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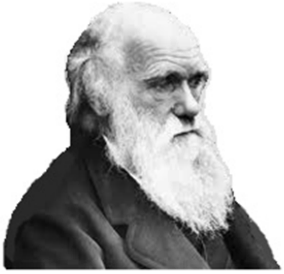

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Ecological evaluation and modeling of metallic contamination levels in soils from the reclaimed section of River Otamiri wetland, Southeastern Nigeria

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ABSTRACT

The study carried out ecological evaluation and modeling of metallic contamination levels in soils from the reclaimed section of River Otamiri wetland in Southeastern Nigeria. The study was aimed at ecological evaluation and modeling of contaminant levels of the reclaimed wetland soils. This was in order to determine the extent of metallic contamination of the wetland. The metallic contamination level was established with the help of Energy dispersive X-ray fluorescence spectroscopy (EDXFS). Pollution models were used to carry out ecological evaluation of the metallic contamination levels. The result revealed that the mean values of the metals were in the order; $0.29 < 0.59 < 0.88 < 16.74 < 50.44 < 129.48 < 259.34 < 341.22 < 518.70 < 563.14 < 39888.63$ mg/kg for Cd <As < Ag < Cr < Pb < Mn < Zn < Cu < Co < Ni < Fe respectively. In comparison with the Department of Petroleum Resources (DPR) target value, Cr, Mn, As, Pb, and Cd had mean values below the target value; however, the mean values of Co, Fe, Ni, Cu, Zn, and Ag exceeded the DPR value. The PLI values were all >1 for all the samples, which is a serious ecological concern for the reclaimed wetland as it implies that the area is polluted. Geo-accumulation index analysis ranged from no accumulation to moderate accumulation. Result of ecological risk index analysis point to the fact that the risk posed by the metals ranged from low to high risk. The radar plot, principal component analysis (PCA) and hierarchical component analysis (HCA)

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suggested that related sources were responsible for the metallic contamination of the wetland. Hence, there is need to discontinue further reclamation of the area for human habitation due to elevated metallic contamination of the area.

Keywords**:** River Otamiri, wetland, ecological evaluation, metallic elements, contamination

1. INTRODUCTION

According to Moreno-Ramón *et al*. (2015), wetlands make up between 8 and 10 million km^2 or roughly 5–7% of the planet's surface. An area of land that has a near-surface water table or that is submerged in water for the majority of the year is considered a wetland because it can support aquatic ecosystems. Wetlands also referred to as inland valleys, which are typically connected to hydrophytic plants, hydric soils, and various other naturally occurring processes that are suited to the moist environment (Hector *et al*., 2018).

Human civilizations have used wetlands for their own advantage from ancient times, despite society's perception of them as unhygienic places where illnesses and poverty shorten life expectancy (McInnes, 2011). Compared to environmentally sensitive upland areas, wetlands are naturally more resilient to land-use/land-cover stresses, both biologically and climatically (Fenessy and Dresser, 2016; Alvarez *et al*. 2000). The fine-textured soils and abundant biodiversity of wetlands are characteristics of the region (Coralie *et al*. 2015; Sintondji *et al*. 2016; Johnes *et al*. 2020). In addition to offering pure air and water, they have the potential to be extremely fruitful locations for agricultural development (Rebelo et al., 2010; Djagba *et al*., 2018). Their morphology consists of a valley floor and small flood plains that could be underwater almost throughout the year (Russel and Beauchamp, 2017).

According to Raza *et al*., (2015), wetlands are considered as one of the most significant ecosystems on Earth because they offer a distinctive and large habitat for a diverse range of plants and animals. In Imo State, freshwater wetlands such as that of Otamiri River is valued as vital natural resources. Due to the excellent nutrient content of the soils, the wetlands sustain large farming activities year-round and serve as the primary source of water for the Imo State Water and Sewage Cooperation. Because they serve a multitude of ecological, social, and economic purposes, wetlands have the ability to provide a living for the communities in their vicinity (Nabulo *et al*., 2008).

Ecosystems and the sustainability of the environment depend on wetlands. They serve diverse crucial purposes, including regulating storms and floods, stabilizing shorelines, retaining sediment and removing nutrients, purifying water, replenishing groundwater, providing habitat for fishes and other wildlife, and serving as biodiversity reservoirs. Nevertheless, the accessible natural wetlands have drastically decreased due to land expansion, agricultural operations, and hydrologic changes (Das *et al*., 2011). For marine organisms, wetlands are important sources of organic matter and nutrients.

The enhanced water availability, marginally higher soil fertility, and decreased erosion hazards in comparison to uplands make wetlands highly promising for intensive and sustainable land use (Sharip, 2018). In view of these reasons, creating effective water management plans requires an understanding of the hydrology and hydrogeology of an interior valley. Additionally, as noted by Ibe et al., (2016), making ecologically conscious judgments for agricultural and developmental planning requires a thorough grasp of the local hydrology and soil quality of inland basins.

Numerous investigations have been done across the globe on wetlands concerning their nutrient fluxes, water resource availability, contamination and agricultural management (Apan *et al*., 2002; Uhlemann *et al*., 2016; Mander *et al*., 2017; Lloyd *et al*., 2019; Johnes *et al*., 2020).

