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Physicochemical Analysis and Pollution Indices for Heavy Metal Assessment in Flooded and Non-flooded Soils of Obunagha, Bayelsa State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil samples from flood affected areas and non-affected areas of different farmlands in Obunagha, Bayelsa State, Nigeria; were collected for this study. The study was conducted to evaluate the physicochemical properties, and pollution indices of flooded and non-flooded farmlands to see if the flood had any effect in the fertility state of these soils. Atomic absorption spectroscopy (AAS) was used to identify and quantify the several heavy metals (Cd, Cr, Ni, and Zn) that were discovered in the collected soil samples. The findings indicated increased acidity since the pH of the soil varied between 4.8 and 5.7 in farmlands that were flooded and between 4.9 and 5.7 in farmlands that were not. In flooded areas, electrical conductivity ranged from 0.2x101 to 4x101 µS/cm, while in non-flooded areas, it was between 0.2x101 and 2x101 µS/cm. The cation exchange capacity in flooded farmlands was 0.16 to 0.24 meq/100 g, while in non-flooded farmlands it was 0.18 to 0.22 meq/100 g. Variations in metal contamination were found in different farming situations based on the contamination factor (CF) analysis. Chromium CF values ranged from 0.3 to 0.8 in both flooded and non-flooded farmlands, with certain non-flooded farmlands having slightly higher values. Cadmium contamination in flooded farmlands was much higher (25.5 to 43.7 CF) than in non-flooded farmlands (20.0 to 32.0 CF). Nickel contamination levels were from 0.7 to 1.1 in flooded farmlands and 0.5 to 0.8 in non-flooded farmlands, suggesting moderate pollution. Zinc contamination was consistently low throughout all circumstances, with CF values ranging from 0.2 to 0.4. According to the contamination factor average, Cd was followed by Ni, Cr, and Zn in decreasing order. The ecological pollution degree for the study area was low indicating no possible pollution by all the heavy metals. In conclusion, the study area is significantly contaminated with cadmium. Therefore, we urgently recommend monitoring the soil in the surrounding farmlands, particularly for cadmium, to prevent a potential environmental crisis.

Keywords: Flooding; physicochemical properties; contamination factor; heavy metals.

1. INTRODUCTION

Heavy metals are natural components of the earth crust and as a result they are found naturally in soils and rocks with a subsequent range of natural concentration in soils, sediments, waters and organisms [1]. Human activities, including industrial, agricultural, traffic, domestic, mining, and other anthropogenic processes, have contributed to elevated and toxic levels of heavy metals, surpassing those from geogenic or lithological sources [2].

Flooding is one of the most critical sources through which heavy metals are deposited in the soil. Flood water has the capacity of transporting materials from one point to another [3-6]. The flood transported materials mainly sediments into the low lands where the water becomes relatively stagnant [3]. Floods can transport heavy metals attached to soil particles, originating from sources such as soil erosion, rock weathering, and the dissolution of water-soluble salts [7].

Soil is a major sink of heavy metals from the atmosphere, hydrosphere and biota; the presence of heavy metals in soil poses potential threats to the environment and can also affect human health through absorption pathways like direct ingestion, dermal contact, diet through the soil-food chain, inhalation and oral intake [8]. As noted in Song et al. [9], most individuals become exposed to toxic elements mainly via dietary sources. High concentrations of heavy metals in the food chain may accumulate in the human body and can lead to serious health disorders when ingested beyond the permissible limit [10]. Children are more susceptible to heavy metal accumulation from the food chain than adults because they consume more food for their body development. These heavy metals can lead to impaired growth, brain damage, organ and nervous system damage, and even death.

Pollution index is a powerful tool for processing, analyzing, and conveying raw environmental to decision makers, managers, technicians, and the public [11]. According to Onwudike et al. [12], contamination/pollution index is a method of comparing the concentration of soil heavy metals with an international standard to determine the degree of pollution or contamination of a given location and the effect of the concentration on soil plant and environment.

