Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/15579
DOI URL: http://dx.doi.org/10.21474/IJAR01/15579

RESEARCH ARTICLE

SEASONAL METAL POLLUTION LEVEL AND ECOLOGICAL RISKS OF THE SUPERFICIAL SEDIMENTS FROM A TROPICAL LAGOON AREA

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Manuscript Info

Manuscript History
Received: 30 August 2022
Final Accepted: 30 September 2022
Published: October 2022

Key words:-
Ébrié System, Ecological Risks, Metal Pollution, Grand-Bassam, Côte d'Ivoire

Abstract

The aim of this study was to the assessment of the seasonal level metal contamination of the superficial sediments from the lagoon area II and to deduce the likely seasonal ecological risks which results. This study were conducted during one year (from June 2020 to May 2021) and the concentration in eight trace metals (As, Cd, Cr, Cu, Hg, Pb, Ni and, Zn) of these substrates, obtained in this period, were used. Seven metal contamination indexes, six ecological risks indexes and, two sediment qualities guidelines were used for this purpose. The results highlighted the very severe contamination of these superficial sediments in all season by all these trace metals in the whole, especially by As, Cd and Hg. So, the seasonal ecological risks for its fauna, particularly for its benthic fauna, were very severe. The population of its benthic fauna threatened by this pollution was relatively important, to 21% in this period.

Introduction:-

The increases in metal consumers, in the standard of living (increase in individual demand for metals) and, in industrial development (increase in the mass of metals used for production) have led to a very high generalized increase in trace metal requirements, more than that of population increase. These results in significant and increasing discharges of trace metal residues from urban, industrial, mining and, agricultural activities in the entire ecosystem. The consequences are the increasing in metal pollution of all ecosystem compartments (van der Voet et al., 2013). This is the particular case of surface waters. Sediments, considered as a memory indicator of aquatic pollutions, are frequently used to characterize their metal pollution (Aydi et al., 2022; Ugochukwu et al. (2022).

The dynamics of trace metals in sediments is due to several biogeochemical and physical factors, influenced by the hydroclimate. This is highlighted by several recent hydrochemical studies. Mathew et al. (2022) were highlighted the influence of upwelling in the fate of trace metals, through its effect on the dissolved oxygen and the temperature of the open waters in the distribution of trace metals in the superficial sediments from the coastal area of the southern Arabian Sea. Anandkumar et al. (2022) were noted the important influences of atmospheric, sedimentation, seasonal sediment inputs from Miri River in the biogeochemical distribution of trace metals in the superficial

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sediments of NW Borneo Bay. In Côte d'Ivoire, several recent studies were shown the influences of seasonal water inputs in the metal contamination of the superficial sediments from Ébrié system, including those of Diagoné et al. (2020), Irié et al. (2020), Traoré et al., (2014), Touré et al. (2018) and, Wognin et al. (2017).

Two approaches are commonly used to assess the metal pollution levels of sediment. This relates to metal contamination indexes, ecological risks indexes and, Sediment Quality Guidelines (SQGs). The metal pollution indexes frequently used for that are: Geoaccumulation Index (Igeo) (Muller, 1969), Contamination Factor (CF) (Håkanson, 1980), Contamination Degree (CD), Enrichment Factor (EF) (Ackerman, 1980), Pollution Load Index (PLI) (Tomlinson et al., 1980), Modified Contamination Degree (MCD) (Abrahim and Parker, 2008) and, Potential Contamination Index (PCI) (Davaulter and Rognerud, 2001). With regard to the approach to ecological risks, they relate in most cases to the benthic fauna. Several SQGs are implemented for this purpose, include Consensus Based Sediment Quality Guidelines (CB SQGs) (Threshold Effect Concentrations (TEC) and Probable Effect Concentrations (PEC)) established by MacDonald et al. (2000) and SQGs of Long et al. (1995) (Effect Range Low (ERL) and Effect Range Medium (ERM)). The ecological risks indexes are also added to SQGs for a better estimate of the likely effects of metal pollutants on the benthic fauna according to their concentrations in sediment. There are several, including Potential Ecological Risk Index (PERI) (Håkanson, 1980), Sediment Pollution Index (SPI) (Rubio et al., 2000), Toxic Units (TUs) (Pedersen et al., 1998), mean Effect Range Medium Quotient (mERM-Q) (Long et al., 2006) and, mean Probable Effect Concentrations Quotient (mPEC-Q) (MacDonald et al., 2000).

Located at the extreme Eastern of Ébrié system, the lagoon area II is subject to strong anthropogenic pressures due to the important population increase and the important development of human activities on its watershed. This situation has contributed to its degradation, particularly that of its open waters, as highlighted by Mahi et al. (2022a, b,c). The studies relating to the metal pollution of its superficial sediments are scarce. The most recent is those of Keumean et al. (2013, 2020). There are taking in account four trace metals in their studies. So, their studies do not give more information about the metal pollution of the superficial sediments from this lagoon area. Knowing its important remarkable biodiversity, especially its benthic fauna, the studies of the metal pollution of its sediments must be conducted for a good approach of its metal pollution and the ecological risks by taking in account an important number of trace metals. It is in this context that this study was carried out. Its main objective is to assess the seasonal metal pollution level of its superficial sediments by eight trace metals (As, Cd, Cr, Cu, Hg, Pb, Ni and, Zn). Its secondary objective is to assess the seasonal ecological risks for its benthic fauna, therefore for all the chain food.