However, there is still paucity of scientific understanding of wetland resources, hence the need for more studies on issues affecting wetland ecosystems and its management for developmental planning. The major concern of the present study is that some part of the wetland was used as waste dumpsite for so many years and now has been reclaimed with developmental projects ongoing in the reclaimed sections without any form of remediation. Otamiri River is the principal source of water for industrial and domestic uses in the area, as Imo State Water and Sewage Cooperation drown water from this source for domestic supply. Reclamation of some part the wetland has not only exposed the buried waste in the affected area but has also increased the migration of contaminants into the wetlands. Also, the occupants of the commercial and residential buildings in the reclaimed portion of the wetland may be dumping their wastes directly into the river for easy disposal as these wastes are seamlessly washed into the wetland. This practice may play a role in elevating the pollution level of the wetland soils. People residing in this area, especially children may be at the danger of contamination due to increased heavy metal level as the use the playgrounds.

Furthermore, earlier study carried out in the area under investigation by Ibe *et al*., (2021) revealed elevated concentration of contaminants within this wetland environment. However, due to lack of fund the study investigated only few groundwater sources, hence the need to study other components of the environment within the reclaimed sections of this wetland like surface soil.

The aim of the study was to establish the metallic contamination levels in the soil of the reclaimed section of River Otamiri wetland. To achieve this aim ecological evaluation and modeling of the contaminants in the reclaimed wetland soil was carried out to ascertain the magnitude of wetland soil contamination.

2. MATERIALS AND METHODS

2. 1. Study location

Fig. 1 shows the map of study area. The research was undertaken in Owerri, the Imo state capital, located in the Southeastern area of Nigeria. Owerri Municipal is geographically located within longitudes 6° 50′ E - 7° 25′ E and latitudes 4° 23′ N - 7° 15′ N. The demographic of the area was projected at 200,413 in 2010 (NBS, 2011). It is believed that this figure must have increased tremendously after more than a decade. The reclaimed section of River Otamiri wetland is located around Akachi road and Aba Owerri road, Imo State, Nigeria, as presented in Fig. 1. The area was formally used as waste dumpsite for so many years.

The site was later abandoned for over 10 years and reclaimed with some part of the wastes covered with the wetland soils. The study area was opened up for developmental activities after the reclamation of the wetland by Government agents (Fig. 2). Residential and commercial buildings were successively set up in these reclaimed portions. The occupants of the residential and commercial buildings in the reclaimed wetland could be at the danger of contamination by heavy metals through consumption of edible plant cultivated in the area and the children could be exposed to increased pollution load due to the heavy metals in the playground. Hence, the need for ecological evaluation and modeling of contamination levels in soils from the reclaimed section of River Otamiri wetland.

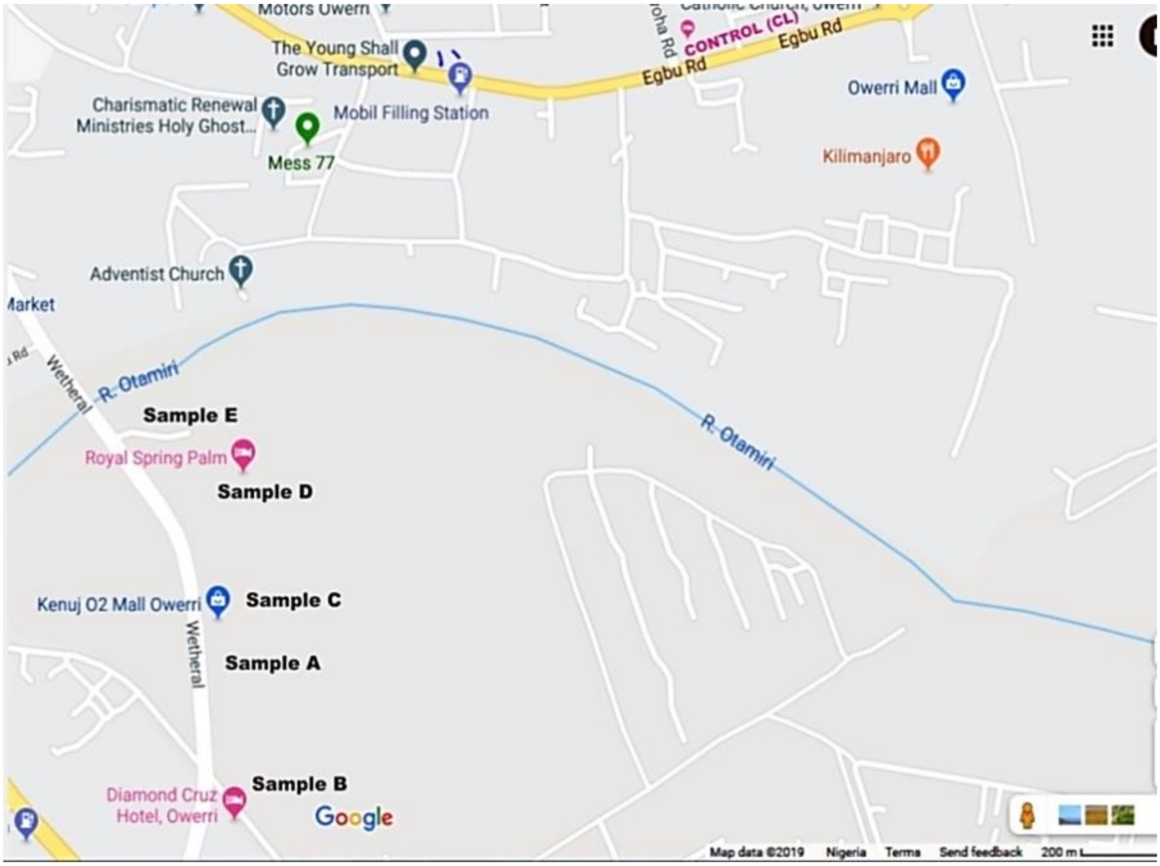


Fig. 1. Google map of study area (Ibe et al., 2021)