The application of pollution indices is considered the most comprehensive method for evaluating soil pollution. The most widely used indices include the Enrichment Factor (EF), Index of Geoaccumulation (Igeo), Contamination Factor (CF), Ecological Risk Factor (Er), Degree of

Contamination (Cd), Pollution Load Index (PLI), and Potential Ecological Risk Index (PERI). Pollution indices assist in the evaluation of environmental risk and soil degradation, the prediction of future ecosystem sustainability as well as provide the opportunity to increase environmental awareness in society [13].

The aim of this study is to evaluate the quantification of heavy metals using contamination and pollution index and also to know the physicochemical properties in some flooded and non-flooded farmlands in Obunagha, Bayelsa State, Nigeria. It is expected that the findings from this study will pave the way for enhancing public consciousness on the pollution level of the soil in the study area.

2. METHODOLOGY

2.1 Description of Study Area

The geographical location is latitudes $4^0 59^1$N and $5^0 28^1$ N and Longitudes $6^0 15^1$E and $6^0 21^1$E. The area experiences average farming and commercial activities. The community also experiences adverse flooding during raining seasons. Obunagha experience flooding due to the overflow of river Nun and adjoining Taylor's creek.

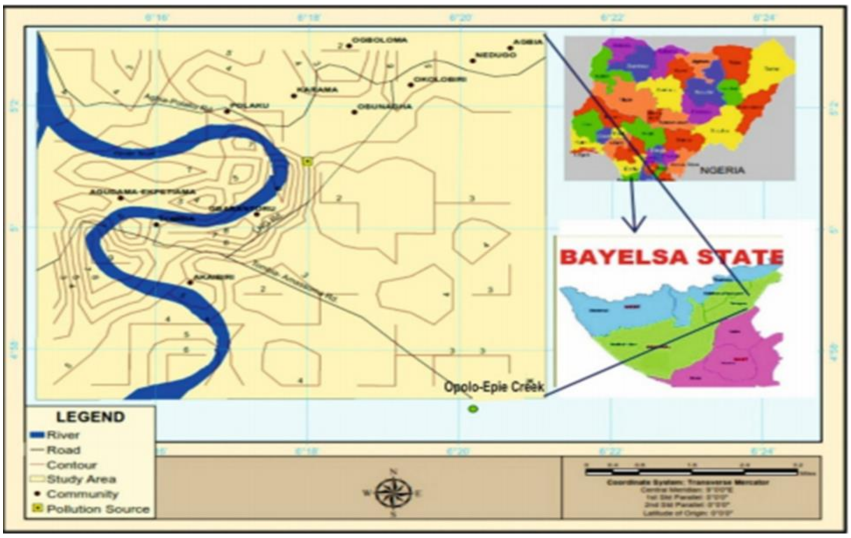
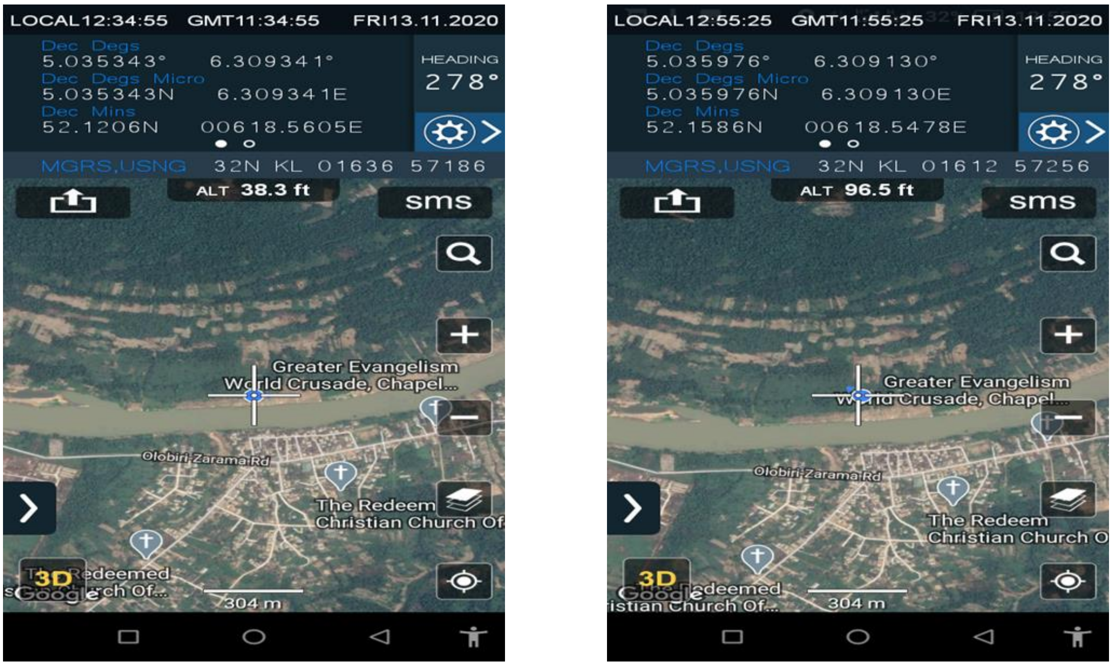


