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Full Length Research Article

ESTIMATION OF REDOX-SENSITIVE METALS IN LAFARGE CEMENT COMPANY'S AREA IN AKAMKPA NIGERIA: ASSESSMENT OF ECOLOGICAL HEALTH RISK

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ABSTRACT

Toxic compounds such as redox-sensitive metals usually contaminate the soil. They are implicated in the causation of oxidative stress, a precursor of human diseases and ecological extinction. Having uncontaminated soil serves as the link between plant and animal health quality, and a sustainable ecosystem. Geological accumulation and spatial distribution of redox-sensitive metals in agricultural land can significantly hinder soil fertility, ecological health, food safety, and food security. This study used the soil samples from farmlands near the Lafarge industrial area at Mfamosing, Akamkpa local government area of Cross River State, Nigeria, to assess eight redox-sensitive metals (Cadmium, Chromium, Copper, Nickel, Lead, Arsenic, Cobalt, and Zinc), their spatial distribution, and geo-accumulation. The redox-sensitive metals were screened with an atomic absorption spectrophotometer connected with mass spectroscopy. A geographic information system (GIS) and ArcMap version 10:8:2 was used to infer the risk of the industrial area regarding geo-accumulation, and spatial distribution of redox-sensitive metals in the farmlands. The result shows Cd, Cr, Cu, Ni, Pb, As, Co and Zn have different concentrations among the samples. Three samples - MS2, MS3, and MS8, had the highest arsenic concentration, while samples Ms1, Ms2, Ms5, and Ms8, had the second-highest concentrations of Cadmium, Lead, and Chromium, respectively. The polluted area was moderately contaminated and distributed with other metals - Cu, Ni, and Co, respectively. Comparing these results with those of non-industrial areas, one can infer that the Lafarge industrial area is more contaminated with redox-sensitive metal. To advance this investigation, some microorganisms within the area can be used to verify a metal-hazard impact on the ecosystem and monitor the rise in redox-sensitive metals to predict the risk.

Keywords: Environmental sustainability, redox elements, ecological risk, crop protection, and biogeochemical

1. INTRODUCTION

Human health depends on healthy soil (Valerie and Jane). To grow crops, produce food, and maintain populations, healthy soil is necessary (Steffan *et al*., 2018). It offers vital ecological functions, including pollination, and supports a variety of ecosystems. Floods are avoided and water is stored. It reduces global warming by capturing carbon. Human health is increasingly at risk from soil pollution. Redox-sensitive metals, organic compounds like insecticides, viruses, and micro- and nano-plastics can all poison soil. The soil's capacity to produce food is diminished by pollution. It causes sickness and contaminates food crops. On Earth, electron transfer or redox reactions are directly tied to life and element cycling. Understanding biogeochemical redox processes is essential for predicting and safeguarding environmental health, and it can open new avenues for designing remediation (Brevik *et al.,* 2020).