Fig. 2. Reclaimed section of River Otamiri (Ibe et al., 2021)

2. 2. Sample collection

In order to carryout ecological evaluation and modelling of contamination levels in soils from the reclaimed section of River Otamiri wetland, soil samples were collected from the reclaimed portions of the wetland in September, 2024. The soil sampling procedure followed random sampling method at every sample point. Uniform soil samples were gathered from each point of sample collection from five representative samples in a "W" outline. Samples were obtained at the depth of 1 – 10 cm with the help of soil auger. The collected soil samples were transferred into black plastic bags and labelled sample A to E as described by earlier reports (Onyechere *et al*., 2022)

2. 3. Sample preparation and analysis

Irrelevant constituents of the soil samples were removed and the sample was dried in an oven at 105 °C for two hours with Drying Oven, DHG – 9023A by B. Brans Scientific Instrument Company, England. The samples were then pulverized with mortar and pestle, sieved using a nylon sieve having a diameter of 0.45 mm. Metal content of the soil sample was established by X-Ray fluorescence spectrometry using Skyray Energy Dispersive (EDXRF) EDX3600B, China according earlier reports (Ibe *et al*., 2020).

2. 4. Statistical and data analysis

Statistical evaluation of the data using Micro Soft Excel 2020 was used in the determination of the Contamination factors (Cf), pollution load index (PLI), Geo-accumulation index (Igeo), and Potential ecological risk (RI). Minitab and statkigdom were utilized for principal component analysis (PCA) and hierarchical component analysis (HCA) to establish the source and similarity in the occurrence of the metallic contaminants.

2. 5. Contamination factor and pollution modeling

Contamination factors (C_F) and pollution load index (PLI) were decided using the expressions in Eq. (1) and (2). Estimation of the contamination factor was achieved by division of concentration of heavy metal in the soil with their reference values. The reference values for soil were obtained from the Department of Petroleum Resources (DPR, 2002). The reference values for the soil samples are presented in Table 1.

$$\mathrm{C_F} = \frac{C_M}{C_{DPR}} \tag{1}$$

$$PLI = (\mathrm{C_{F_1}} x\, \mathrm{C_{F_2}} x\, \mathrm{C_{F_3}} \dots \dots . \mathrm{C}_{F_x})^{1/x} \tag{2}$$

where C_F = contamination factor, C_M = concentration of the metal in soil, C_{DPR} = Department of petroleum resources reference values and x = number of analyzed metals used for the computation. The values obtained from contamination factor calculation was categorized according to $C_F < 1$ indicating low contamination, C_F of $1 \leq 3$ suggests moderate contamination, C_F value of $> 3 \leq 6$ is an indication of considerable contamination, while C_F value > 6 means very high contamination. Also, for pollution load index PLI value less than one (< 1) indicates no pollution, while PLI > 1 is suggestive of polluted environment.

2. 6. Geo-accumulation index (Igeo)

Igeo was computed according to Eq. (3). The value, 1.5 in Eq. 3 is the matrix correction factor which accounts for any variation that may arise due to lithogenic influence, c_M is the mean value of the metals determined in the samples, while C_{ref} is the concentration of the element used as reference in the study.

$$\mathrm{Igeo} = \log_2\left(\frac{c_M}{1.5C_{ref}}\right) \tag{3}$$

The world average value in shale was taken as the reference concentration used in this study. The value of world average in shale used in this study are as follows: 47200, 92, 20, 19, 45, 90, 68, 850, 13, 50, and 0.3 mg/k for Fe, Zn, Pb, Co, Cu, Ni, Mn, As, Ag, and Cd respectively (Edori and Kpee, 2017). The value of *Igeo* is classified into seven groups from 0 to 6 for uncontaminated to very heavily contaminated soil (Onyechere et al. 2021).

2. 7. Potential ecological risk index (RI)

RI was determined as presented in Eq. (4) and (5). RI of the heavy metals can be established as indicated below (Eq. 4 - 6).

$$RI = \sum E_r \tag{4}$$

$$E_r = C_F\, x\, T_i \tag{5}$$

where E_r is an indication of the monomial ecological risk due to the metals, C_F is the contamination factor. T_i represents the toxic response factor due to the investigated heavy metals. T_i provides facts about the possible transport of poisonous elements in the ecosystem. T_i for the heavy metals in the soil are Cr = (2), As = 10, Co = Pb = Cu = 5, Ni =6, Cd = 30, Zn = 1, the heavy metals; Fe and Ag whose values were not found were not part of the calculation.

The E_r posed by analyzed metals were classified as $E_r < 40$ for low risk, 40 – 79 for moderate risk, 80 -159 indicating considerable risk, 160 – 319 is an indication of high risk, and Er > 320 indicates very high risk. Similarly, RI < 150 stands for low risk, 150 – 299 indicates moderate risk, 300–599 is an indication of considerable risk, and RI > 600 indicates very high risk (Onyechere et al. 2020).