Fig. 1. Location map of the study area



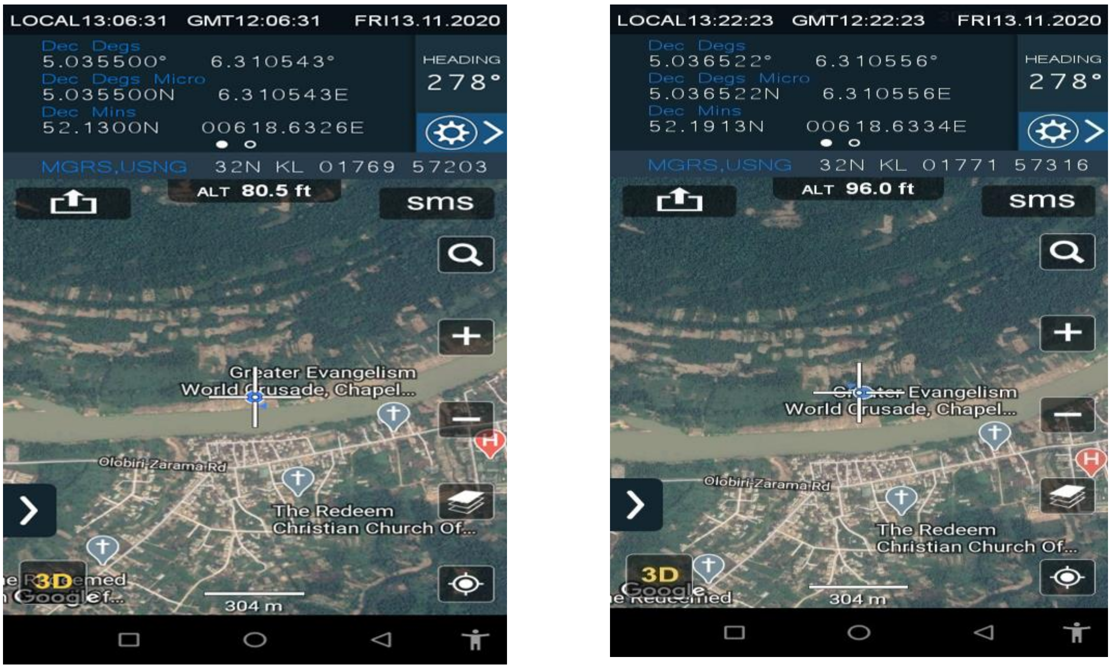


Fig. 2. Shows the GPS positions of the sampling sites

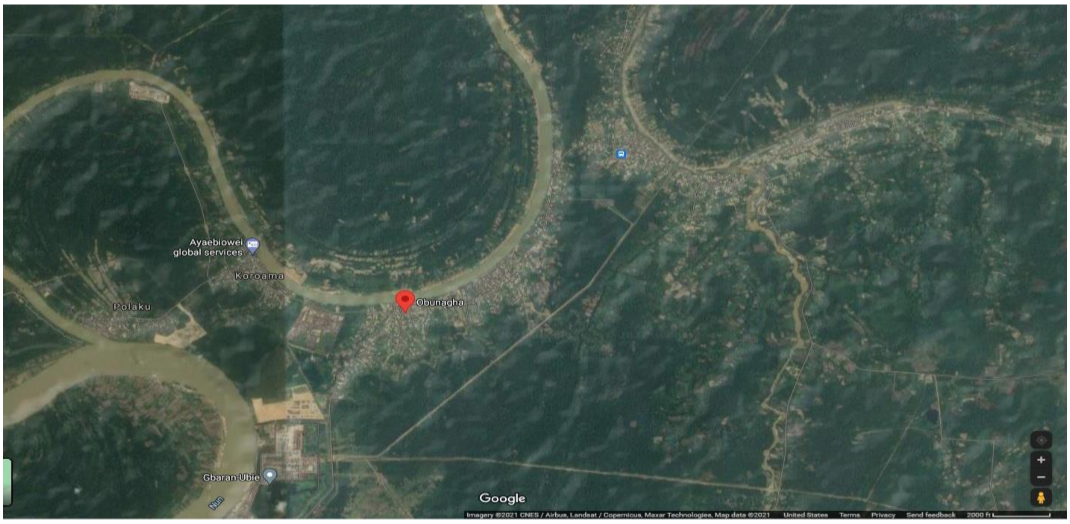


Fig. 3. Google Satellite imagery showing Obunagha 2021

2.2 Collection of Sample

Samples were collected using soil auger from different farm lands at different depths in Obunagha, Yenagoa Local Government Area of Bayelsa State, Nigeria and labelled accordingly.

Farm 1

FMIA - 2mm deep (flooded Area)
FMIB - 150mm deep (Flooded Area)
FMIC - 2mm deep (Non-flooded Area)
FMID - 150mm deep (Non-Flooded Area)

Another farmland labeled Farm 2

FM2A - 2mm deep (Flooded Area)
FM2B - 150mm deep (Flooded Area)
FM2C - 2mm deep (Non-Flooded Area)
FM2D - 150mm deep (Non-Flooded Area)

2.3 Preparation of Sample

The samples were air dried for seven (7) days, crushed using a ceramic mortar and pestle, sieved using a 2mm plastic sieve. The finely sieved samples were stored and well labeled in plastic containers for laboratory use.

2.4 Chemical Analysis

2.4.1 pH determination

10g of finely sieved soil samples were measured and placed in eight pre-washed 100 mL well labeled beakers and 20 mL of distilled water added into each beaker. The suspensions were stirred at regular internal for 30mins. Then the pH was determined by immersing the electrodes of the pH meter in the suspension and recorded appropriately.

2.4.2 Determination of electrical conductivity

10g of finely sieved soil samples were measured and placed in eight prewashed 100 mL Beakers and 20 mL of distilled water were added into each beaker. These were stirred intermittently for about 30min. The electrical conductivity of the supernatant liquids was determined using the electrical conductivity meter and the readings taken appropriately.

2.4.3 Determination of cation exchange capacity

2g of the finely sieved soil samples (FMIA, FMIB, FMIC, FMID, FM2A, FM2B, FM2C, FM2D) were measured using analytical weighing balance into a funnel containing medium filter paper which were placed in a pre-washed conical flask (125 mL). The samples were leached with 20 mL of the 0.1M $BaCl_2.2H_2O$ slowly and allowing it to soak into the soil samples before adding another quantity of 0.1m $BaCl_2.2H_2O$.

Furthermore, the soil samples were leached with 600 mL of 2mm $Bacl_2.2H_2O$, applied in six separate 10 mL portions, with each portion allowed to soak into the soil before adding more. Then the last 10 mL leachates were saved for pH determination. After the pH readings were taken, the filter paper plus the soil samples on the paper were carefully transferred to a pre-weighed 125 mL conical flask and 10.0 mL of 5mM $MgSO_4$ were added into each filter paper containing the soil samples.

