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Assessment of Environmental Pollution on the Soil, Plants, and Water Chemistry of Insurgency-Inflicted Communities of Madagali, Adamawa State Nigeria

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Abstract

In this study, soil, plant, and water samples were analyzed toward establishing the level of pollution-induced by insurgency/military action in the crisis-inflicted areas of Madagali. The respective samples taken from a crisis-free areas of Maksi (MK) were used in this study as a reference station to evaluate and establish the level of pollution buildup due to insurgency in samples collected from the crisis-inflicted communities of Angwan mission (AM), Magar (MG), and Bakin kasuwa (BK). The total concentrations of Iron (Fe), Zinc (Zn), Copper (Cu), lead (Pb), Chromium (Cr), and Cadmium (Cd) ions determined in the soil samples from the study areas based on the Pollution Index (PI) and the integrated pollution load index (PLI) showed the soil samples to be slightly-to-moderately polluted. Anthropogenic-related activities were further observed to contribute >100 % to the pollution levels in the soil samples at AM, MG, and BK respectively. The results further showed Cr, Pb, Cu, and Zn to be of a low ecological risk (Er < 40) in the samples from AM, MG, and BK. However, Cd was observed to be of a moderate-to-considerable ecological risk (40 < Er < 86) in the samples from AM and BK. On the whole, the Potential Ecological Risk Index (Ri) estimated for samples from AM, MG, and BK was observed to be of a low potential ecological risk (R_i<150). The water quality for drinking purposes according to the Water Quality Indices (WQI) is classified as good for drinking for the samples from MG (47.42), BK (36.85), and AM (28.63). Only the water samples from MK, having a value of 19.76 was observed to be of excellent quality (WQI<25). The results were observed to be significantly ($p<0.5$) higher in the insurgeny-inflicted areas of AM, MG, and BK compared to the values obtained from MK, the reference site.

Keywords: Heavy metal, Pollution index, Ecological risk Index, Water quality

1. Introduction

Ban Ki-moon in a statement presented at the UN's International Day for Preventing the Exploitation of the Environment in War and Armed Conflict placed emphasis on the devastating effects of war on the environment; crying out that the environment has long been a silent casualty of war and armed conflicts (https://www.theguardian.com/environment/2014/nov/06/whats-the-environmental-impact-of-modern-war). Certini et al. (2013) in their review hypothesized a possible decline in the state–state warfare, and an increase in localized warfare/insurgencies across the globe. According to the assessment, the state–state warfare will increase the levels of localized contamination of the environmental medium by chemical warfare agents. In Nigeria, hostilities, communal clashes, and insurgency are quantified to be of epic proportion; creating systematic and dire environmental consequences of similar proportions. In northeastern Nigeria, the carbon footprint from Boko Haram activities and its vices have created a devastating humanitarian crisis, disease outbreak, refugee surge, food insecurity, and water stress among others (Nwakaudu, 2012). The situation rendered 8.5 million people, among which 1.78 million are internally displaced persons (IDPs) who rely solely on humanitarian-based assistance (OCHA, 2017a). Close to 75% of water/sanitation facilities in the region are destroyed due to insurgency, with about 200 health facilities rendered useless (OCHA, 2017b).

Though, the attention of researchers is primarily drawn to several aspects of insurgency especially in northeastern Nigeria (Awortu, 2015; Chukwurah et al., 2015; Iliyasu et al., 2015; Emmanuelar, 2015; Shuaibu et al., 2015; Dunn, 2018), these efforts, however, are observed to be limited to economic, social, agricultural and health-related implications of the insurgency. The immediate environmental effects resulting from insurgency activities, with particular attention to the effects of pollutants to the soil, water, and the entire food chain are seldom investigated and reported. During Insurgency or hostilities, the greatest threat is manifested in the risk of environmental pollution and ecocide (Heiderscheidt, 2018). Research findings in war-tone countries further support these observations, bringing to the fore, the causative effects of conflict and environmental-

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based pollution (Heiderscheidt 2018). Such activities was observed to mediate the deposition of pollutants in the soils, water, and bioaccumulation in plants (Kokorīte et al., 2008; Lewis et al., 2010; Meerschman et al., 2011; Bazzi et al., 2020).

Insurgency or hostility-mediated activities were reported to lead to loss of functional properties of the biota, and were further observed to trigger economic and social crisis to the inflicted areas (Sims et al., 2019). Such activities may lead to the degradation of the soil ecosystem, generating pollutants from heavy military vehicles, explosives, gun residues, and bullet cache (Kokorīte et al., 2008; Briggs et al., 2016; Gębka et al., 2017). Studies show that Pb dust and debris are generated in surface soils at the shooting range (Chen et al., 2002; Cao et al., 2003; Levonmäki et al., 2006). Soil as a repository of contaminants can readily accumulate HMs, which if substantially accumulated in the soils, can be released to other ecosystems, such as groundwater, rivers, atmosphere, and crops (Wei and Yang 2010). Through the casualty flow, the risk from conflict-mediated pollutants through several reaction pathways could impinge heavily on the health of the population (Meerschman et al., 2011; Das, 2014; Heiderscheidt, 2018).

Against this backdrop, this present study was undertaken to ascertain the level of pollutants in the soil, plants, and water sources of insurgency/hostility areas of Adamawa State, Nigeria. The research covering the conflict zone in the state is limited by the unavailability of access to the inflicted areas for a full-scale assessment. Thus, this study was narrowed toward evaluating the environmental pollution levels in the soil, plants, and water sources of Madagali LGA of the State. Due to the non-availability of data on pollution indices in the study location before the conflict, the study will consider sampling data from crisis-prone areas and areas that experience no insurgency or hostilities around the study locations. The research work will serve as a pilot effort to experimentally study the effects of insurgency/hostilities on environmental indicators (Heavy metals, Physicochemical and bacteriological parameters) for a small number of samples and sample locations.