Material and Methods:-

The lagoon area II of Ébrié system is located within latitudes 5°200000-5°21176471 N and longitude 3°400000-3°500000 W. Its length is estimated to 17.143 km and, that of its width to 5.714 m. Its surface is around to 87 km^2. It was the most important estuary of this system (Figure 1) (Mahi et al., 2022a,b,c,d).

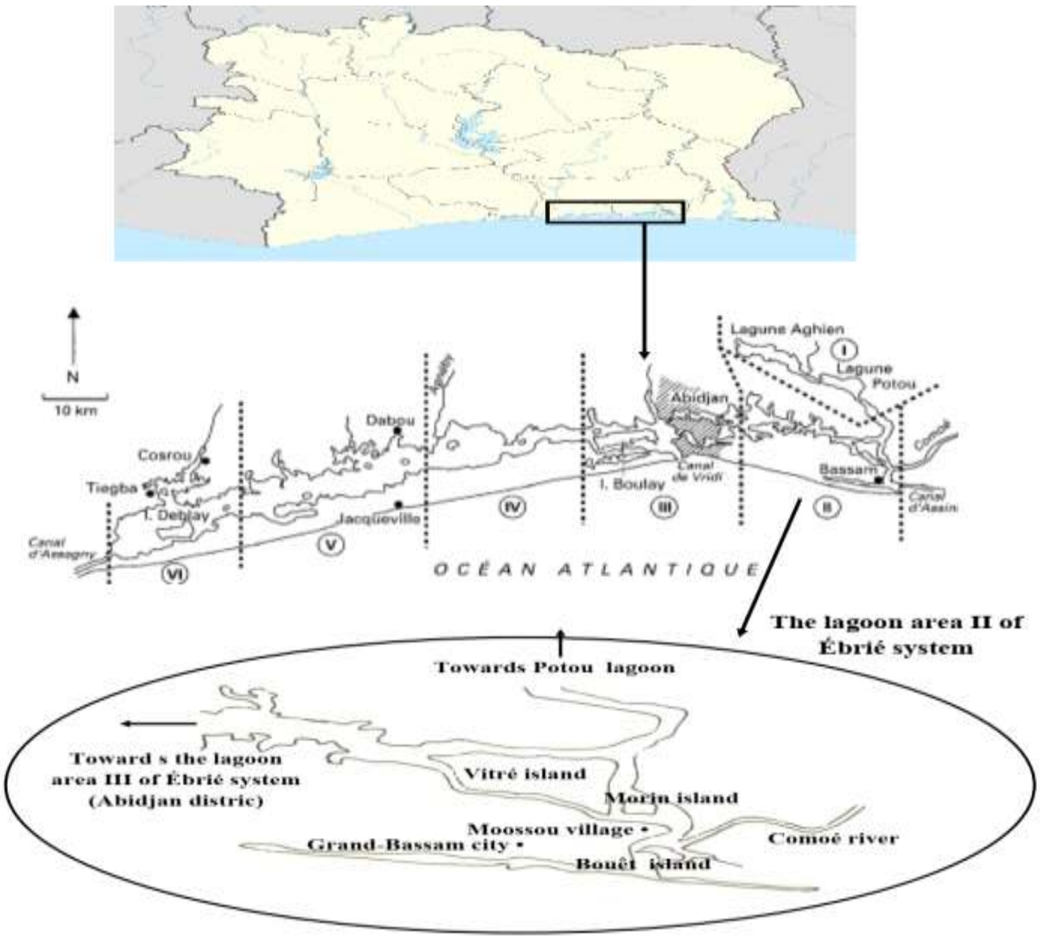

Figure 1:- Localization of the lagoon area II of Ébrié system (Mahi et al., 2022 a,b,c,d).

Its hydrology is dominated by Atlantic Ocean, Mé river and, Comoé river. Mahi et al. (2022 a,b,c,d) describe its water seasons as follows:

- Hot Season (HS), where the influence of the marine inputs from Atlantic Ocean is relatively maximum due to low meteorite inputs. During this season, these marine inputs carry into this estuary the inputs from lagoon area III. All these inputs have an important metal pollution (Kouamé et al., 2016; Oura et al., 2021; Touré et al., 2018);

- Rainy Season (RS), where meteorite inputs are significant and reduce the effects of the marine inputs from Atlantic Ocean. These meteorite inputs are dominated by those of meteorite runoff waters by leaching the banks of this ecosystem and, Mé river draining those of Potou lagoon and those of Aghien lagoon which it crosses to flow into this lagoon area. The same is true for those of Comoé river from its watershed located in Southern of Côte d'Ivoire. These inputs from these rivers, lagoons and, meteorite runoff waters are also relatively rich in trace metal (Diagoné et al., 2020; Keumean et al., 2013; Keumean et al., 2020; Traoré et al., 2014);

- Flood Season (FS), characterized by the high presence of Comoé river in this lagoon area. Nevertheless, this aquatic ecosystem also receives the inputs of runoff meteorite waters and those of Mé river, Adjn lagoon and, Potou lagoon in favor of the short rainy season on the coastline of this country. These meteorite inputs in this season are less important than those brought in RS.