3. RESULT PRESENTATION AND DISCUSSION

3. 1. Metallic contamination level

The result of metallic contamination levels, within the reclaimed River Otamiri wetland is presented in Table 1, Fig. 3 and 4. The result in Table 1 revealed that a total of eleven metallic elements were recorded in the reclaimed wetland. Concentration of the metals varied from 6.80 – 38.60, 80.50 – 181.00, 363.10 – 523.10, 31938.10 – 45741.10, 439.10 – 698.00, 296.70 – 414.00, 152.00- 850.10, 0.34 – 0.90, 10.20 – 128.00, 0.20 – 2.80, and 0.18 – 0.56 mg/kg respectively for Cr, Mn, Co, Fe, Ni, Cu, Zn, As, Pb, Ag, and Cd. It was observed that the mean values of the metals are in the order; 0.29 < 0.59 < 0.88 < 16.74 < 50.44 < 129.48 < 259.34 < 341.22 < 518.70 < 563.14 < 39888.63 mg/kg for Cd <As < Ag < Cr < Pb < Mn < Zn < Cu <

Co < Ni < Fe respectively. It was further observed that Zn has the highest % CV of 1260.21, while the % CV of Cr has the lowest value of 5.79. In comparison with the DPR value, Cr, Mn, As, Pb, and Cd had mean values below the DPR standard; however, the mean values of Co, Fe, Ni, Cu, Zn, and Ag were above the DPR standard. This is an indication that the presence of these metals could constitute ecological problems. Fig. 3 shows the surface plot of concentration of the metals indicating the metal with highest value and the sample site. In this study, the surface plot revealed that Fe had the highest concentration in sample A, C, and E. It was noted that Fe showed elevated intensity when measured up with other elements. This was seen in its increased concentration in comparison with other element, and these values were a little above the DPR standard (Table 1) in sample A, C and E.

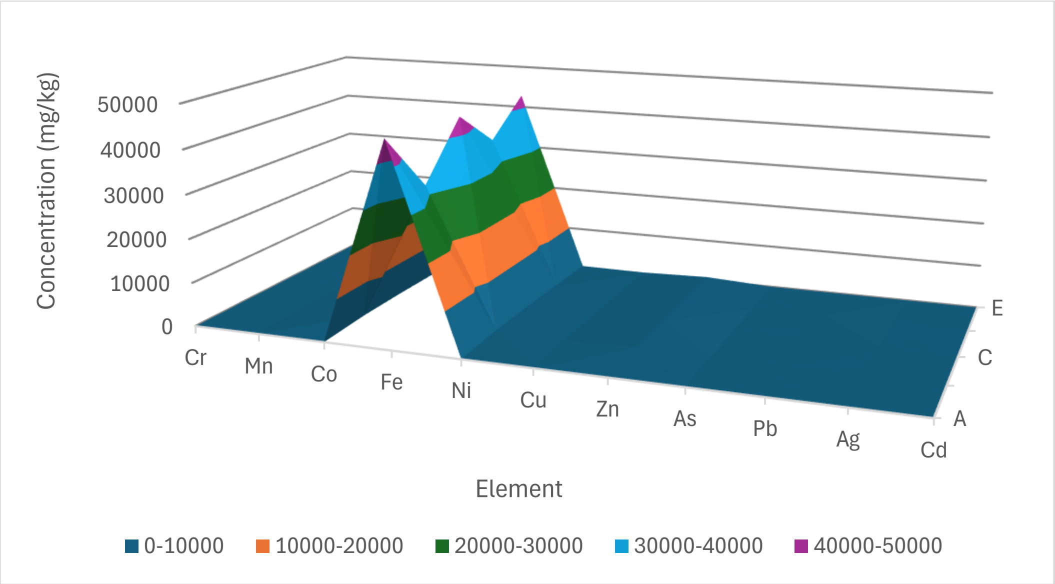


Fig. 3. Surface plot of the metals

Table 1. Concentration of metallic contaminants in the soil and their descriptive statistics.

Element (mg/kg)	A	B	C	D	E	MEAN	SDV	%CV	DPR (2002)
Cr	6.80	26.00	7.71	4.60	38.60	16.74	14.93	5.97	100.00
Mn	181.00	171.60	80.50	104.00	110.30	129.48	44.28	34.20	850.00
Co	454.00	515.30	523.10	363.10	738.01	518.70	138.32	26.67	20.00
Fe	45741.00	31938.10	43906.03	35049.00	42809.00	39888.63	6032.23	15.12	38,000.00
Ni	647.00	587.40	698.00	624.200	439.10	563.14	108.55	19.28	35.00
Cu	414.00	296.70	342.00	308.00	345.40	341.22	45.83	13.43	36.00
Zn	152.00	703.30	850.10	705.10	786.20	259.34	3268.23	1260.21	140.00

As	0.72	0.47	0.54	0.34	0.90	0.59	0.22	37.28	1.00
Pb	65.00	19.20	29.80	128.00	10.20	50.44	48.09	95.34	85.00
Ag	0.50	0.30	0.20	0.62	2.80	0.88	1.08	122.72	0.80
Cd	0.18	0.24	0.21	0.56	0.26	0.29	0.15	51.72	1.00

where: SDV = standard deviation, % CV = % coefficient of variation, DPR = Department of Petroleum Resources

3. 2. Contamination and Pollution indices

Table 2 and Fig. 4 are the results of C_F and PLI analysis of the metals. The result revealed that the contamination factor levels of the metals are in the order; Co>Ni>Cu>Zn >Ag >Fe >Pb > As > Cd > Cr > Mn, indicating that Co had the highest contamination factor, while the least contamination factor was shown by Mn. Also, the PLI analysis showed the order; E > D > B > A > C, which is an indication that sample E had the highest PLI while C had the least value. However, PLI > 1 was recorded for all the samples, which is a serious ecological concern for the reclaimed wetland as it implies that the area is polluted. This result is not unexpected especially as the area was an abandoned waste dump site for more than 10 years before it was reclaimed. So, the high pollution load of the area may be associated with paste activities like dumping of municipal, household, as well as industrial wastes before the area was reclaimed for developmental purposes as reported in earlier publication (Ibe *et al*., 2021).