2. Materials and Methods

2.1 Description of the Study Area

Madagali LGA as shown in Figure 1 is located in the northern senatorial zone of Adamawa state in the northeast region of Nigeria. Situated at latitude $10^{0}51^{1}$N and $10^{0}58^{1}$N and longitude $13^{0}36^{1}$E and $13^{0}42^{1}$E, 420 meters above the sea level (Ahmed et al., 2015). Since August 2014, the area has been experiencing a series of hostilities by Boko Haram insurgency, creating humanitarian, social, and health-related crises in the region. The majority of the people living across the crisis area lack access to basic sanitation, and safe water.

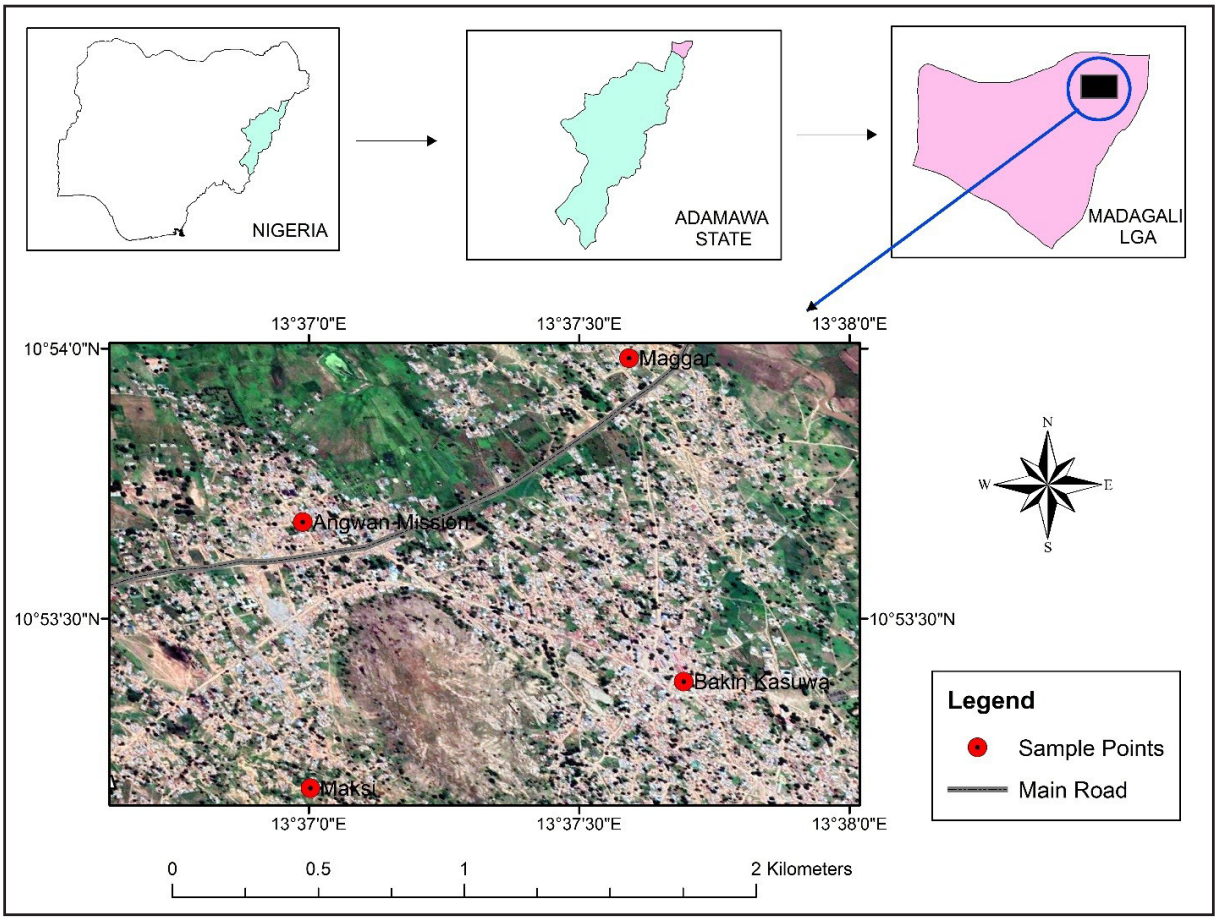


Figure 1. Map of Madagali showing the sampling points.

2.2 Sampling and Preparation

Surface soils and water samples were collected randomly across three major wards in Madagali LGA which has experienced likely changes in the soil and water quality due to frequent attacks by insurgents and military-related response action. The locations as shown in the map in Figure 1, include the Anguwan mission (AM) located at Mararaba under the Madagali ward, Bakin kasuwa/Police station (BK) located at Madagali central, and Magar (MG) situated at Wagga ward. The fourth location is Maksi (MK), a community in the Dirif unit in Bebel ward close to Mt. Maksi in Cameroun. Maksi is considered to be a community that did not experience any insurgent attacks and thus served as a reference station for the study. In each of the four sample locations, soil samples were taken randomly from six sub-points. The samples taken from the six sub-points are pooled to form a composite for each of the study locations. The samples obtained at a depth of approximately 5-10 cm were disaggregated and sieved through a 250 µm mesh. From the respective sample locations, one of the widely and popularly consumed vegetables (Sorrel) in the area was also sampled for analysis. Ten sorrel plants were taken at each of the six sub-points and were homogenized to make a composite sample for each of the four sample locations. The sorrel vegetable samples were processed following the procedure described by Aderinola et al. (2012). The water samples were collected from both hand-dug wells and boreholes located in each of the four sample locations. The samples were treated based on the method described in ASJ (2012).