The superficial sediments from this estuary are dominated by coarse sands according to Mahi et al. (2022d). The concentrations in trace metals of these substrates obtained by Mahi et al. (2022d) were all less important than those determined by Keumean et al. (2020); and less important than those determined by Keumean et al. (2013), excepted to those of their concentrations in Cu and Ni.

Implementation of this study

Source of the data used

This study was conducted during one year (from June 2020 to May 2021). Eight trace metals were taking in account in this study: As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and, Zn. The seasonal and annual mean values of their concentrations in these trace metals, obtained by Mahi et al. (2022d) in this period, were used for the assessment of the seasonal metal pollution level and ecological risks of the superficial sediments from this lagoon area in this study.

Assessment of the metal contamination level of these sediments

The assessment of the metal contamination level of the superficial sediments from the lagoon area was implemented by using the following indexes: Igeo (Muller, 1969), CF (Håkanson, 1980), CD (Håkanson, 1980); EF (Ackerman, 1980), PLI (Tomlinson et al., 1980), MDC (Abrahim and Parker, 2008) and, PCI (Davaulter and Rognerud, 2001).

Contamination Factor (CF) index

Defined by Håkanson, (1980), CF for a trace metal in sediment is expressed by:

$$\mathrm{CF} = \frac{[\mathrm{Me}]_{\mathrm{sediment}}}{[\mathrm{Me}]_{\mathrm{background}}} \quad \text{(I)}$$

With: [Me]sediment, the concentration in the trace metal Me of sediment; [Me]background, the reference geochemical concentration of this trace metal.

So, the contamination of sediment due to this trace metal is:

- low for CF < 1;
- moderate for 1 ≤ CF < 3;
- severe for 3 ≤ CF < 6 and;
- very severe for CF ≥ 6.

Contamination Degree (CD) index

As concerned CD, also defined by Håkanson, (1980), it is obtained as follow:

$$\mathrm{CD} = \sum_{i=1}^{n} \mathrm{CF_i} \quad \text{(II)}$$

With: CF_i, the contamination factor of sediment obtained with the trace metal i; n, the total number of trace metals taking in account.

So, the contamination of sediment due to all these n trace metals is:

- low for CD < 6;
- moderate for 6 ≤ CD < 12;
- severe for 12 ≤ CD < 24 and;
- very severe for CD ≥ 24.

Modified Contamination Degree (MCD) index

Abrahim and Parker (2008) were defined MCD, which translating the mean degree of metal contamination related to the number n of trace metals taking in account. This formulation makes it possible to define several metal contamination levels by trace metals compared to that of Håkanson (1980). This metal contamination index has for expression:

$$\mathrm{MCD} = \frac{\mathrm{CD}}{\mathrm{n}} = \frac{\sum_{i}^{n} \mathrm{CF_i}}{\mathrm{n}} \quad \text{(III)}$$

With: CD, the contamination degree obtained with all the n trace metals; CF_i, the contamination factor of sediment obtained with the trace metal i; n, the number of trace metals taking in account.

The contamination level of sediment by all the n trace metals is:

- very low for MCD < 1.5;
- low for 1.5 ≤ MCD < 2;
- moderate for 2 ≤ MCD < 4;
- important for 4 ≤ MCD < 8;
- very severe for 8 ≤ MCD < 16;

- extremely severe for $16 \leq MCD < 32$ and;
- ultra severe for $MCD \geq 32$.

Pollution Load Index (PLI) index

PLI was developed by Tomlinson et al. (1980) and its expression is:

$$PLI = \sqrt[n]{\prod_{i=1}^{n} CF_i} \qquad (IV)$$

With: CF_i, the contamination factor of sediment obtained with the trace metal i; n, the number of trace metals taking account.

Sediment is:

- non polluted by all the n trace metals if $PLI \leq 1$ and;
- polluted by these trace metals if $PLI > 1$.

Pollution Contamination Index (PCI) index

PCI was proposed by Davaulter and Rognerud (2001). Its expression is the same as that of CF (Håkanson, 1980), but differs by the use of the maximum concentration in the trace metal Me of sediment:

$$PCI = \frac{[Me]_{maximum\ \ sediment}}{[Me]_{background}} \qquad (V)$$

With: [Me]maximum sediment, the maximum concentration of the trace metal Me in sediment; [Me]background, the reference geochemical concentration of the trace Me.

According this index, the contamination of sediment is:

- low for $PCI < 1$;
- moderate $1 \leq PCI < 3$ and;
- severe or very severe for $PCI \geq 3$

Geoaccumalation index (Igeo) index

Igeo is another index for the assessment of the metal contamination level of sediment. Defined by Muller (1969), Igeo is express by:

$$I_{géo} = \frac{[Me]_{sediment}}{1{,}5.\,[Me]_{background}} \qquad (VI)$$

With: [Me]sediment, the concentration in the trace metal Me of sediment; $[Me]_{sediment}$, the reference geochemical concentration of the metal Me; 1.5, a constant factor minimizing the probable effects of variations in its geochemical concentration, which would be linked to its different mineralogical varieties.