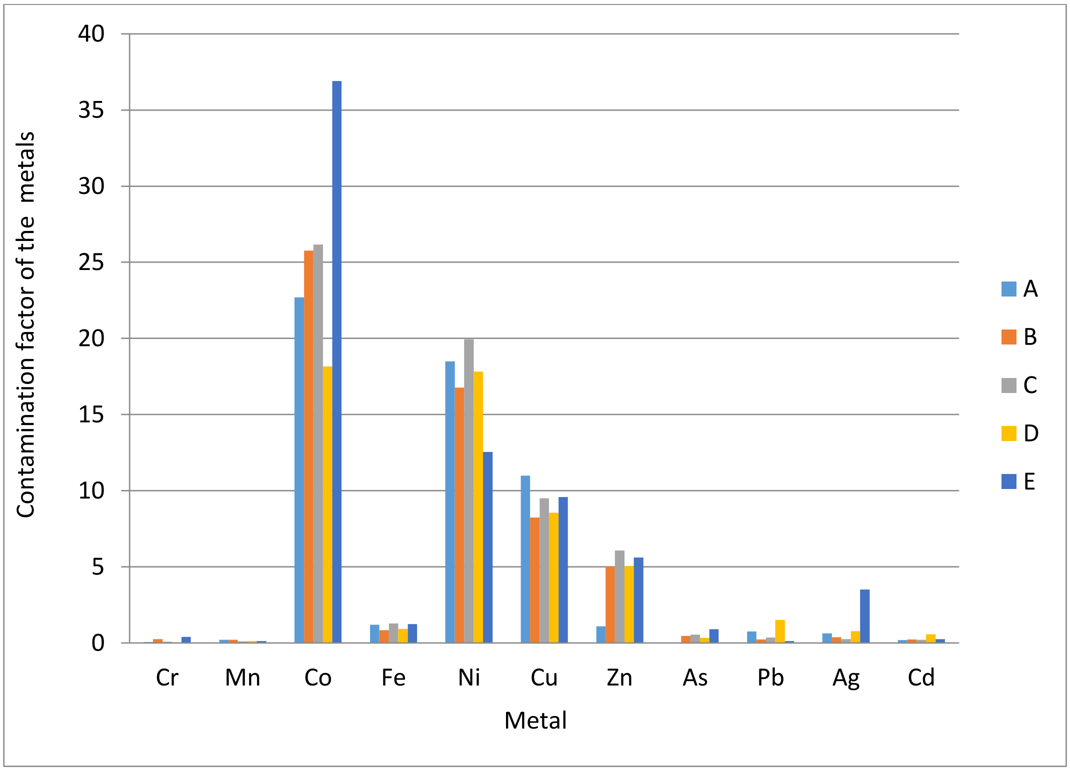


Fig. 4. Contamination factor of the analyzed metals

Table 2. Result of C_F and **PLI** of the analyzed metals.

Samples	**Contamination factor of the metals**											**PLI**
	Cr	Mn	Co	Fe	Ni	Cu	Zn	As	Pb	Ag	Cd	
A	0.068	0.21	22.70	1.20	18.49	11.00	1.09	0.72	0.76	0.63	0.18	**1.17**
B	0.26	0.20	25.76	0.84	16.78	8.24	5.02	0.47	0.23	0.38	0.24	**1.20**
C	0.08	0.10	26.16	1.29	19.94	9.50	6.07	0.54	0.35	0.25	0.21	**1.11**
D	0.05	0.12	18.16	0.92	17.82	8.56	5.04	0.34	1.51	0.78	0.56	**1.30**
E	0.39	0.13	36.90	1.23	12.55	9.59	5.62	0.90	0.12	3.50	0.26	**1.58**

3. 3. The geo-accumulation index of the analyzed metals

The result of geo-accumulation index of the analyzed metallic contaminants is presented in Table 3. The result suggested that the soil samples have no accumulation or not polluted by Cr, Mn, Fe, As, and Ag, except for Pb in sample A and D as well as Cd in sample D. However, the levels of Co, Ni, Cu, and Zn revealed that the area has moderate accumulation or polluted by these metals. A related study in Makurdi and Gboko located in central part of Nigeria reported low and strong pollution of the studied area (Aloysius *et al*., 2013). Therefore, this suggested that the reclaimed wetland is polluted by some of the examined metals which could be associated with past anthropogenic activities in the investigated area prior to reclamation. In terms of geo-accumulation, Co was noticed to be more accumulated in the studied sites more than any other metal. This could be linked to the numerous activities such as dumping of all kinds of municipal waste prior to reclamation of the study site which may have introduced these elements in the investigated site.

Table 3. The geo-accumulation index of the contaminants.