Atomic Absorption Spectrophotometer (AAS) (Buck Scientific, VPG 210) was used to determine the total concentrations of Fe, Zn, Cu, Pb, Cr, and Cd in the samples. Before the analysis, sieved soil and powdered plant samples were subjected to acid-digestion using aqua regia at a ratio of 3:1 of concentrated HCl: HNO_3. While 10 ml of 8 M HNO_3 was used for the digestion of the water samples. The HMs concentrations in the soil were used for the Environmental Pollution study using the following tools: bioaccumulation (BF), pollution index (PI) and the integrated pollution index (PLI), anthropogenicity (APn%), the ecological risk factor (E_r), and the potential ecological risk factor (R_i). For the water sample analysis, Sodium (Na) and Potassium (K) were carried out using a Flame Photometer. The presence of anion such as chloride was determined using the argentometric titration method, acid-base titration using methyl orange as an indicator for the Bicarbonate (HCO_3^-) ions, Nitrate (NO_3^-), and Sulphate (SO_4^{2-}) using Sci-04 model of water LaMotte Analyzer. The pH was measured using pH meter while Dissolved Oxygen was determined using a DO meter (JENWAY 970). Total Dissolved Solids was determined using a multipurpose JENWAY portable combined TDS/ Conductivity meter. The total hardness of the water samples was determined using the titration method with EDTA, while. The turbidity of the samples is measured by Nephelometer. The data were evaluated based on a statistical description using a statistical Package for Social Sciences (SPSS) software (Version 20). The analysis was run in triplicate, and the results were expressed as Mean ± SD. Furthermore, the data analyzed were considered significant at $p < 0.05$.

2.3 Environmental Pollution Study

2.3.1 Bioaccumulation Factor

The Bioaccumulation Factor (BAF) was used to establish the transfer dynamics of the HMs in the soil to the Sorrel plants; an indicator used to determine possible contamination in plants. The units of BAF were calculated using the expression in equation 1.

$$BAF = C_{leave}/C_{Soil} \quad (1)$$

Where C_{leave} and C_{soil} are metals concentration in the Sorrel plant (mg/kg) and soil (mg/kg).

2.3.2. Assessment of Pollution Index

The integrated pollution index (PLI) reveals the overall pollution status of the soil samples. The PLI was calculated using the expression in equation 2

$$PLI = (PI_1 \times PI_2 \times PI_3 \times \ldots \times PI_n)\ 1/n \quad (2)$$

Where PI is the pollution index obtained from equation 3

$$PI = C_i/C_{Rei} \quad (3)$$

Where C_i is the concentration of the ith element in soil samples (mg/kg), and C_{REi} is its corresponding reference concentration (mg/kg). Since no available information on the natural background values for heavy metals in the study location, the concentration of HMs in the surface soils from MK (insurgent free area) will be considered as the C_{REi} value. Similarly, the world average natural background values will be adopted for comparison (Turekian and Wedepohl, 1961). The PI is classified into, no pollution ($PI \leq 1$), slight pollution ($1 < PI \leq 3$), moderate pollution ($3 < PI \leq 5$), and severe pollution ($PI > 5$). The PLI is classified into seven levels: background concentration ($PLI = 0$), no pollution ($0 < PLI \leq 1$), no-to-moderate pollution ($1 < PLI \leq 2$), moderate pollution ($2 < PLI \leq 3$), moderate-to-high pollution ($3 < PLI \leq 4$), high pollution ($4 < PLI \leq 5$), or very high pollution ($PLI > 5$) (Sun and Chen, 2018)

2.3.3. Assessment of Anthropogenicity

Anthropogenicity (Apn%) directly measures the anthropogenic influence on the metal concentrations in the soil samples. It is calculated as follows:

$$APn\% = \frac{Mc}{Bn} x100 \quad (4)$$

Where M_c = measured concentration, while B_n = world average natural background values (Turekian and Wedepohl, 1961). Values taken from Maksi (MK) were equally adopted as the reference or natural background values.

2.3.4. Ecological Risk Assessment

An ecological risk assessment is used to determine the nature or potential effects of the anthropogenic-related actions of pollutants in the soil samples on public health and the environment. This is estimated using the Ecological Risk factor E_r and Potential Ecological Risk Index (R_i) proposed by Hakanson (1980), and was expressed in equation 5.

$$Er = Ti\ x\ \left(\frac{Cm}{Bn}\right) \quad (5)$$

Where E_r is an ecological risk factor, T_i is a toxic response factor of a certain metal. The values for each metal is in the order of Zn=1<Cr=2<Cu=Pb=5<Cd=30 (Hakanson1980). The Cm is the metal content in the soil and

Bn is a background value of metals in soil. The following terminology are used to describe the potential ecological risk factor: E_r< 40 indicates a low potential ecological risk, 40 <E_r< 80 indicates a moderate potential ecological risk, 80 <E_r< 160 indictaes a considerable potential ecological risk, 160 <E_r< 320 means a high potential ecological risk and E_r> 320 denotes a very high potential ecological risk

$$Ri = \sum E_r^i \text{ (6)}$$

Where R_i is the potential ecological risk calculated as the sum of the ecological risk factor for heavy metals in the soil. E_i is an ecological risk factor. The following terminology is used to describe the potential ecological risk index: R_i< 150 indicates low ecological risks, 150 ≤ R_i> 300 indicates moderate ecological risks, 300 ≤ R_i> denotes 600 considerable ecological risks, and R_i> 600 indicates a very high ecological risk

2.4 Water Quality Assessment

The water quality index (WQI) was assessed using the HMs concentrations and the physicochemical parameters in Table 1. The assessment was conducted using the expressions in equation 8 (Guettaf et al., 2017).