Redox processes allow energy to be released and stored by microorganisms by oxidizing labile organic carbon or inorganic molecules (electron donors) and reducing electron acceptors such as iron-bearing minerals, transition metals, metalloids, and actinides (Lee *et al*., 2014). Redox reactions in the environment play an important role in the development and dissolution of mineral phases (Morford *et al.,* 2009). The sequestration of inorganic pollutants is controlled by the redox cycling of naturally occurring trace elements and their host minerals (Rachel and Avner, 2020). Chemical speciation, bioavailability, toxicity, and mobility are all controlled by redox-active compounds, and mineral surfaces can promote the redox transformation and degradation of organic pollutants (Adebambo *et al.,* 2015). Many trace elements are redox-dependent and pose a health risk when mobilized into the soil. Arsenic, manganese, chromium, selenium, vanadium, cobalt, zinc, and nitrogen as nitrates, are a few examples of redox-sensitive trace elements (Guo *et al.,* 2016). Arsenic is mobilized in soil under two conditions: reducing conditions, which mobilize ferrous iron and arsenate; and high pH, which causes the ferric oxyhydroxides to lose their positive charge (Giménez-Forcada and Smedley, 2014). Manganese is mobilized as Mn^{2+} under mildly reducing circumstances, and persistent exposure to crops may damage mental capacity if more than permissible limits (Gómez *et al*., 2006). Under oxidizing circumstances, chromium is mobilized as hazardous chromite. Manganese oxides have the potential to oxidize Cr (III) solids. Chromium can arise from both natural and man-made sources like industrial actions (Haiyan *et al.,* 2016). Selenium, an essential element, rarely exceeds safe limits, however, irrigation with increased selenium groundwater could result in harmful selenium intake through crop bioaccumulation and water intake. Under oxidizing circumstances, selenium gets mobilized in groundwater (Levanon *et al.,* 2013; Russak *et al*., 2016). Nitrate from fertilizer overuse may be a contributing factor or source of methemoglobinemia in bottle-fed children under the age of one year (Fakayode, 2005). Many factors influence the mobility and toxicity of redox-sensitive elements. For effective redox signaling and metal (e.g., iron, zinc, and copper) homeostasis, cells require careful regulation of intracellular redox balance and, as a result, reactive oxygen species. This balance is disrupted by a variety of illnesses, including cancer (Gunnar, 2017). Thus, anticancer medicines that target redox systems, such as glutathione and thioredoxin, have become popular. Arsenic, copper, vanadium, cobalt, manganese, and molybdenum) have been demonstrated to interact with cellular redox homeostasis and even disrupt Agyeman *et al.* (2021). In this context, the "activation by reduction" hypothesis, as well as the "hard and soft acids and bases", the idea of the coordination of metal ions to cellular ligands, are key concepts for understanding the molecular mechanisms of action of metal ions.

Transition metal ions are important components of a variety of biological activities, from oxygen production to hypoxia sensing, and their homeostasis is maintained by tightly regulated absorption, storage, and secretion mechanisms (Zukowska and Biziuk, 2008). The oxidative damage to biological macromolecules such as DNA, proteins, and lipids can be caused by the uncontrolled creation of reactive oxygen species (ROS) (through the Fenton reaction, which produces hydroxyl radicals), and reactive nitrogen species, (RNS) (Godwill *et al*., 2018). Oxidative stress is defined as an imbalance between the generation of free radicals and their removal by antioxidant defense systems. The cell membrane is the most vulnerable to free radical attack, as it may experience increased lipid peroxidation, eventually creating mutagenic and carcinogenic malondialdehyde, 4-hydroxynonenal, and other exocyclic compounds (Witkowska *et al*., 2021). While redox-active metals like iron (Fe) and copper (Cu) undergo redox cycling processes, redox-inactive metals like arsenic (As) and cadmium (Cd) are harmful primarily through glutathione depletion and protein sulfhydryl group bonding (Witkowska *et al*., 2021). Although arsenic has been shown to bind directly to key thiols, other processes have been hypothesized, including the generation of hydrogen peroxide under physiological settings (Balali-Mood *et al.,* 2021). The most abundant metal in the brain is redox-inert zinc (Zn), which is a key component of many proteins engaged in biological defense systems against oxidative stress (Jadhav *et al*., 2007). Zinc deficiency may exacerbate DNA damage by interfering with DNA repair pathways (Kianoush *et al*., 2015). Arsenic and cadmium poisoning can cause metabolic problems with redox-active copper and iron, resulting in the formation of hazardous metals (Linos *et al.,* 2011). Liu et al. (2009), stated that when the antioxidant defence system, which is maintained by antioxidants like ascorbic acid and alpha-lipoic acid, is overwhelmed, oxidative stress will ensure.