Samples	Cr	Mn	Co	Cu	Fe	Ni	As	Ag	Zn	Pb	Cd
A	-1.30	-0.85	1.20	0.78	-0.19	0.80	-1.43	-2.18	0.03	0.34	-0.40
B	-0.72	-0.88	1.26	0.64	-0.35	0.76	-1.62	-2.40	0.69	-0.19	-0.27
C	-1.24	-1.12	1.28	0.71	-0.21	0.84	-1.56	-2.55	0.78	-2.90	-0.33
D	-.1.47	-2.09	1.11	0.66	-0.31	0.79	-1.76	-2.08	0.69	0.63	0.09
E	-0.54	-1.06	1.41	0.71	-0.22	0.63	-1.34	-1.43	0.74	-0.47	-0.24

3. 4. The ecological risk index

The monomial ecological risk Er and the potential ecological risk index RI of the metals analyzed in the samples are presented in Table 4. The result indicated that the danger posed by the metals ranged from low risk to considerable risk. It was observed that As, Cd, Cr, Pb, and Zn posed low monomial ecological risk, while Ni and Cu posed moderate E_r. However, Co in sample E posed considerable E_r. Similarly, risk ranging from low to moderate was observed for the metals for RI evaluation. As stated in Table 4, Co presented a very high risk in the studied area, while Ni posed considerable risk for the inhabitants of the investigated site. The present study reported values similar to that of an earlier study in Suleja, Nigeria that recorded moderate to low potential ecological risk (Yisa *et al*., 2012)

Table 4. The ecological risk index of the metals

Sample	**E_r**							
	Cr	Co	Ni	Cu	Zn	As	Pb	Cd
A	0.01	113.50	110.94	55.00	1.09	7.20	3.80	5.40
B	0.52	128.75	100.68	41.20	5.02	4.70	1.15	7.20
C	0.16	130.80	119.64	47.50	6.07	5.40	1.75	6.30
D	0.10	90.80	106.92	42.80	5.04	3.40	7.55	16.80
E	1.70	184.50	75.30	47.95	5.62	9.00	0.60	7.80
RI	**2.49**	**647.55**	**513.48**	**234.45**	**22.84**	**29.70**	**14.85**	**43.48**

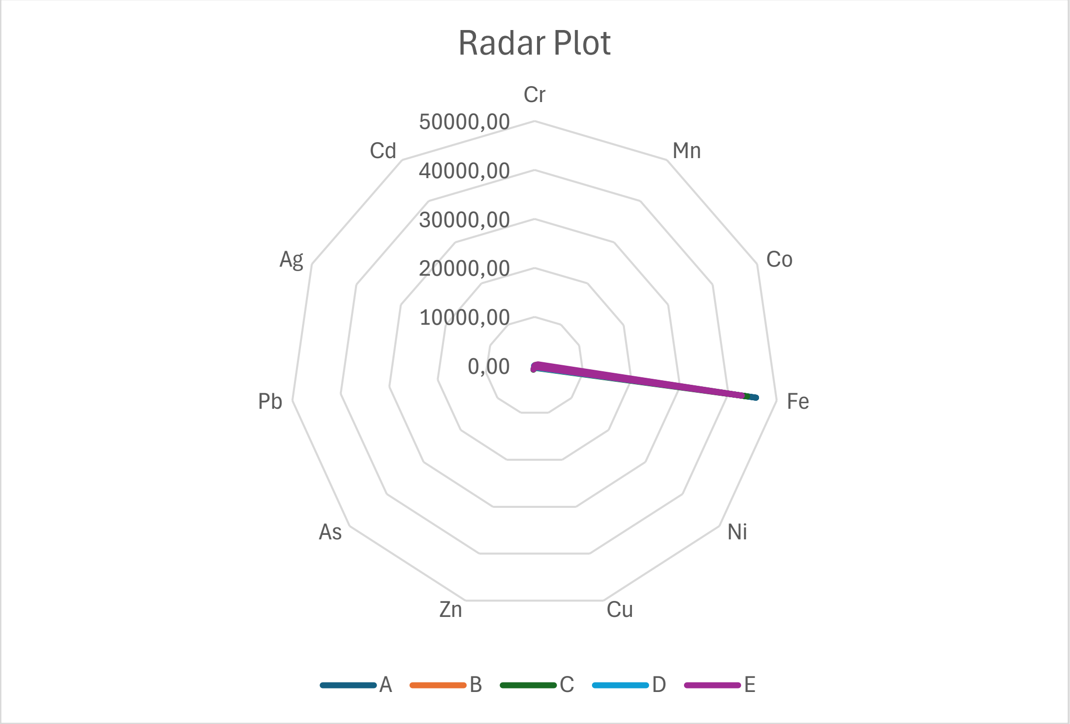


Fig. 5. Radar plot of the analyzed contaminants

3. 5. Radar plot of the analyzed metallic elements

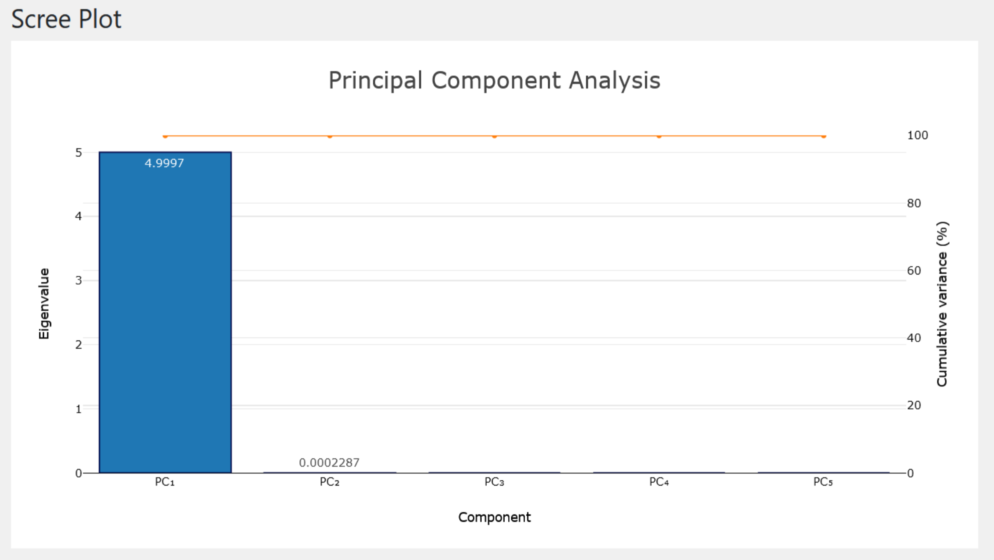
The radar plot of the investigated parameters in the soil samples is shown in Fig. 5. The heptagonal shape is a representation of the individual observation in terms of occurrence of the parameters that were analyzed. The radar plot suggested that a strong relationship exist in the occurrence of Fe in sample C and E. This observation is supported by the coloured portion of the radar plot pointing towards Fe as shown in Fig. 5.