$$\text{WQI} = \sum_{i=1}^{n} \text{SIi (8)}$$

Where SI is the water quality sub-index determined using the equation

$$SI = RWi\ x\ qi \text{ (i)}$$

Where Wi is the relative weight of each parameter, and qi is the rating scale for each parameter obtained from the expressions below

$$RWi = \frac{Wi}{\sum_{n=1}^{n} Wi} \text{ (ii)}$$

Where Wi is the assigned weight for each parameter, and RWi is the relative weight. The Wi are assigned to reflect the relative importance of each parameter in the overall quality of water for drinking purposes

The results are presented in Table 1

$$qi = \left(\frac{Ci}{Si}\right) x\ 100 \text{ (iii)}$$

Where Ci is the concentration of each parameter, and Si is the corresponding standards from WHO

Table 1. The weight (Wi) and relative (RWi) for each parameter used in WQI determination

	Literature values									This study	
Parameters	WHO (2004)	Guettaf et al. (2017)	Pesce and Wunderlin (2000)	Abdul Hameed et al. (2010)	Abu Khatita et al. (2017)	Al-Mutairi et al. (2014)	Şener et al. (2017)	Tyagi et al. (2013)	Olasoji et al. (2019)	Wi	RWi
pH	6.5-8.5	3	1	2.1	2.1	0.11	4	4	4	2.5	0.05
E.C (µs/cm)	1000	3	4	2.4	ND	ND	ND	ND	ND	3.1	0.06
TDS (mg/l)	1000	5	ND	ND	ND	0.08	ND	5	ND	3.4	0.06
Turbidity (NTU)	5	ND	2	2.4	ND	ND	ND	ND	ND	2.2	0.04
Total hardness (mg/l)	100	3	1	1.1	ND	ND	ND	ND	ND	1.7	0.03
Chloride (mg/l)	250	3	ND	ND	ND	ND	3	3	1	2.5	0.05
Calcium (mg/l)	75	2	ND	ND	ND	ND	2	3	2	2.3	0.04
Magnesium (mg/l)	30	2	ND	ND	ND	ND	2	3	2	2.3	0.04
Phosphate (mg/l)	1	ND	ND	ND	ND	0.1	ND	ND	ND	0.1	0.00
Na (mg/l)	200	3	ND	1	ND	ND	2	ND	ND	2.0	0.04
DO (mg/l)	6-8	ND	4	4	4	0.17	ND	ND	ND	3.0	0.05
Nitrate (NO_3^-) (mg/l)	50	5	2	2.2	2.2	0.1	5	4	ND	2.9	0.05
Fluoride (F^-) (mg/l)	1.5	ND	ND	ND	ND	ND	ND	4	ND	4.0	0.07
Sulphate (mg/l)	250	3	ND	ND	ND	ND	4	4	ND	3.7	0.07
Cd (mg/l)	0.003	ND	ND	ND	3	ND	ND	ND	ND	3.0	0.05
Cu (mg/l)	1	ND	ND	ND	2	ND	ND	3	4	3.0	0.05
Cr (mg/l)	0.05	ND	ND	ND	3	ND	5	ND	5	4.3	0.08
Fe (mg/l)	0.3	5	ND	ND	ND	ND	ND	2	ND	3.5	0.06
Pb (mg/l)	0.01	ND	ND	ND	5	ND	5	2	ND	4.0	0.07
Zn (mg/l)	0.1	ND	ND	ND	2	ND	ND	ND	ND	2.0	0.04
										55.5	1.00

ND: Stands for not determined in the study

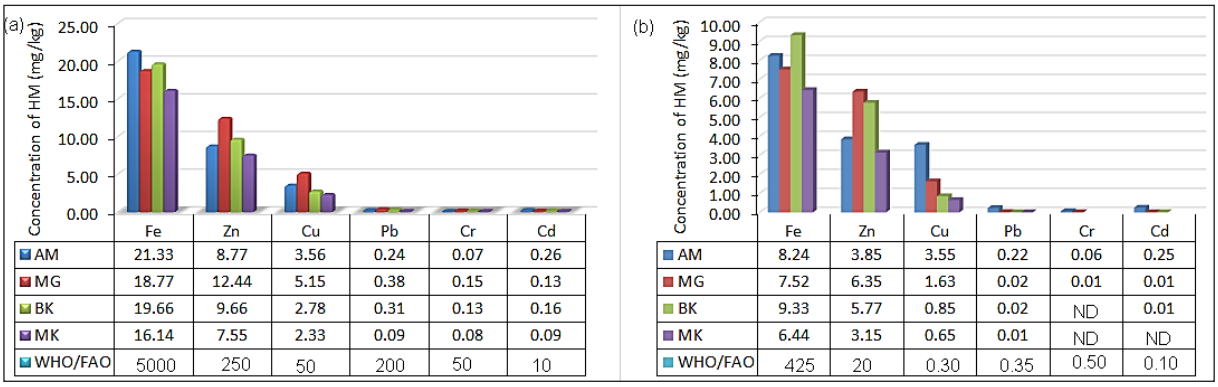
3. Results and Discussion:

