Vridi Canal to the south.

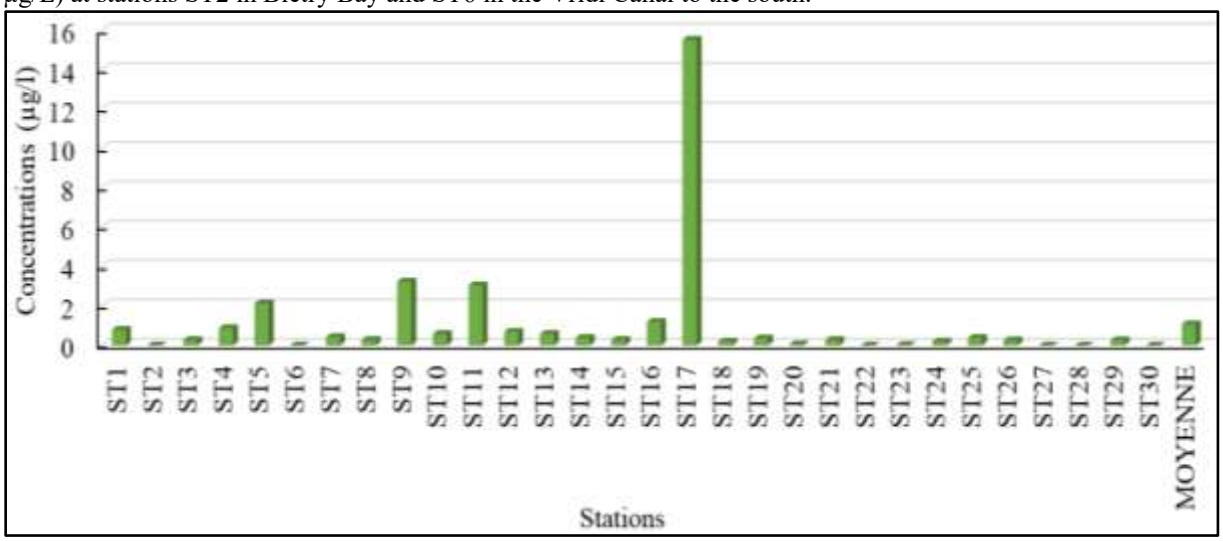

Figure 4 : Concentrations of benzo(b)fluoranthene in the estuary

- **Benzo(a)anthracene**

The concentration of benzo(a)anthracene ranges from 0.01 to 3.03 µg/L, with an average concentration of 0.19 µg/L (Fig. 5). Water samples taken at stations ST1, ST4, ST5, ST7, ST9, ST10, ST11, ST12, ST13, ST16, ST22 and ST28 showed no presence of benzo(a)anthracene. The highest concentration was recorded at station ST26 in Bingerville Bay (3.03 µg/L) in the North-East of the estuary, and the lowest (0.01 µg/L) at station ST23 in M'Badon Bay in the North of the estuary.