3. 6. Principal Component Analysis (PCA)

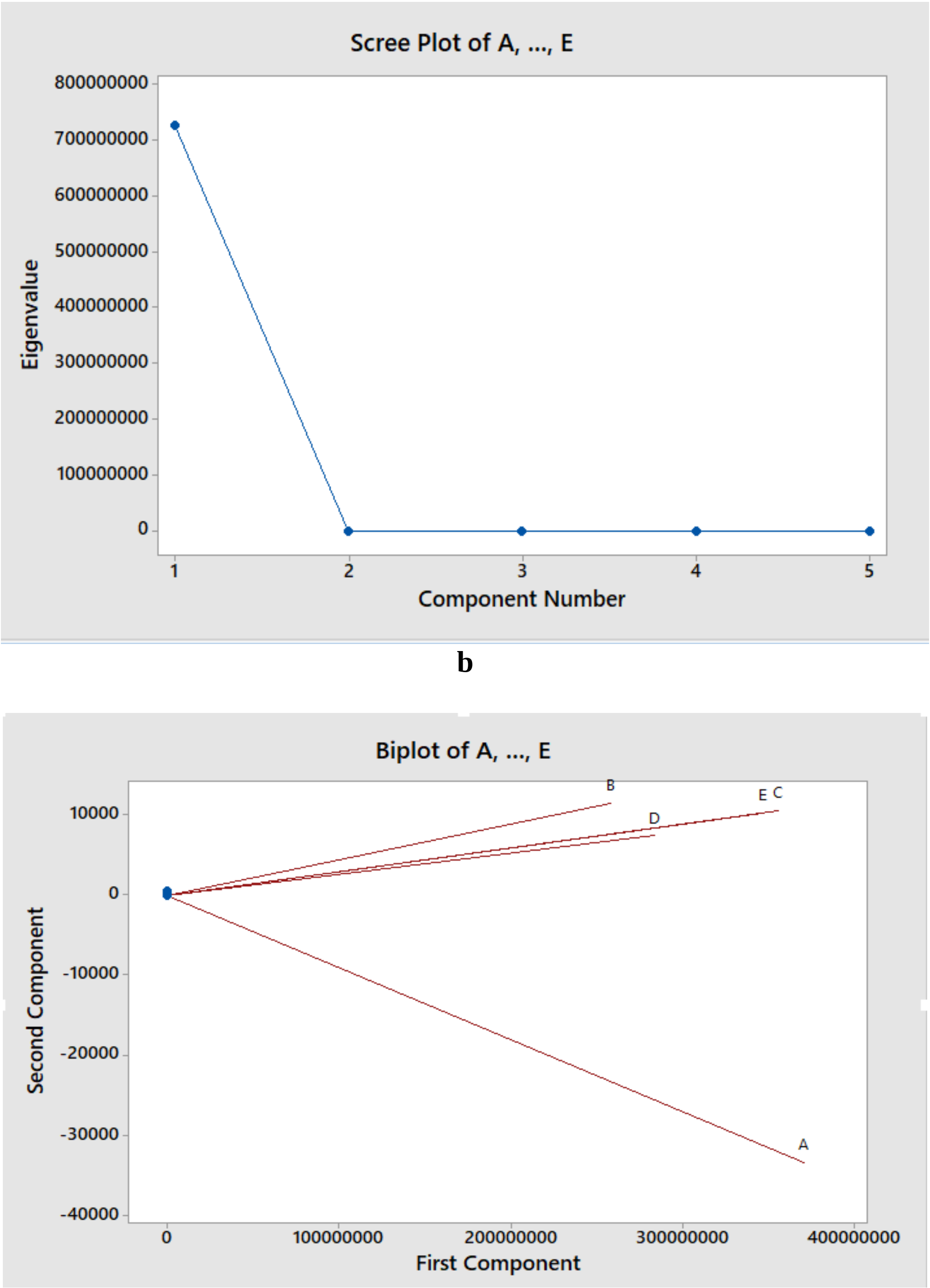
PCA was carried out in this study to establish the variation of the metals at different sample points. The result of PCA is presented in Table 5 and Fig.6 a, b and c. Table 5 shows the eigenvalues, % of variance and cumulative (%). The result suggested that there is only one component with eigenvalue greater than one (>1). This component accounts for the 99.9937 % of the variance. Fig.8a and b are the scree plots of PCA which revealed that the measured parameters with highest values were found in PC1. However, Fig. 8c which is the biplot of the PCA suggested that sample B, C, D, and E are more related in terms of the occurrence of the measured metallic components, which is an indication that these samples sites must have been affected by similar anthropogenic influence.

Table 5. Eigenvalues of the components.