3.1 Heavy Metal Pollution in the Surface Soil and Sorrels with their BAF

The concentration of the HMs (Pb, Cu, Cr, Zn, Fe, and Cd) in the surface soil and the Sorrel samples from AM, MG, BK, and MK wards of Madagali LGA in Adamawa statem Nigeria are presented in Figure 2. From the results in Figure 2(a), Fe was observed to be the predominant species in the surface soils across the wards, constituting a 58.3% distribution followed by Zn (29.5%) and Cu (10.6%). The least metals found in the soil samples across the wards are Cr, constituting only 0.3%. The predominant Fe in the surface soil is reported to be consistent with its behavior in association with elements such as Cr, Pb, and Cu (Edith-Etakah et al., 2017). However, when compared with the standard set by WHO, the concentrations of all the species in all the wards were below their respective permissible limits (PL) (WHO/FAO, 2001). From Figure 2, except for Cr which shows an insignificant ($p>0.05$) decrease in the soil samples from AM (0.07±0.03), the distribution of the heavy metals in the surface soils of AM, MG, and BK was observed to be significantly ($p<0.05$) higher compared to the corresponding values from the insurgent free soils of MK. A similar trend was observed in the Sorrels sampled from the study locations, showing Fe as the predominant species accounting for a 54 % abundance, to be followed by Zn (33%) and Cu (11.5%) (Figure 2b). Chromium was detected only in the samples from AM (0.06±0.04) and a 0.1% abundance was found in samples from MG (0.01±0.01). Except for Cu (in all the samples) and Cd in the samples from AM (0.25±0.01), all the other species were found to be below the PL set by WHO. The concentration of Fe, Zn, and Cu in the samples from AM, MG, and BK were observed to be significantly ($p<0.05$) higher than their corresponding values in MK. Lead was found to be significantly ($p<0.05$) higher in the samples from AM (0.22±0.02) and BK (0.02±0.02) compared to the values in MK (0.01±0.02). Chromium and Cd were not detected in the samples from MK.

However, it will suffice to conclude that geogenic and anthropogenic-related activities might be the major contributor to the HMs availability in the study locations. Factors other than agriculture may likely come into play considering the significant variation in concentrations between the conflict areas and MK. Environmental disturbances from insurgents/military-related activities may likely play additional roles in the metal buildup in these locations. Studies show that the environmental disturbances initiated by war/hostilities facilitated the changes in soil morphology, composition, and chemistry (Certini et al., 2013; Bazzi et al., 2020). In a study conducted by Gębka et al. (2016), the concentration of Hg in soil samples collected from a military-active range, in southern Baltic in 2014 and 2015 was observed to increase tenfold in soil samples collected in an area with an active gun range compared to a nonmilitary range, used as a reference point in the study. The source of the Hg, according to the study, is mercury fulminate used in the manufacturing of ammunition primers (Knobloch et al., 2013). In a related study, Meerschman et al. (2011) using about 731 data points collected from Ypres battlefield showed the source of Cu and Pb to be from war-related activities. Bullets or ammunition residues through several chemical processes, over time, release HMs into the environment medium, which is either biotransformed by plants or enriched in the soil (Lewis et al., 2010).

The empirical effect of warfare on the environment depends on some environmental attributes, largely defined in terms of the size (scale), locations (international or locally-induced war) or developmental (either by developed or developing countries) (Reuveny et al., 2010). Even though this study could be considered locally-induced, not a full-blown or large scale, it shows that war has through the wake of the hostilities increases aggregated environmental stress leading to the observed variation in the heavy metal contents in the surface soil of AM, MG, and BK compared to MK.



	Fe	Zn	Cu	Pb	Cr	Cd
AM	21.33	8.77	3.56	0.24	0.07	0.26
MG	18.77	12.44	5.15	0.38	0.15	0.13
BK	19.66	9.66	2.78	0.31	0.13	0.16
MK	16.14	7.55	2.33	0.09	0.08	0.09
WHO/FAO	5000	250	50	200	50	10

	Fe	Zn	Cu	Pb	Cr	Cd
AM	8.24	3.85	3.55	0.22	0.06	0.25
MG	7.52	6.35	1.63	0.02	0.01	0.01
BK	9.33	5.77	0.85	0.02	ND	0.01
MK	6.44	3.15	0.65	0.01	ND	ND
WHO/FAO	425	20	0.30	0.35	0.50	0.10

Figure 2. The concentrations of Heavy Metals in the Soil (a) and Sorrel vegetable (b) and their corresponding PL by WHO/FAO. Results are presented in Mean ±SD of three replicate analysis.

Plant-soil chemistry is an effective and sustained pathway for metal enrichment in a plant. The complexity of the interaction depends on several environmental factors that influence metal availability and variability in the soil for an efficient uptake by plants (Garba et al., 2018; Magili and Bwatanglang, 2018). The persistence of bioavailable HMs in a soil medium through several reaction mechanisms is readily transformed and transferred across the trophic levels (Ali et al., 2019). The number of research work in Nigeria reported a high accumulation of HMs from contaminated soils into plants (Akinola and Ekiyoyo, 2006; Adesuyi et al., 2015). Other studies show a direct relationship between vehicular emission, the application of agrochemicals, and other anthropogenic-

related activities with heavy metals accumulated in soils and in plants (Bwatanglang et al., 2019). The estimation of metal bioavailability in soils and its contamination status in plants are also used as an indicator for assessing the environmental pollution status (Shtangeeva, 1995). While being efficient in phytoremediation, it also serves as a conduit for toxic metal mobility and can be utilized scientifically toward establishing pollution dynamics from the soil, to the food chain and public health.

From the results in Figure 3, Cu, Pb, Cd, and Cr, out of the six heavy metals analyzed, show BF of ~1 in the samples collected from AM. Only Zn, out of the six HMs analyzed in MG, Zn and Fe analyzed in BK give a BAF of 1. Furthermore, BAF of <1 was recorded in all the metal species analyzed in MK. The major contributor to heavy-metal buildup in the surface soil in the study location could be attributed to agricultural activities such as the application of agrochemicals. However, the variation in the results from the AM, MG, and BK samples compared to the least values in MK further suggest possible man-made activities that could be linked to insurgency/military-related activities. The higher contents in those locations are translated into a higher uptake by the plant and higher BAF in the insurgent areas (AM, MG, and BK) compared to the reference area (MK).