The different metal contamination levels of sediment by the trace metal Me are as follow:

- class 0, Igéo ≤ 0, unpolluted;
- class 1, 0 < Igéo ≤ 1, from non polluted to moderately polluted;
- class 2, 1 < Igéo ≤ 2, moderately polluted;
- class 3, 2 < Igéo ≤ 3, from moderately polluted to severe polluted;
- class 4, 3 < Igéo ≤ 4, severe polluted;
- class 5, 4 < Igéo ≤ 5, from severe polluted to extremely polluted;
- class 6, Igéo > 5, extremely polluted.

Enrichment Factor (EF) index

Like the other indices, EF also assesses the metal contamination level of sediment. This index was developed by Ackerman (1980) and differs from the others indexes by its expression which is:

$$EF = \frac{\left(\frac{[Me]}{[R]}\right)_{sediment}}{\left(\frac{[Me]}{[R]}\right)_{background}} \qquad (VII)$$

With: [Me]sediment, the concentration in the trace metal Me of sediment; $[Me]_{background}$, the reference geochemical concentration of the trace metal Me; [R], the concentration in the reference trace metal R of sediment; $[R]_{background}$, the reference geochemical concentration of the trace metal R.

The contamination of sediment by the trace metal Me is:
- of natural origin if its FE value is between 0.5 and 1.5 and;
- of anthropogenic origin if its Fe value is beyond 1.5.

Al, Fe or organic matter are commonly used as references, because they represent the elements with which other trace metals are associated in sediments. In this study, Fe was used as a reference trace metal because it is essentially of natural (geochemical) origin in the sediments on the one hand, and its content in these substrates is very little disturbed by the various biogeochemical processes, on the other (Yao et al., 2017). The reference geochemical concentration of Fe used in this study was that given by Wedephol (1995).

The reference geochemical concentrations of these eight trace metals used in this study were those of their consensus geochemical concentrations provided by Rudnick and Gao (2014).

Assessment of the ecological risks
Two approaches were used to assess the ecological risks due to their metal contamination. The first approach has concerned to the use of CB SQGs of MacDonald (2000) and, the second by the use of five potential ecological risks indexes.

CB SQGs of MacDonald (2000)
In this study, CB SQGs of MacDonald et al. (2000) was used to assess the ecological risks due to the concentrations in As, Cd, Cr, Cu, Hg, Ni, Pb and, Zn of these superficial sediments. The Consensus Based Threshold Effect Concentrations (CB TEC) and the Consensus Based of Probable Effect Concentration (CB PEC) for these metals are given in the table 1.

Table 1: TEC and PEC from CB SQGs of MacDonald (2000) for the trace metals used in this study.

Trace metals	TEC	PEC
As	9.79	33
Cd	0.99	4.98
Cr	43.4	111
Cu	31.6	149
Hg	0.18	1.06
Ni	22.7	48.6
Pb	35.8	128
Zn	121	459

TEC, Consensus Based Threshold Effects; PEC, Consensus Based Probable Effects.

Potential ecological risk indexes used
The ecological risks indexes used in this study were:
- the potential ecological risks based on Contamination Factor (CF) index (PERI) (Håkanson,1980);
- the potential ecological risks based on Enrichment Factor (EF) index (SPI) (Ackerman,1980);
- the potential ecological risks based on PEC from SQGs of MacDonald (2000) (TUs and mPEC-Q);
- the potential ecological risks based on ERM from SQGs of Long et al. (1995) (mERM-Q).

Potential ecological risks based on CF and EF indexes
Potential Ecological Risk Index (PERI)
PERI is one of the indexes for assessing the ecological risk level due to the metal pollution of sediment in relation to the toxicity of metal pollutants. Developed by Håkanson (1980), this ecological risks index is based on CF (Håkanson, 1980). Its expression is:

$$E_r^i = T_r^i \text{ X } FC_i \quad \text{(VIII)}$$

$$PERI = \sum_{i=1}^{n} E_r^i \quad \text{(IX)}$$

With: E^i_r, the individual potential ecological risk (for the trace metal i); T_r^i, the toxicity response factor for the trace metal i. CF_i, the contamination factor for the trace metal i. The T_r^i values are 10 for As, 30 for Cd, 2 for Cd, 5 for Cu, 40 for Hg, 5 for Pb and, 1 for Zn.

According to the E_r^i and PERI values, the ecological risk level of sediment is:
- $E_r^i < 40$ / PERI < 150, low ecological risks;
- $40 \leq E_r^i < 80$ / $150 \leq$ PERI < 300, moderate ecological risks;
- $80 \leq E_r^i < 160$ / $300 \leq$ PERI < 600, severe ecological risks;
- $160 \leq E_r^i < 320$ / $300 \leq$ PERI < 600, very severe ecological risks;
- $E_r^i \geq 320$ / PERI $\geq$ 600, ultra severe ecological risks.