Parameter	PC_1	PC_2	PC_3	PC_4	PC_5
Eigenvalue	4.9997	0.0002287	0.00006896	1.645E-05	0.00000257
% of Variance	99.9937	0.004573	0.001379	0.000329	0.00005141
Cumulative (%)	99.9937	99.9982	99.9996	99.9999	100



a



b

c

Fig. 6. (**a,b**) Scree plots of the eigenvalues, components, cumulative (%) and (**c**) biplot of the PCA

3. 7. Hierarchical Component Analysis (HCA)

This analysis was carried to ascertain if there is relationship in the factors that affect the levels of the analyzed metals in the samples. The HCA result is shown in Fig. 7 and Table 6.

Fig. 7 is the HCA dendrogram showing the complete linkage and correlation coefficient distance of the samples. Table 6 is the cluster observation of the samples indicating steps, number of clusters, similarity level, distance level, clusters that are joined, and others as presented in the table.

The result of HCA dendrogram (Fig. 7) suggested that there are four clusters in step one with a similarity level 100.000 as presented in Table 6. This implies that the sample sites are affected by similar factors. This is in agreement with the observed result in PCA which discovered that majority of the sample sites were grouped in one component (PC1). This is a further indication that the study area was actually impacted by related activities like wastes materials that were dumped in the area before the wetland was reclaimed.

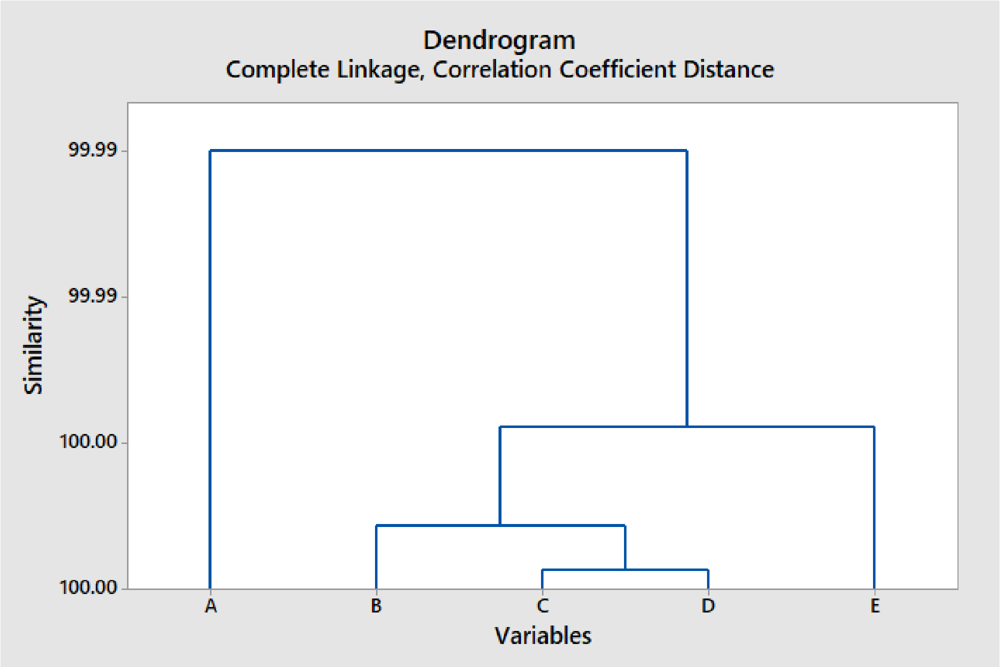


Fig. 7. Dendogram of sample sites of the analyzed metals

Table 6. Cluster observation of the samples.

Step	No of clusters	Similarity level	Distance level	Clusters joined	New clusters	No of Observations in cluster
1	4	100.000	78 e^{-7}	3 and 4	3	2
2	3	99.999	254 e^{-7}	2 and 3	2	3
3	2	99.997	649 e^{-7}	2 and 5	2	4
4	1	99.991	1761 e^{-7}	1 and 2	1	5

4. CONCLUSION

The study observed elevated levels of metallic contamination due to increased concentration of most of the analyzed parameters above DPR values. It was noticed that some parameters like Zn, Cu, Ni, Fe, and Co were above DPR value in some sample sites, suggesting that the area was negatively influenced by abandoned waste materials dumped in the area. Contamination factor analysis revealed high contamination values. Also PLI result revealed that the values were all above unity (>1), indicating that the area was polluted by the investigated metals. Geo-accumulation index analysis indicated that the samples have low geo-accumulation of Pb in sample A and D as well as Cd in sample D. However, higher geo-accumulation index was observed for Co in all the sample sites. This is suggestive of the fact the area is polluted by these metal. The result of ecological risk suggested that the risk posed by the metals ranged from low risk to considerable risk. It was observed that As, Cr, Zn, Pb, and Cd posed low E_r, while Ni and Cu posed moderate E_r. However, Co in sample E posed considerable E_r. Similarly, low to moderate risk was noted for the metals for RI analysis.

The radar plot suggested a strong relationship in the occurrence of Fe in sample C and E, which is an indication of the fact that the sample sites must have been impacted by related human activities in the area. The result of PCA suggested that there is only one component with eigenvalues greater than one (>1). This component is responsible for the 99.9937 % of the variance. Also, the biplot of the PCA indicated that sample B, C, D, and E were more related in terms of the occurrence of the measured metallic components, which is indicative of the fact that these samples sites must have been impacted by similar anthropogenic influence. Finally, the HCA revealed that both the samples and measured parameters formed one major cluster.

The result of HCA is in line with PCA which also revealed one major component, which is suggestive of the fact that metallic contamination of the study area was due to similar source of pollution. The study therefore recommends that due to elevated metallic contamination of the wetland there is need to discontinue further reclamation of the area for human habitation.

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