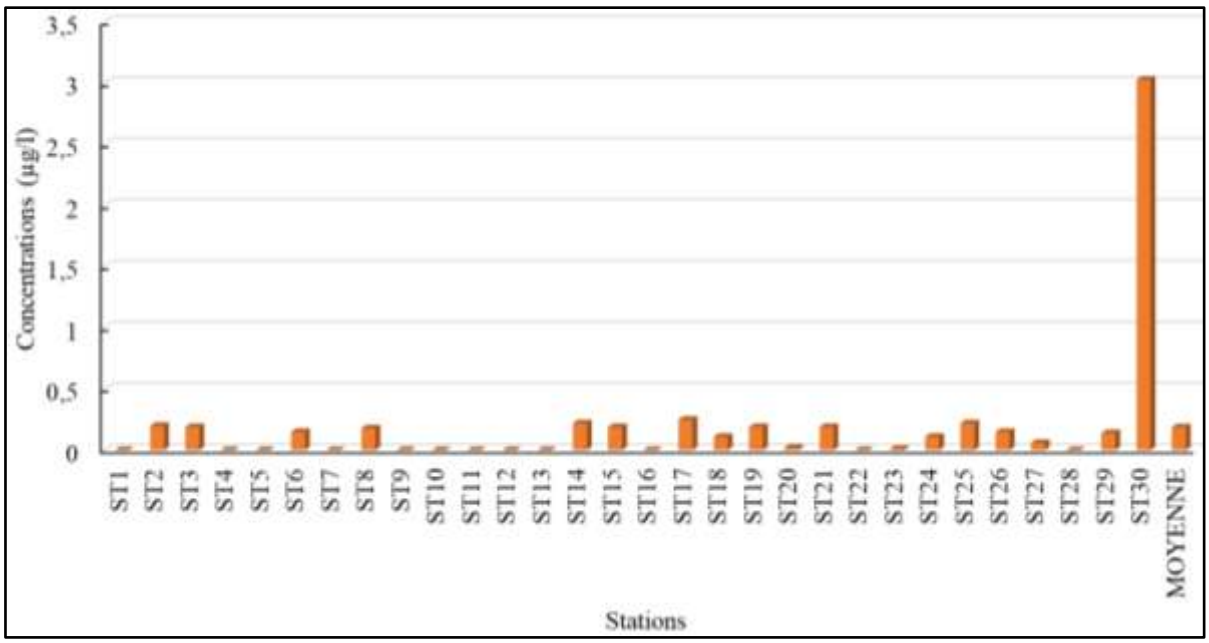

Figure 5: Concentration of benzo(a)anthracene in the estuary

- **Pyrene**

Pyrene concentrations range from 0.06 to 79.60 µg/L, with an average value of 9.11 µg/L (Fig. 6). Stations ST12, ST20, ST22, ST23, ST28 and ST30 do not have high concentrations of pyrene. However, at station ST11 in Adiopodoume Bay, the concentration of pyrene is high (79.60 µg/L) and low at station ST14 in Banco Bay and station ST2 in the South of Bietry Bay.

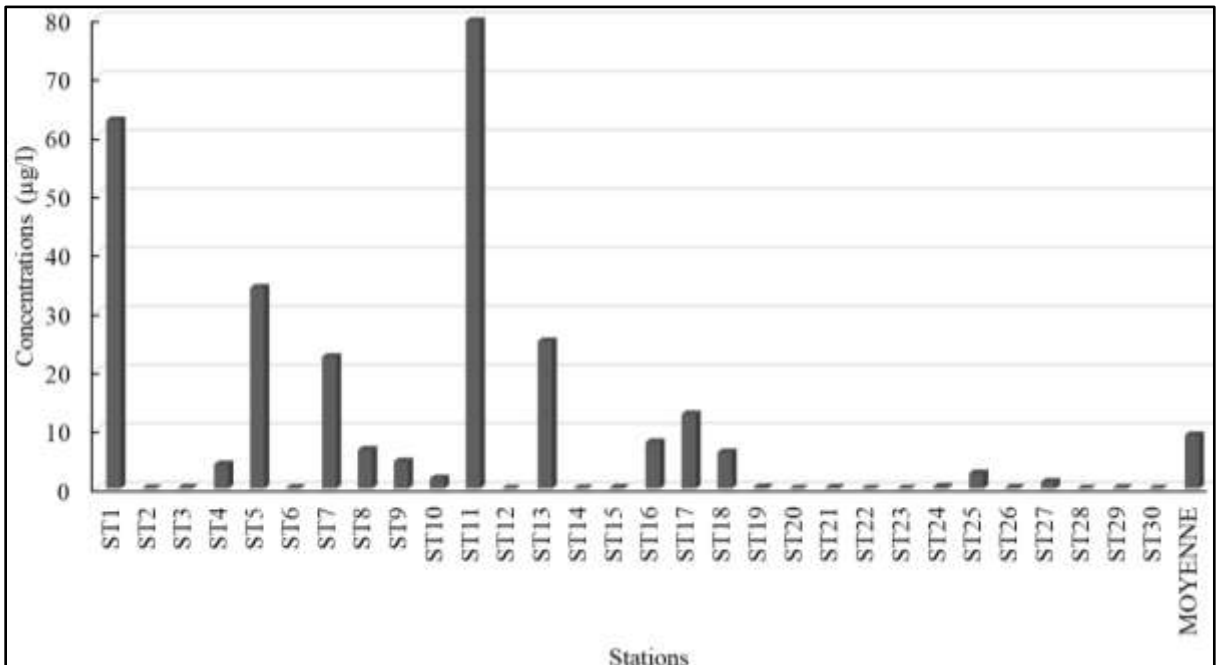

Figure 6: Concentration of pyrene in the estuary

- **Benzo(a)pyrene**

Benzo(a)pyrene concentrations ranged from 0.01 to 19.48 µg/L, with an average value of 1.88 µg/L (Fig. 7). Benzo(a)pyrene was detected at stations ST8, ST14, ST19, ST20, ST23, ST25, and ST26. The highest concentration

was recorded at station ST5 (19.48 µg/L) south of the estuary in the Vridi Canal, and the lowest (0.01 µg/L) at stations ST6 in the Vridi Canal and ST21 in M'Badon Bay.