After 1 hour of occasionally swirling, the flasks were weighed for the final solution weight. Conductivity of the 1.5mm $MgSo_4$ solution which should be 300NS or Nmhos. The conductivity of the sample solutions was determined, and it should be 1.5x the value of the conductivity of the 1.5mM MgSO4, when they were not up to that 001mL increment of 001 MgSO4 were added in the sample solution until the needed values were recorded, while keeping the tracks of the quality of added 0.1M MgSO4.

The sample solutions pH was determined and recorded. The values were compared with the previous PH values recorded which should be in a limit of 0.1 units but when some were not, 0.05M H_2SO_4 were added drop wise until pH ranges were obtained.

Distilled water was added in the mixture until the conductivity is equal with that of 1.5mM $MgSO_4$. The end points were reached by adjusting the pH and the conductivity alternatively. The pre-weighed flasks containing the sample solutions were dried and weighed using analytical weighing balance.

2.5 Assessment of Metal Contamination

2.5.1 Contamination factor (CF)

The contamination factor is an expression of the level of metal contamination in the surface sediment. It is the quotient attained by division of the concentration of each metal in the soil by the reference value [14,15]. It is given by the formula:

$$\mathrm{CF} = \frac{C_{metal}}{C_{background}} \tag{1}$$

Where C_{metal} is the concentration of a given metal in the sediment and $C_{background}$ is the metal concentration of a control sample.

2.5.2 Heavy metal potential ecological risk coefficient and potential ecological index

Potential ecological risk index method advanced by Swedish Scholar Hakanson, according to the characteristic of heavy metal and its environment behavior, is an approach to evaluate the heavy metal contamination from the perspective of sedimentology.

It does not only consider heavy metal level in the soil, but also associates ecological and environmental effects with toxicology, and evaluates pollution using comparable and equivalent property index grading method. The potential ecological risk related to individual pollution coefficient, heavy metal toxicity response coefficient, and its formula is as follows:

$$RI = \sum E_r^i = T_r^i \; X \; C_f^i \tag{2}$$

$$C_f^i = \frac{C_{surface}^i}{C_n^i} \tag{3}$$

Where E_r^i is potential ecological risk individual coefficient, T_r^i is toxicity response coefficient of a certain kind of metal toxicity using standard heavy metal toxicity coefficient developed by Hakanson [14] as reference, in accordance with the normalized toxic response factor of 30, 5, 5, 5, 2 and 1 respectively for Cd, Cu, Pb, Ni, Cr, and Zn.

C_f^i is the accumulating coefficient of element *i* and RI is the potential ecological risk index.

3. RESULTS AND DISCUSSION

3.1 Soil Physicochemical Analysis

3.1.1 pH

According to Olorunfemi et al. [16], soil pH determines soil life and availability of essential soil nutrients for plant growth. As noted in Osakwe [17], pH values between pH 2 - 6 greatly favour the availability and mobility of trace heavy metals. In the current study, pH of soils samples from flooded (the most acidic) and non-flooded farmlands falls within this range which will, thus, favour the availability and mobility of trace heavy metals [10]. In line with Soil Survey Staff [18], the challenge of nutrient deficiencies may arise when soil pH is > 7.8.

The pH values for the soil samples ranged from 4.8 to 6 (Table 1). The results indicated that the soils pH was acidic, which is consistent with the studies of Yang *et al.,* [19]. The lower pH in soils could be attributed to intensive farming practices and low leaching rate of the contaminants. The pH of soil samples from the different farmlands falls within the range required for full utilization of soil nutrients [10]. Also, the acidic pH values shows that the metals under study are mobile as stated by Kumar and Srikantaswamy, [20] that the lower the pH values, the more mobile the metals will be in solution.

3.1.2 Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of ionic concentration in the soils and is therefore related to dissolve solutes such as ions and salts. Soil salinity is generally measured by the electrical conductivity (EC) of a soil extract [21]. Electrical conductivity (EC) values for flooded soil ranged from $0.2x10^1$ to $4x10^1$ µS/cm, while non-flooded cropland had values of $0.2x10^1$ to $2x10^1$ µS/cm and 122.8 µS/cm, respectively. The electrical conductivity of the study region for both the non-flooded and flooded areas of both farms was poor. This implies that the fertility of the study area is low, since it measures the number of salts in the soil (Salinity), thus indicating less microbial activities in the soil. The flooded location A (4×10^1) has the highest EC, whereas the non-flooded areas (C and D) have lower EC values of 0.5 and 0.2 (×101), respectively (Table 1). This suggests that flooding may cause an increase in soil salinity; this may be because salts from floodwaters deposit themselves on the soil.