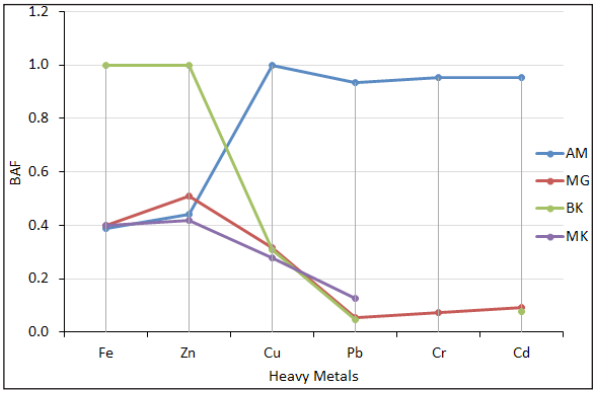


Figure 3. The Bioaccumulation Factor of the Heavy Metals for each sample locations.

3.1 Environmental Pollution Study and Potential Ecological Risk Assessment of the Heavy Metals in Surface Soil

Using MK as reference values, the PI in the soil samples obtained from the insurgent areas (AM, MG, and BK) showed the soil samples to be slightly and moderately contaminated with heavy metals (Table 2). The surface soils in AM, MG, and BK were observed to have PI≤ 3. For these locations, Fe, Zn, Cu, Cr, and Cd are the major contributors to soil pollution. The result further shows the surface soils from MG and BK to be moderately polluted with Pb ($3 < PI \leq 5$). The PLI was further observed to be high ($PLI \leq 4$) in AM and Bk and very high pollution ($PLI > 5$) in MG. In all of the locations, the major contributors to the surface soil pollution are Pb followed by Cd and Cu. The results of the pollution index show that the quality of soil in the study area is slightly-to-moderately compromised. Insurgents/military-related activities in addition to the application of agrochemicals increased the levels in AM, MG, and BK compared to the values obtained from the reference site (MK) (Certini et al., 2013; Bazzi et al., 2020).

Table 2. The Pollution Index and the Integrated Pollution Load Index (PLI) of the Heavy Metals. Established using the data from MK and World natural background value as reference values.

		Reference value (Maksi)			Reference value (Natural background value)			
Metals		AM	MG	BK	AM	MG	BK	MK
Fe	PI	1	1	1	0	0	0	0
Zn		1	2	1	0	0	0	0
Cu		2	2	1	0	0	0	0
Pb		3	4	4	0	0	0	0
Cr		1	2	2	0	0	0	0
Cd		3	1	2	1	0	1	0
PLI		4	7	4	1	1	1	0

Anthropogenicity is a numerical expression (in Percentage) employed to measure the impact of anthropogenic-related activities on the environment. The results are presented in Table 3. Using the HMs concentration at MK as a reference value, the study showed anthropogenic activities contributing more than 100 % in the surface soil at AM, MG, and BK, respectively. Lead, Cd, Cu, and Cr are the HMs most influenced by man-made activities in the surface soils at these locations. Further appraisal of the surface soils at AM, MG, BK, and MK using the world natural background values showed a much lower level of anthropogenic activity. The soil at MK experiences a lesser impact from anthropogenic activities, showing a background concentration for Fe, Pb, and Cr. The highest anthropogenicity of 31% was observed for Cd while, Zn and Cu contribute 8 % and 5% respectively. The anthropogenicity for the heavy metals in AM, MG, and BK shows Cd as the major contributor, accounting for 88%, 44%, and 52%, in that order.

The main occupation of the people residing in the study locations is agriculture; thus, it is logical to conclude that agrochemical will be the major contributor in addition to the natural geologic processes. Phosphate-based fertilizers contain high amounts of Cd ranging from trace quantities to 300 ppm on a dry weight basis (Grant and Sheppard, 2008). The source of this fertilizer, phosphate rock, contains different environmentally-hazardous elements including Cr, Cd, Pb, Hg, and As, (Atafar et al., 2010). Other studies shows a high correlation for these metals associated with phosphate in fertilizers (Ukpabi et al., 2012), and the application of fungicide for Cu enrichment (Semu and Singh, 1996). However, since the concentration of the HMs in the insurgent areas (AM, MG, and BK) is relatively higher than the values in MK, it will not be out of place to suggest additional HMs inputs from the insurgent/military-related activities (Meerschman et al., 2011; Certini et al., 2013; Gebka et al., 2016; Bazzi et al., 2020).

Table 3. The Anthropogenicity (Apn %) of the Heavy Metals in the Surface Soils. Established using the data from MK and World natural background values as the reference value.

	Reference value (Maksi)			Reference value (Natural background value)			
Metals	AM	MG	BK	AM	MG	BK	MK
Fe	>100	>100	>100	0	0	0	0
Zn	>100	>100	>100	9	13	10	8
Cu	>100	>100	>100	8	11	6	5
Pb	>100	>100	>100	1	2	2	0
Cr	84	>100	>100	0	0	0	0
Cd	>100	>100	>100	88	44	52	31

The possible risk associated with these pollutants as shown above can best be understood when subjected to the potential ecological risk assessment of the surface soil. The results of the assessments of the potential ecological risk factor (Er) and the potential ecological risk index (RI) are summarized in Table 4. The Er of the heavy metals in the soils from the study areas factored using the concentration from MK as reference values shows Cd >Pb>Cu>Cr>Zn. The Er for Cr, Pb, Cu, and Zn in the surface soils at AM, MG, and BK were found to be less than 40, wich means a low ecological risk. The surface soils at MG based on the calculated ecological risk factor (Er) of 43 are considered to be of moderate potential ecological risk for Cd, while BK and AM showed a moderate-to-considerable potential ecological risk for Cd, having Er values of 51 at BK and 86 at AM respectively. However, all the RI values estimated for the metals in the surface soil from all the study locations are of low ecological risk, having values R_i<150. Furthermore, when measured against the world's natural background values, the Ri estimated in the surface soils for all the metals, having values <150 was observed to be of no consequences, indicating a no-potential ecological risk.