Sediment Pollution Index (SPI)
SPI makes it possible to estimate the ecological risks on the benthic fauna from all the enrichment factors of sediment by Cd, Cr, Cu, Ni, Pb and, Zn, assigned a weight W. This index was defined by Rubio et al. (2000) and has for expression:

$$SPI = \frac{\sum_{i=1}^{n}(W_i \text{ X } EF_i)}{\sum_{i=1}^{n} W_i} \quad (X)$$

with: EF_i, the enrichment factor of the trace metal i; W_i, the weight for the trace metal i (1 for Cr and Zn; 2 for Cu and Ni; 5 for Pb and 300 for Cd).

This index makes it possible to distinguish five ecological risk levels of sediment for the benthic fauna, as follow:
- $0 \leq$ SPI < 2, healthy sediment;
- $2 \leq$ SPI < 5, lightly polluted sediment;
- $5 \leq$ SPI < 10, moderately polluted sediment;
- $10 \leq$ SPI < 20, very polluted sediment and;
- SPI $\geq$ 20, dangerous sediment.

Potential ecological risks based on SGQs
SQGs are effective tools for determining the environmental risks associated with the metal pollution of sediment, particularly below threshold effect concentration given by these sediment quality guidelines where there are no adverse effects on the benthic fauna on the one hand and, probable effect concentration above which the risks of adverse effects on benthic fauna are high, on the other. However, when the means value of trace metal concentration are between threshold effect concentration and probable effect concentration, the potential risk cannot be ascertained from heavy metal concentrations alone (NYSDEC, 2014). Toxic Units (Pedersen et al., 1998), m-ERM-Q (Long et al., 2006) and, m-PEL-Q (MacDonald and al., 2020) based on SQGs were developped for better assessment the potential ecological risks in this case.

Potential ecological risks based on PEC from CB SGQs of MacDonald (2000)
In this study, PEC values of the trace metals taking in account were given by the table 1.

Toxic Units (TUs)
This index allows assessing the non-acute and/or acute ecological risks of sediment for the benthic fauna linked to their concentration in a set of trace metals. It was defined by Pedersen et al. (1998). For a trace metal i, it is possible to assess its concentration relative to its PEC value given by CB SQGs of MacDonald et al. (2000).

$$TU = \frac{C_s}{PEC_s} \quad (XI)$$

With: TU, toxicity unit (bound to a single metal); Cs, the concentration in the trace metal i of sediment; PECs, PEC value corresponding to the trace metal i.

So, for a set of trace metals, TUs is given by:

$$\sum TUs = \sum_{i=1}^{n} \frac{C_s^i}{PEL_s^i} \quad (XII)$$

The toxicity of all the trace metals considered in sediment for the benthic fauna is:
- $\sum TUs < 4$, non-acute toxicity;
- $4 \leq \sum TUs \leq 6$, non-acute to acute toxicity and;

- $\sum$TUs > 6, acute toxicity.

mean Probable Effect Concentrations Quotient (mPEC-Q)

mPEC-Q is defined by MacDonald et al. (2000) on the basis PEC. Its expression is:

$$\mathrm{mPEC-Q} = \sum_{i=1}^{n} \left(\frac{C_i}{PEC_i}\right) \qquad \text{(XIII)}$$

with: C_i, Concentration in the trace metal i of sediment; PEC_i, Consensus Based Probable Effect Concentration of the trace metal i; n, the number of the trace metals taking in account.

Sediment is defined as:
- toxic if mPEC-Q > 0.5 and;
- nontoxic if < 0.5.

Potential ecological risks based on ERM: mean Effect Range Medium Quotient (mERM-Q)

mERM-Q was developed by Long et al. (2006) on the basis of Effect Range Medium (ERM). mERM-Q is given by:

$$\mathrm{mERM-Q} = \frac{\sum_{i=1}^{n} \frac{C_i}{ERM_i}}{n} \qquad \text{(XIV)}$$

with: C_i, Concentration in the trace metal i of sediment; ERM_i, Effect Range Medium i of the trace metal i; n, the number of the trace metals taking in account.

In this study, ERM values of the trace metals taking in account were those given by Long et al. (1995) (Table 2).

Table 2:- ERM of the trace metals taking in account this study (Long et al., 1995).

Trace metal (mg/g dry weight)	ERM
As	70
Cd	9.6
Cr	370
Cu	270
Hg	0.71
Ni	51.6
Pb	218
Zn	410

Several toxicity probability classes are defined by Long et al. (2006) based on the toxicity quotient values for the benthic organisms:
- mEMR-Q < 0.1, 9 %;
- 0.11 < mEMR-Q < 0.5, 21 %;
- 0.51 < mEMR-Q < 1.5, 49 %;
- 1.5 < mEMR-Q < 5.76 % and;
- mEMR-Q > 5, > à 90 %.

Results:-

Level of metal contamination

The table 3 presents the different seasonal and annual means values of CF, PCI, Igeo and, EF relating to the presence of As, Cd, Cr, Cu, Hg, Ni, Pb and, Zn in these superficial sediments in this period.