3.1.3 Cation exchange capacity (C.E.C)

Cation exchange capacity is a measure of its ability to hold, release and exchange positively charged nutrients (cations). It is also a measure of how many negatively charged sites are available in the soil. The cation exchange capacity (C.E.C), its mean value was observed to reduce by 0.04 compared to the control since C.E.C of a soil depicts the capacity of the soil to hold and release required cations; therefore, there was a reduction in cation capture and release for the flooded area of the research.

The physicochemical data indicate that flooding significantly impacts soil properties. Both farms show lower pH and CEC values in flooded regions, suggesting higher acidity and less nutrient retention. Flood-affected regions also exhibit higher EC values, indicating increased salinity. These changes may have an unfavorable effect on soil health and agricultural productivity.

Table 1. Physicochemical characteristics of the soil in the control farmland and flood affected farmlands

	pH	Electrical conductivity	Cation exchange capacity (meq/100 g)
FARM 1A	6	$0.3x1.0^1$	0.22
FARM 1B	4.8	$2x10^1$	0.18
FARM 1C	5.7	$2x10^1$	0.22
FARM 1D	5.2	$2x10^1$	0.20
FARM 2A	5.7	$4x10^1$	0.24
FARM 2B	4.8	$0.2x10^1$	0.16
FARM 2C	5.1	$0.5x10^1$	0.20
FARM 2D	4.9	$0.2x10^1$	0.18

Table 2. Contamination Factor for Farm 1 and Farm 2

	Contamination Factor							
	Farm 1				Farm 2			
	Cr	**Cd**	**Ni**	**Zn**	**Cr**	**Cd**	**Ni**	**Zn**
A	0.7	37.0	1.1	0.4	0.5	25.5	0.8	0.4
B	0.6	43.7	0.8	0.4	0.4	23.7	0.7	0.4
C	0.6	32.0	0.8	0.3	0.4	21.8	0.6	0.3
D	0.8	20.0	0.7	0.3	0.3	21.4	0.5	0.2

Table 3. Contamination scale based on contamination factor (CF) value

CFs value Scale	Classification
1 and less	No contamination
1-2.0	Suspected
2-3.5	Slight
3.5-8	Moderate
8-27.0	Severe
27 and above	Extremely

Table 4. Potential Ecological Risk Factor for Farm 1 and Farm 2

	Potential Ecological Risk Factor	
	Farm 1	**Farm 2**
A	7.2	35.3
B	5.4	34.
C	5.4	33.9
D	5.2	33.3

Table 5. Criteria for degrees of ecological risk cause by heavy metals in sediment

Ri or E_r^i	Ecological Pollution degree
E_r^i< 40 or Ri < 150	Low ecological risk for the sediment
40 ≤ E_r^i< 80 or 150 ≤ Ri < 300	Moderate ecological risk for the soil
80 ≤ E_r^i< 160 or 300 ≤ Ri < 600	Considerable ecological risk for the soil
160 ≤ E_r^i< 320 or 600 ≤ Ri	Very high ecological risk for the soil

3.2 Contamination Factor (CF)

Table 2 shows the results of contamination factors (CFs) measurements made at four different locations (A, B, C, and D) for the elements zinc (Zn), nickel (Ni), cadmium (Cd), and chromium (Cr) in soil samples from two farms (Farm 1 and Farm 2). Locations A and B are flooded areas, while C and D are non-flooded areas. Contamination Factors (CFs) indicates the extent of contamination of the soil samples by the heavy metals considered. The CFs help assess the degree of heavy metal pollution, where values greater than 1 indicate contamination (Table 3).