Table 4. Ecological Risk factor (Er) and Potential Ecological Risk Index (Ri) of the Heavy Metals in the Surface Soil. Established using the data from MK and World natural background concentrations as the reference value.

		Reference value (Maksi)			Reference value (Natural background value)			
Metals		AM	MG	BK	AM	MG	BK	MK
Zn	E_r	1	2	1	0	0	0	0
Cu		8	11	6	0	1	0	0
Pb		14	22	18	0	0	0	0
Cr		2	4	3	0	0	0	0
Cd		86	43	51	26	13	16	9
R_i		110	81	79	27	14	16	10

3.3 Assessment of the Physicochemical Parameters and Heavy Metals in Water Samples against Recommended Permissible Limits

As shown in Table 5, there is no significant (p>0.05) difference in the mean concentration of the parameters in some of the study locations relative to the PL. Except for total hardness, phosphate, and Cd level in MG, the remaining parameters were observed to all fall below the PL set by WHO. The parameters were further observed to be of the least concentration/level in the samples from MK and fall between the optimum pH ranges for first-class drinking water (6.5-8.5).

(Tebbutt, 1998; Sen and Aksoy, 2015). Electrical conductivity (EC) is a reflection of Dissolved Solids' concentrations in water. The EC values of the water samples from the study locations vary within a range of 374–172 µS/cm. The values at the insurgent areas are significantly (p<0.05) higher than the values from the non-conflict area (MK). Similar to the trend observed for EC, the Total Dissolved Solids' (TDS) values in all the study locations were below the WHO PL (1,000 mg/l). The values at BK (186 mg/l) and MG (95 mg/l) are significantly (p<0.05) higher than the values from the non-conflict area (MK, 82 mg/l). The turbidity values of the water samples are between 8.11 and 1.01 NTU. The values in MG (8.11 NTU) are significantly (p<0.05) higher than the WHO (5 NTU) values, and were observed to follow a decreasing trend between the locations (MK<BK<AM<MG). Total hardness (TH) is a function of excessive Ca and Mg concentrations in the water body (Dirican, 2015). The highest value above the WHO limit (100 mg/l) was observed in BK (240.00 mg/l) and MG (240.11 mg/l), followed by a sample from AM (184.01 mg/l). The values in MK were the lowest (80.00 mg/l) and were further observed to be significantly (p<0.05) lower than the values in the insurgent areas. The concentration of TH in water is classified into six categories: ≤50 as soft, moderately-soft (50-100), slightly-hard (100-150), moderately-hard (150-250, hard (250-350), and very hard (>350) (Şener et al., 2017). According to this classification, the samples from MK are soft, that of AM, MG, and BK are moderately-hard (Tebbutt, 1998; Sen and Aksoy 2015). The dissolved oxygen (DO) values in the water samples range from 7.11 to 6.51 mg/L, falling within the recommended values of 6-8 mg/l for quality drinking water (Tebbutt, 1998; Sen and Aksoy, 2015; Dirican, 2015).

The availability of cations in all of the sample locations are in the order of Na>Mg> Ca>Zn>Cu>Fe>Cd>Pb>Cr, with Na as the dominant species. The cations except for Cd (0.008) in the samples from MG were observed to all fall below the PL set by WHO. The HMs in the samples from AM, MG, and BK, though found to be insignificantly (p>0.05) higher than the corresponding values in the samples from MK, could be attributed to phosphate/nitrate-based fertilizers, Cu-based fungicides (Atafar et al., 2010; Ukpabi et al., 2012), or ammunition residues (Lewis et al., 2010). The anions in this study follow the order of Cl^-> SO_4^{2-}> NO_3^->PO_4^{3-} >F^-, with chloride as the dominant species. In this category, phosphate was observed to be above the PL set by WHO. Phosphate levels range from 3.11-6.80 mg/l. The highest value was observed in a sample from BK (6.80±0.14 mg/l), while the least in MK (3.11±0.12 mg/l). Chloride, nitrate, and sulphate are the major anions that adversely alter the drinking-water quality (Şener et al., 2013) and are found to be significantly (p<0.05) higher in the samples from AM, MG, and BK compared to the samples from MK. The presence of chloride ions in the water samples could be related to anthropogenic activities or to the leaching of saline residues in the soil (Chatterjee et al., 2010). Water samples containing ≤25 mg/l of Chloride are considered class-I; and class-II, III, and IV if the chloride concentration in the water is 200 mg/l, 400, and >400 respectively. From the analysis, the water in the study locations could be categorized as class-I, (Tebbutt, 1998; Sen and Aksoy, 2015; Dirican,

2015). The concentration of nitrates in the water samples could be attributed to the nitrate-based agrochemicals or to the leaching of human or animal wastes (Guettaf et al., 2017). Water is considered class-I if it contains ≤5 mg/l of nitrate, class-II; if it contains 6-10 mg/l of nitrate, class-III and IV if it contains 11-20 and >20 mg/l of nitrate respectively. According to these limits, the water samples from the study locations having nitrate values from 3.49-7.50 could be categorized as class-I (Tebbutt, 1998; Sen and Aksoy, 2015; Dirican, 2015). The breakdown of organic materials through soil weathering processes, leaching from sulphate-containing fertilizers, atmospheric deposition and oxidative decomposition of the sulfur compound by bacteria are means of sulphate induction into the water bodies (Guettaf et al., 2017; Dirican, 2015; Şener et al., 2017; Varol and Davraz, 2015; Chatterjee et al., 2010). Sulphate below 200 mg/l in the water samples is classified as class-I, class-II if it is 200 mg/l. If 400 or >400 mg/l they are categorized class-III and IV respectively (Dirican, 2015). The water samples from all the study locations based on the concentration of sulphate are classified as class-I (Tebbutt, 1998; Sen and Aksoy, 2015; Dirican, 2015).