The seasonal mean values of CF and PCI obtained in this period highlighted very severe contamination of these superficial sediments by As, Cd, Hg; their moderately contamination by Ni and; their slightly contamination by Cr, Cu, Pb and, Zn in all seasons. So, they were in all season extremely polluted by As, Cd and, Hg; moderately polluted by Ni and; non polluted by Cr, Cu, Pb and, Zn, as shown again by the seasonal mean values of Igeo. The monitoring of the seasonal dynamics of these three metal contamination indexes (CF, PCI, Igeo) highlighted that the seasonal contamination of these superficial sediments by As increased from HS to FS, unlike that by Ni which decrease from HS to FS. Those by Cd, Cu, Hg and, Pb were important in HS, but low in RS. As for their seasonal contamination by Zn, it was important in FS, but low in RS in this period.

The mean seasonal values of EF highlighted that Cu was of natural origin and, the other trace metals were of anthropogenic origin in these superficial sediments in this period. The enrichment of these substrates by Cd and Hg decreased from HS to FS. Those by Cu and Pb were relatively important in HS, but relatively low in RS. As concerned to their enrichments by As, Cr and, Ni, they were relatively considerable in RS, relatively low in HS for As and, in FS for Cr and Ni. That by Zn was relatively important in FS, but relatively low in HS.

Table 3:- Mean Seasonal and annual values of CF, PCI, Igeo and, EF relating to the presence of As, Cd, Cr, Cu, Hg, Ni, Pb and, Zn in these superficial sediments obtained in the study period.

Trace metals	Seasons	CF	PCI	Igeo	EF	Trace metals	Seasons	CF	PLI	Igeo	EF
As	HS	8.510	11.705	5.674	162.369	Hg	HS	15.815	27.340	10.543	301.726
	RS	8.565	11.963	5.710	170.743		RS	14.552	21.740	9.701	290.101
	FS	8.622	12.263	5.748	163.189		FS	14.685	26.320	9.790	277.945
	Annual	8.572	12.263	5.715	165.474		Annual	15.040	27.340	10.027	290.329
Cd	HS	11.659	16.556	7.773	222.446	Ni	HS	1.241	1.642	0.827	23.671
	RS	9.134	12.444	6.089	182.077		RS	1.225	1.627	0.817	24.421
	FS	9.394	12.644	6.263	177.810		FS	1.221	1.642	0.814	23.118
	Annual	10.089	16.556	6.726	194.754		Annual	1.229	1.642	0.819	23.718
Cr	HS	0.508	0.691	0.339	9.698	Pb	HS	0.789	0.896	0.526	15.049
	RS	0.520	0.642	0.346	10.359		RS	0.673	0.848	0.449	13.412
	FS	0.502	0.570	0.335	9.505		FS	0.731	0.858	0.487	13.832
	Annual	0.508	0.691	0.339	9.809		Annual	0.731	0.896	0.487	14.107
Cu	HS	0.035	0.048	0.024	0.676	Zn	HS	0.087	0.108	0.058	1.657
	RS	0.030	0.042	0.020	0.597		RS	0.084	0.102	0.056	1.684
	FS	0.032	0.047	0.021	0.610		FS	0.091	0.115	0.060	1.717
	Annual	0.033	0.048	0.022	0.633		Annual	0.088	0.115	0.059	1.700

These superficial sediments were in all seasons very severe contaminated by these eight trace metals according to the seasonal mean values of CD and, severe contaminated in accordance with the seasonal mean values of MCD in this period. So, they were severe polluted by all these trace metals in all seasons in accordance with the seasonal mean values of PLI. The contamination of these sediments by all these trace metals, and consequently their pollution, is relatively important in HS, but relatively low in RS (Table 4).

Table 4:- Mean seasonal and annual values of CD, MCD and, PLI values relating to the eight trace metals taking in account obtained in the study period.

Seasons	DC	MCD	PLI
HS	38.644	4.830	1.116
RS	34.782	4.348	1.026
FS	35.279	4.410	1.057
Annual	36,.289	4.536	1.070

The contamination of these superficial sediments by Cr, Cu, Pb and, Zn in this period were less important than those observed by Keumean et al. (2020) at the end of the previous decade, unlike that by Cd which was important. However, these substrates exhibited a higher metal contamination level in this period than that determined by Keumean et al. (2020). Also, the pollution of these superficial sediments by Cr, Ni, Pb and Zn were very low in this period compared to those observed by Keumean (2013) in this lagoon area ten years earlier, except to their pollution by Cu. The same is true of their pollution by Cd, Hg and, Zn in this period relative to those of Aghien lagoon (Traoré et al., 2014), except to their pollution by Pb. They were more polluted by As, Cd, Cr, Cu, Ni, Pb and, Zn in period than those of Potou lagoon (Diagoné et al., 2020). The same is true of their high contamination by Cd and Ni compared to those of all Abidjan district lagoon bays (Wognin et al., 2017), with the exception of their pollution by Cu and Zn. However, they were polluted by Cu, Pb and Zn than the superficial sediments from Mondoukou lagoon (Guindo et al., 2016) (Table 5).

Table 5:- Comparison of annual mean values of some contamination indexes obtained in this study to those determined by some authors in this lagoon area and in other lagoon.