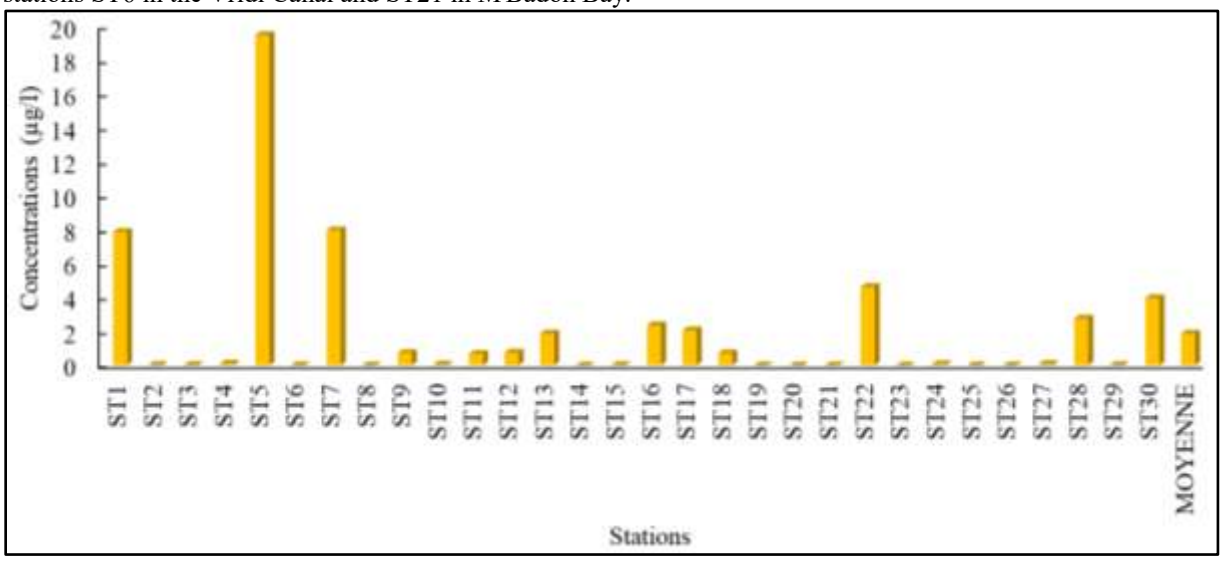

Figure 7: Concentration of benzo(a)pyrene in the estuary

- **Benzo(g,h,i)pyrene**

Benzo(g,h,i)pyrene concentrations range from 0.11 to 5.52 µg/L, with an average value of 0.32 µg/L (Fig. 8). Benzo(g,h,i)pyrene is present at only seven stations, namely ST8, ST17, ST20, ST23, ST24, ST29 and ST30. The highest value was recorded at station ST8 (5.52 µg/L) to the west of the estuary in Adiopodoume Bay, and the lowest at station ST23 (0.11 µg/L) to the North-East of the estuary in M'Badon Bay.