3.4 Water Quality Assessment

The water quality index (WQI) values are classified into five types namely, excellent water (0< WQI<25), good water (25< WQI<50), poor water (50 < WQI< 75), very poor water (75< WQI< 100), and water unsuitable for drinking (WQI > 100) (Guettaf et al., 2017). The WQI values were estimated using the assigned weighted values in Table 1 and equations 8. From the result in Table 5, the quality of water for drinking purposes is good for samples from MG (47.42), BK (36.85), and AM (28.63) respectively. Only the water samples from MK, having a value of 19.76 were observed to be of excellent quality (WQI<25). Anthropogenic-related activities from agrichemical and environmental disturbances created during insurgency may have introduced additional levels of contaminants into the water body. This may equally explain the low WQI values registered in the three study locations inflicted by insurgency (AM, MG, and BK). Total hardness, phosphate level, and the presence of Cd in addition to the cumulative effects from sulphate, nitrate, and chloride could be the possible reasons for the observed drop in water quality from AM, MG, and BK.

Table 5. Physicochemical and Heavy-Metal Analysis in Water Samples from the Study Locations and the WHO Standards.

Parameters	AM	BK	MG	MK	WHO
pH	7.10±0.05	7.20±0.10	7.69±0.12	7.05±0.11	6.5-8.5
E.C (µs/cm)	174.00±0.20*	374.00±0.03*	189.00±1.05*	172.00±0.15	1000
TDS (mg/l)	87.12±1.06*	186.00±0.04*	95.01±0.11*	82.02±0.14	500
Turbidity (NTU)	2.00±1.10	2.00±0.07	8.11±0.09*	1.01±2.12	5.0
Total hardness(mg/l)	184.01±0.05*	240.00±0.11*	240.11±0.12*	80.00±0.13	100
Chloride (mg/l)	106.00±0.82	64.51±0.15	42.54±0.11	54.95±1.01	250
Calcium (mg/l)	0.06±0.03	0.09±0.02	0.05±0.01	0.05±0.02	75
Magnesium(mg/l)	0.09±0.03	1.15±0.02*	1.14±0.04*	0.08±0.03	30
Phosphate (PO_4^{3-}) (mg/l)	6.70±0.12*	6.80±0.14*	6.41±0.13*	3.11±0.12	1.0
Na (mg/l)	5.5±0.11*	4.1±1.55	4.2±1.05	4.1±0.06	200
DO (mg/l)	7.0±0.04	6.51±0.11	6.71±0.72	7.11±1.09	6-8
Nitrate (NO_3^-) (mg/l)	7.50±0.11*	6.30±0.42*	6.20±0.51*	3.49±0.19	50
Fluoride (F^-) (mg/l)	0.11±0.51	0.16±1.05	0.21±0.13	0.10±0.51	1.5
Sulphate (mg/l)	26.00±0.11*	25.11±0.41*	31.21±0.01*	20.11±0.15	500
Cd (mg/l)	0.002±0.01	0.001±0.01	0.008±0.02	0.001±0.02	0.003
Cu (mg/l)	0.04±0.01	0.09±0.02	0.06±0.03	0.01±0.08	1.0
Cr (mg/l)	ND	0.004±0.03	ND	ND	0.05
Fe (mg/l)	0.02±1.50	0.02±0.03	0.03±0.11	0.02±0.11	0.3
Pb (mg/l)	ND	0.008±0.005	ND	ND	0.01
Zn (mg/l)	0.05±0.03	0.07±0.01	0.09±0.03	0.03±0.03	0.1
WQI	28.63	36.85	47.42	19.76	
Quality	Good	Good	Good	Excellent	

**Denoted level of significance to the reference value at MK*

4. Conclusions

Environmental disturbances created during insurgent hostilities leave behind salient but causative effects, releasing toxic substances which often take a longer time to be manifested, and whose consequences are often undervalued and underreported. Environmental pollution induced by toxic substances through several reactive pathways may induce changes in the functional properties and quality of the soil and water, thus increasing the likelihood of health risk to the public on the long run. These observations necessitated an investigation using a small sample-size reported in this work. The distribution of HMs in the surface soils and sorrel plants in samples from AM, MG, and BK were observed to be significantly ($p<0.05$) higher than in samples from MK. The Pollution Index (PI) values showed the soil samples to be slightly-to-moderately polluted. With >100 % of the HMs availability in the samples derived from anthropogenic-

related activities. The study further revealed the Ecological Risk Index (Ri) for samples from AM, MG, and BK as a low potential ecological risk (R_i<150), however, it revealed a moderate-to-considerable ecological risk (40<Er<86) concerning Cd levels. The WQI shows the samples from MK, having WQI≤19 to be of an excellent quality compared to the samples from AM, MG, and BK (<28WQI<47). The overall assessment conducted in this study shows that the environmental indicators analyzed were significantly (p<0.5) higher in the crisis-inflicted areas (AM, MG, and BK) compared to the reference station (MK). Though the study was limited by the unavailability of access to all the insurgent communities for full-scale assessment, the results however establish a possible link toward pollution buildup from conflict/military-related activities which suggest that if the insurgents' hostilities are not tamed, they will create additional stress on the environment, increasing public exposure to contaminants whose effects overtime will supersede the immediate impact initiated during the crisis. Therefore, further research is, however, encouraged to cover a larger number of sample sizes across the northeastern state of Nigeria, especially in communities where data on the environmental indicators exist before the insurgency. The effort will provide additional information toward marshaling out an ecological and remediatory intervention plan in the affected areas.

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