Farm 1 displays chromium (Cr) concentrations ranging from 0.6 to 0.8, with non-flooded position D having the highest concentration (0.8). Farm 2 on the other hand has lower Cr CFs, ranging from 0.3 to 0.5, with non-flooded spot D having the lowest CF (0.3) and flooded location A having the greatest CF (0.5). Given very modest amounts of contamination are found in both flooded and non-flooded locations, it appears that flooding does not considerably enhance Cr pollution. Cadmium (Cd) CFs are very high in Farm 1, especially at flooded locations A (37.0) and B (43.7). Even non-flooded location D has a high CF (20.0). Farm 2 shows lower but still high CFs (21.4 to 25.5), highest at flooded location A (25.5). Flooding significantly increases Cd contamination. For Nickel (Ni) CFs in Farm 1 range from 0.7 to 1.1, highest at flooded location A (1.1). Farm 2's CFs are lower (0.5 to 0.8), with the greatest in flooded spot A (0.8). Flooding marginally increases Ni pollution. Zinc (Zn) CFs are modest on both farms (0.2 to 0.4), with no effect from flooding.

Farm 1 exhibits higher levels of pollution in Cr, Cd, and Ni than Farm 2. Both farms have considerable Cd contamination, which is especially severe in flooded areas. Flooded farmlands A and B contain the highest contamination levels for most metals in both fields, implying that flooding exacerbates heavy metal pollution, particularly Cd and Ni. Zinc contamination is limited on both farms, with CFs considerably below 1 (Table 3), showing that Zn pollution is not a serious concern. Cd, Ni, Cr, and Zn were in decreasing order in terms of contamination factor average for all metals. The study area is extremely contaminated with Cd.

3.3 Ecological Pollution Degree ($\boldsymbol{E_r^i}$)

Ecological Pollution Degree (E_r^i) gives a simple ecological risk assessment of the soil samples. The Ecological Pollution Degree (E_r^i) analysis results of selected heavy metals in the sediments of the flooded and non-flooded area of both farmlands are represented in Table 4. The ecological risk factor is a critical statistic for assessing heavy metals' possible negative environmental impact. Higher ecological risk factor values indicate greater environmental risk.

The ecological risk factor values for Farm 1 range between 5.2 and 7.2. The largest ecological risk factor was found at location A (7.2), which is a flooded area. Locations B, C, and D, which comprise both flooded and unflooded areas, had lower and more similar ERF values (5.4, 5.4, and 5.2). This shows that flooding at location A may have contributed to a somewhat larger ecological risk than other areas.

Farm 2 had much higher ecological risk factor values, ranging from 33.3 to 35.3. The largest ecological risk factor is discovered at position A (35.3), which is a flooded area similar to Farm 1. The other sites (B, C, and D), which include both flooded and unflooded areas, have ecological risk factor values of 34.0, 33.9, and 33.3, respectively. These values indicate a that ecological risk values were higher across all locations in Farm 2 compared to Farm 1, with minimal variation between flooded and non-flooded areas. However, the overall Ecological Pollution Degree (E_r^i) in each sampling site were far less than 40 ($\boldsymbol{E_r^i}$< 40), indicating low potential ecological risks (Table 5).

4. CONCLUSION

The results obtained from the physicochemical analysis of the soil samples revealed that the flooded and non-flooded farmlands were acidic. The Electrical Conductivity of the study area for both non-flooded and flooded areas of both farms were relatively low. This implies that the fertility of the study area is low, since it measures the number of salts in the soil (Salinity), thus indicating less microbial activities in the soil. The cation exchange capacity (C.E.C) in flooded areas decreased by 0.04 compared to the non-flooded areas, indicating diminished soil capacity to retain and release essential cations. The contamination factors were observed generally to indicate low contamination by the heavy metals (Cr, Ni, & Zn) across the farmlands; whereas a high degree of contamination was seen for Cd in all the farmlands. The measure of ecological risk factor for all the soil samples indicates no sign of pollution by all the heavy metals. Therefore, we recommend that due to the high contributing factor of Cd to the contamination factor of the area, intensive study should be conducted to determine the actual route of Cd introduction to the soil. Also, efforts should be made to bioremediate some metal contents of the soils, especially Cd, to reduce ecotoxicological problems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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