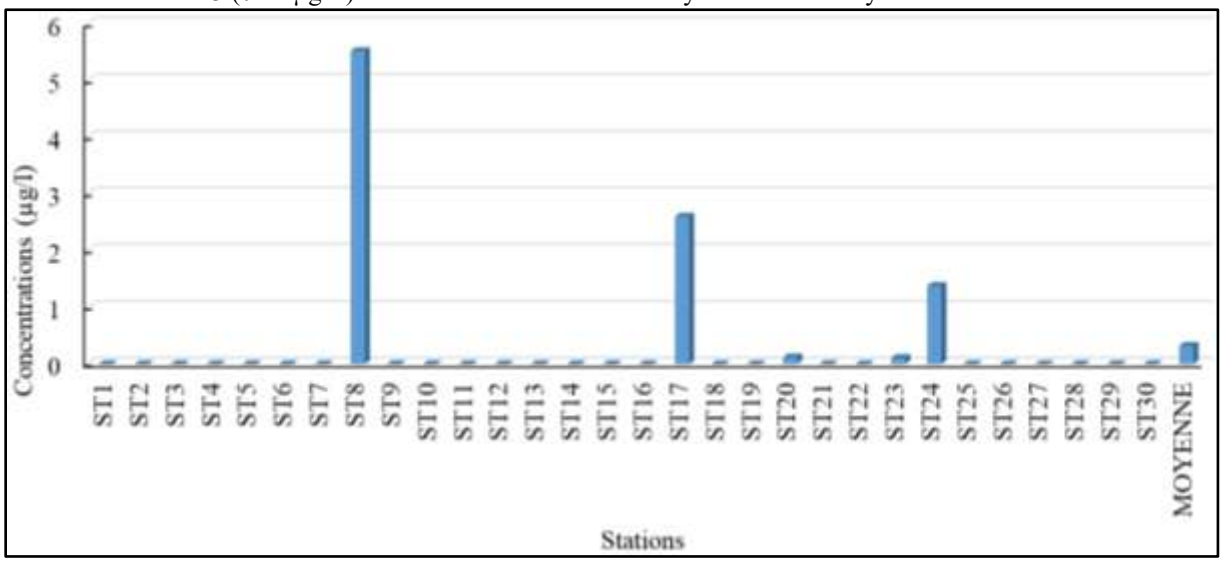

Figure 8: Concentrations of benzo(g,h,i) pyrenein the estuary

- **Indeno(1,2,3-cd) pyrene**

Indeno(1,2,3-cd)pyrene concentrations ranged from 0.19 to 85.83 µg/L, with an average value of 5.86 µg/L (Fig. 9). Water samples taken at stations ST7, ST8, ST20, ST23, ST26, ST24, ST27, ST28 and ST30 had zero concentrations of indeno(1,2,3-cd)pyrene. The highest concentration was recorded at station ST5 (85.83 µg/L) South of the estuary in the Vridi Canal, and the lowest at station ST17 (0.19 µg/L) in Cocody Bay.