Trace metals	Annual mean values of some contamination indexes obtained in this study				Lagoon area II of Ébrié system) (Keumean et al., 2013)	lagoon area II of Ébrié system) (Keumean et al. (2020)		Mondoukou lagoon (Gouin et al., 2016)		Aghien lagoon; (lagoon area I of Ébrié system) (Traoré et al., 2014)	Potou lagoon; (lagoon area I of Ébrié system) (Diagoné et al., 2020)		Abidjan district lagoon bays (lagoon area I of Ébrié system) (Wognin et al., 2017)
	CF	EF	MCD	Igeo	Igeo	CF	MCD	Igeo	EF	EF	Igeo	EF	EF
As	8.572	165.474		5.715							-2.62	0.22	
Cd	10.089	194.754		6.726		3.30				23.85	-1.56	0.47	5
Cr	0.508	9.809		0.339	0.49	1.63					-1.56	0.44	
Cu	0.033	0.633		0.022	-0.57	0.55		6.35	76.08		-0.88	0.67	2.800
Hg	15.040	290.329	4.536	10.027			2.34			558.9			
Ni	1.229	23.718		0.819	0.98						-2.21	0.28	2.734
Pb	0.731	14.107		0.487	1.07	4.89		7.64	3215.10	4.32	3.90	0.13	
Zn	0.088	1.700		0.059	-0.66	1.33		6.59	30.85	25.76	0.77	2.12	3.034

Ecological risks level

The different mean seasonal values of E_r^i highlighted the low ecological risks of these superficial sediments in all seasons due to Cr, Cu, Ni, Pb and, Zn; unlike to their severe ecological risks in all seasons related to As and, their ultra severe ecological risks due to Cd and Hg. The ecological risks of these superficial sediments due to Ni decreased from HS to FS, unlike those due to As which increased from HS to FS. Those due to Cd, Cu, Hg and, Pb were relatively high in HS. They were relatively low in RS for Cd, Cu and, Pb and; in FS for Hg. As concerned to those due to Zn, they were relatively high in FS, but relatively low in RS. As for those related to Cr, they were relatively high in RS and, relatively low in FS in this period (Table 6).

The ecological risks of these superficial sediment due to all these trace metals were ultra severe in all seasons, as highlight the different mean seasonal values of PERI, SPI, TUs and, mPEL-Q. The rate of benthic fauna exposure to this kind of ecological risks was 21% in all seasons, as show the mean seasonal values of mERM-Q determined in this period (Table 7).

Table 6:- Seasonal and annual mean values of E_i^r of these eight trace metals obtained in this study.

Trace metals	Sesons	E_i^r	Trace metals	Seasons	E_i^r
As	HS	85.104	Hg	HS	632.587
	RS	85.648		RS	582.080
	FS	86.220		FS	587.400
	Annual	85.721		Annual	601.600
Cd	HS	349.778	Ni	HS	0.827
	RS	274.000		RS	0.817
	FS	281.834		FS	0.814
	Annual	302.667		Annual	0.819
Cr	HS	1.990	Pb	HS	3.944
	RS	2.034		RS	3.364
	FS	1.966		FS	3.654
	Annual	1.989		Annual	3.654
Cu	HS	0.177	Zn	HS	0.087
	RS	0.150		RS	0.084
	FS	0.161		FS	0.091
	Annual	0.164		Annual	0.088

Table 7:- Seasonal and annual mean values of PERI, SPI, TUs, mERM-Q and, mPEL-Q relating to all these trace metals determined in these superficial sediments in this period.

Seasons	PERI	SPI	TUs	mERM-Q	mPEL-Q
HS	1073.667	215.013	6.637	0.393	0.707
RS	947.360	176.052	6.426	0.377	0.682
FS	961.325	171.932	6.453	0.378	0.686
Annual	995.883	188.286	9.797	0.383	0.692

Discussion:-

The important metal pollution of the superficial sediments from this lagoon area and its high ecological risks confirm the results obtained by Mahi et al. (2022a,b,c) for the metal pollution of its open waters in this period. This situation is the corollary of the high anthropogenic pressures on its watershed, particularly linked to the important agricultural, mining and, industrial practices, which are constantly increasing. The impact of this fact on the metal pollution of this lagoon estuary is reinforced by the low rate of its water renewal following the silting up of the pass of Bassam, the natural pass of Ébrié system with Atlantic Ocean (Bamba et al., 2008). Mondoukou lagoon, resembling a lake and located far downstream from this lagoon area, seems to be more affected by this situation in view of the level metal contamination of its superficial sediments by Cu, Pb and, Zn (Gouin et al., 2016) greater than those obtained in this study. Comoé River, responsible for two thirds of the metal pollution of Ébrié system according to Pottier et al. (2008), would be the main source of the metal pollution of the superficial sediments from this aquatic ecosystem, as it constitutes the largest part of its terrestrial watershed (Mahi et al., 2022a). This would justify the relatively high metal contamination of these superficial sediments, particularly by Cd, Cu and, Ni, relative to those from all Abidjan district lagoon bays (Wognin et al., 2017). Mé River, whose watershed is also impacted by the important agricultural and mining practices, but slightly compared to those of Comoé River (Mahi et al., 2022a), contributes partially to their pollution through Aghien lagoon (Diagoné et al., 2020) and Potou lagoon (Traoré et al., 2014). This situation would also contributed to the relatively high metal pollution of these superficial sediments obtained in this period, but also by Keumean (2013; 2020), relative to those from Potou lagoon (Diagoné et al., 2020). It would be the same for those from Aghien lagoon, less polluted by Cd and Pb (Traoré et al., 2014) than these superficial sediments (Keumean et al., 2013, 2020). Nevertheless, the superficial sediments from Aghien lagoon seem to retain more Hg and Zn (Traoré et al., 2014). This would lead to low contamination of the superficial sediments from Potou lagoon by these two trace metals (Diagoné et al., 2020), consequently those from the study area (Keumean et al., 2013, 2020; Mahi et al., 2022d).