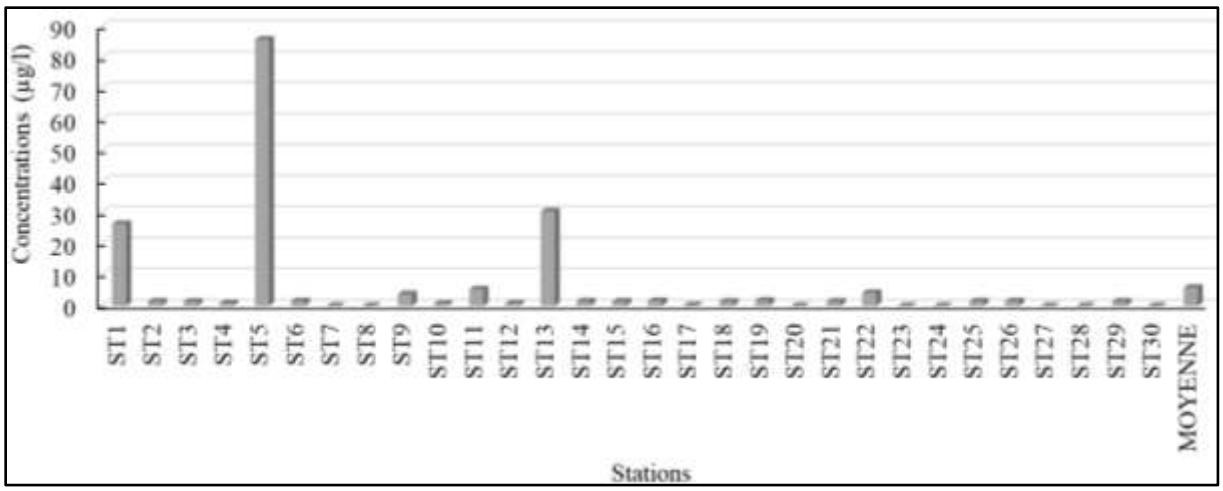

Figure 9: Concentrations of indeno(1,2,3-cd) pyrenein the estuary

Discussion:-

In this study, the concentration of pyrene ranges from 0.06 to 79.60 µg/L, with an average value of 9.11 µg/L. In M'Badon Bay, the average concentration of pyrene in the water is 1.69 µg/L, with a maximum of 4.56 µg/L (Gnonsoro et al., 2023). The average concentration of pyrene in this study is higher than that obtained in M'Badon Bay. This could be due to differences in the methods used to measure PAHs, the number of samples taken in each study, and the activities carried out around the two areas. Studies conducted in Ologe Lagoon in Nigeria and in the river estuary in South Africa show that pyrene is among the most concentrated PAHs in water (Obanya et al., 2019; Adeniji et al., 2019). The average concentration of pyrene in these two studies is 1.33 µg/L and 1.32 µg/L, respectively. These values are low compared to the average concentration in this study, which is 9.11 µg/L. This could be explained by a significant discharge of pyrene into the waters of the Ebrie Lagoon estuary compared to the two water bodies.

The high concentrations of pyrene (79.6 µg/L) and indeno(1,2,3-cd)pyrene (85.83 µg/L) observed in this study could be explained by their emission sources and location.According to studies by Yunker et al. in 2002 and Ravindra et al. in 2008, pyrene comes mainly from vehicle exhaust gases, and indeno(1,2,3-cd)pyrene is linked to industrial and automotive emissions. This analysis shows that the highest concentrations are found in areas of high anthropogenic activity, such as the Vridi Canal and Adiopodoume Bay in this study. In addition to emission sources, studies by Dia et al. (2023) showed that upstream bays receive greater external inputs, which could explain the higher concentrations of organic pollutants in these waters.

Benzo(g,h,i)pyrene is present in seven stations, with low concentrations ranging from 0.11 µg/L to 5.52 µg/L. It was not detected in the other 23 water samples. Benzo(a)anthracene was observed in 18 stations and absent in 12 stations. These concentrations are low, ranging from 0.01 µg/L to 3.03 µg/L. According to Colinet's 2003 studies, this variation in concentration could be linked to the hydrodynamics of the lagoon, dilution, or partial biodegradation of light compounds. In this study, the maximum concentration of benzo(a)pyrene is 19.48 µg/L. This concentration exceeds the environmental quality standards set by international regulations. Indeed, European Directive 2008/105/EC, as revised in 2013 (Directive 2013/39/EU), sets the threshold for benzo(a)pyrene in water at a maximum concentration of 0.027 µg/L. In addition, the WHO (2017) recommends a maximum concentration of 0.7 µg/L in water. The concentration of benzo(a)pyrene (19.48 µg/L) is well above the standards. This value could indicate a potential risk to the health of aquatic ecosystems and, in the long term, to the food security of riparian populations.

Conclusion:-

This study shows that all surface water samples taken from the Ebrie lagoon estuary contain eight (08) polycyclic aromatic hydrocarbons (PAHs). The concentrations range from 0.01 to 24.54 µg/L for fluoranthene, 0.06 to 79.60 µg/L for pyrene, 0.10 to 18.59 µg/L for benzo(k)fluoranthene, for benzo(a)pyrene between 0.01 and 19.48 µg/L, for indeno(1,2,3-cd)pyrene from 0.19 to 85.83 µg/L, for benzo (g,h,i)pyrene between 0.11 and 5.52 µg/L, for Benzo(a)anthracene between 0.01 and 3.03 µg/L and for Benzo(b)fluoranthene between 0.01 and 15.53 µg/L. Some

areas stand out due to their high concentrations, particularly indeno(1,2,3-cd)pyrene, with a concentration of 85.83 $\mu g \cdot L^{-1}$ at station 5 on the Vridi Canal, while pyrene has a maximum concentration of 79.60 $\mu g \cdot L^{-1}$ at station 11, located in Adiopodoume Bay. These high values are likely linked to anthropogenic sourcessuch as industrial and port activities and maritime traffic, as well as hydrodynamic exchanges. On the other hand, certain areas show a total absence of certain PAHs such as benzo (g,h,i)pyrene. These results can be explained by the hydrodynamic exchanges in the environment and its physicochemical characteristics. The results of this study thus demonstrate that the Ebrie lagoon estuary is a highly fragile environment.

Conflict of interest: -
The different authors confirm that they do not have any conflict of interest to notify.

Authors' Contributions:-
This article is the result of a collaborative effort in which authors contributed based on their experience to achieve this result. Professor CoulibalyAoua supervised this project and DrIrie conducted the literature review. Koffi Affoua Rose epse Ahi and DrKouassiMoïse collected the samples. KoffiAffouaRose epse AHI wrote the original manuscript. All authors read and approved the final document.

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