The low contamination of the superficial sediments from this lagoon estuary by Cr, Cu, Pb and, Zn in this period compared to those observed Keumean et al. (2020) would explain the intensification of biogeochemical phenomena, such as sedimentation and bioremediation, favored by the exceptional flooding of Comoé river induced by the significant climatic variation in the study period. The failure to take As and Hg into account in their studies led Keumean et al. (2013; 2020), to conclude in the unpolluted and moderately polluted levels of these superficial sediments respectively, with low ecological risks. This contrasts with this study, in which As, Cd and, Hg very severely contaminated these superficial sediments in this period. Moreover, the relative high presence of these three trace metals, especially Hg, in these substrates would illustrate the high mining practices on the watershed of this lagoon area, particularly in that of Comoé river marked by important clandestine gold panning practices over this decade (Kouyaté et al., 2021). The same is true for agricultural activities by As and Hg, particularly from the intense use of pesticides in its watershed (Mahi et al., 2022a; Burnol et al., 2006). The low presence of Cr in these substrates could be explained by its low use in its watershed, in particular as an additive in cooling waters in industry activities (Burnol et al., 2006) in Côte d'Ivoire. Those of Cu, Ni, Pb and, Zn would be explained by their low inputs in one hand and, by an important bioremediation and sedimentation would take place here, on other. Also, pH of these superficial sediments, very close to neutral, would also have disadvantaged the presence of these trace metals in the forms of insoluble carbonate and sulphide metal complex (Correia, 2018; Schneider, 2016; Ferriz, 2020). In the particular case of Cu, it would seem to be used more by fauna and flora aquatics than Zn in this lagoon area, since both are essential trace elements for aquatic life (Petrovic and Krivokapic, 2020; Ragnvaldsson et al., 2020).

The marine inputs, draining the industrial and urban discharges of Abidjan district, would have further favored the increase in the enrichment of anthropic origin of these superficial sediments by Cd, Hg and, Pb in HS. However, the meteorite inputs, by the leaching of geological base, would have led to a drop in this enrichment, particularly in RS for Cd and Hg and, in FS for Pb with particularly those of Comoé river. The biogeochemical process, such remediation and sedimentation, would more contribute to it. The anthropogenic enrichment of these substrates by As, Cr and Ni were particularly important in RS with meteorite inputs, mainly due to agricultural and mining discharges. It would be lessened with the marine inputs for Cd in HS, due to the low industrial use of this trace metal and; with the inputs from Comoé river for Cr and Ni, probably because of its acidity which does not favor the stability of these two trace metals in the superficial sediments from this lagoon area in this period. The anthropogenic enrichment of these sediments by Zn would be more related to agricultural discharges in view of its increase from HS to FS. For Cu, its low inputs and its significant use by aquatic fauna and flora would seem to mask its anthropogenic origin, in particular in HS where its natural character was more pronounced at the same time as the relatively important marine inputs. This would seem to be explained by a partial decomposition of some floating macrophytes, such as *Eicchornica crassipes*, favoring an increase in the salinity of the open waters of this lagoon estuary (Mahi et al., 2022a). However, the inputs from agricultural and mining practices, majority bring to this estuary by meteorite inputs, would contribute to lessen its natural character in these substrates.

The very severe seasonal metal contamination of these superficial sediments would be essentially due to their relatively high concentration in As, Cd and, Hg, observed in all season during this period. This would be especially in HS. The meteorite inputs would cause a slight decreased in their very severe contamination, due to the slight decrease in their total concentration in these three metals, especially in RS. In view of the high toxicity of As, Cd and Hg, even at low doses, for aquatic fauna on the whole, and for the benthic fauna in particular (Ros et al., 2020), these sediments would therefore be very toxic for benthic fauna in all seasons. This would have been particularly in HS. Also, this study confirms the conclusion of Irié et al. (2020) as to the proportion of benthic fauna of this lagoon area threatened by this pollution, namely 21%.

Conclusion:-

This study highlighted the very severe metal contamination of the superficial sediments from this tropical lagoon. This is essentially due to their very severe contamination by As, Cd and, Hg. So, the ecological risks for its benthic fauna is very severe, estimated for 21% of their population. This study must be complete by others, concerned to the assessment of the distribution and the mobility of these trace metals in these superficial sediments for more information in its ecological risks. That would also be the case of the study of the diffusion flux of these metals in the water-sediment interface from this lagoon area, to approach the knowledge of the character of its superficial sediments as metal pollutant sink or source.

Acknowledgements:-

The authors thank the governing authorities of National Drinking Water Office of Côte d'Ivoire and the techniques staff of Water Quality Analysis and Control Laboratory (WQACL) of this institute for their invaluable help in carrying out of this study.

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