A sample of soil may contain multiple chemicals in many situations (McGrory *et al*., 2018). Chemicals in combination may have unanticipated negative consequences that cannot be expected based on individual exposure to each chemical involved. As a result, using individualized health risk limits (HRLs) to assess the safety of a mixture of compounds may not give an acceptable margin of safety. The processes for measuring exposure to various contaminants outlined in the HRLs Rules for soil pollution are predicated on an additive model (Tsuji *et al.,* 2014). Given what is known about how chemicals interact in the body, the US Environmental Protection Agency (EPA) views this model as a reasonable approach. Chemicals with the same health endpoint are tested together. Chemicals that have no health endpoint (e.g., None) are not listed in any of the groups. Similar health endpoints (e.g., thyroid (E) = thyroid) are judged similar and should be added together in the Health Risk Index (HRI). Assessment of various chemical exposures. A ratio is established for each chemical that shares a health endpoint by comparing the chemical's soil concentration to the exposure duration-specific health-based guideline for that chemical. Within each health endpoint category, the ratios are grouped by duration and averaged. The chemicals are categorized according to their noncancer health endpoints, such as liver, kidney, and nervous system, to assess whether the sum surpasses the multiple chemical health index of one noncancer. For each exposure duration, a ratio of the observed concentration of each chemical in groundwater to the appropriate health-based recommendation value for that chemical is calculated. It has become necessary to determine the degree of metal transport across spatial and temporal scales by taking into account the function of redox-sensitive metals and their availability in crops. Depending on their redox state, redox-sensitive metals (RSMs) may exhibit a variety of environmental characteristics. Under the oxidizing state, trace metals produce soluble oxyanions, although their reduced forms are particle-reactive (O'Connor et al., 2022). To determine the redox condition of the soil at the time of their deposition and the oxygen content of the surrounding water, redox-sensitive metals have been widely used as geochemical proxies. These paleoredox proxies need to have their geochemical behaviour calibrated for the soil with known redox status to be used for reliable soil samples (Bennett and Canfield, 2020). Several redox-sensitive elements have been reduced, and this has allowed researchers to reconstruct paleoceanographic conditions (Moe et al., 2020). Based on the effects of redox-sensitive components and their derivatives, this investigation was designed to evaluate the redox-sensitive components in the farmlands surrounding the Lafarge Cement company in Calabar, Cross River State. Assess the environmental health risks and determine the spatial distribution of the redox-sensitive elements.

2.0 MATERIALS AND METHODS

2.1. Collection of soil samples

Four different soil samples were collected from the neighbouring communities' farmlands around Lafarge Cement Company and were used to screen for redox-sensitive elements.

2.2. Study Area

The local government of Akamkpa is located in Nigeria's Cross River State's Central Senatorial District. In 1976, the region was established. It has a 4,300 square kilometre land area. Akamkpa is bordered to the west by Odukpani, to the south by Akpabuyo, and the northwest by the Biase and Yakurr local governments. Figure 1 shows the map of the Akamkpa Local Government Area that was carved out from the Nigeria map far left, with the Cross River state map indicated in red. The middle map represents the Cross River State map bearing the study area (Akamkpa, also indicated in red), while the main figure is the map of Akamkpa bearing the neighbouring communities. The communities include Okomita, Ekong, Awi, Oban, Okpon, Aningeje, Mfamosing, Asuk-Arim, and Akansoko, respectively. These communities are proximal to the cement plant, where the samples were taken. Mfamosing (the Lafarge host community) is 5 kilometres to the north, 5 kilometres to the northwest, Akansoko Village is 8 kilometres to the southwest, and Asuk Arim Village is 7 kilometres to the northwest. It has a latitude of 5.06405°, or 5° 3' 51", a longitude of 8.51456°, or 8° 30' 52", with an open location code 6FQC3G77+JR, and open street-Map ID 669764962 which describes the area where the cement mill is located. Most of the soils are sandy loam and sandy clay loam. These soils are deep (>100 cm), with sandy loam surface textures on top of sandy clay to sandy clay loam subsurface textures which were all deposited by wind and moving water. In some spots, the landscape is gentle to severely undulating. Due to mining and quarrying. The region's original rainforest has been altered by human activity. It has a tropical humid climate with annual precipitation between 2500 and 3000 mm, mean annual temperatures between 26 and 31 °C, and relative humidity between 80 and 90 % during the rainy season (Aki and Ediene, 2018).

The company is known as Lafarge. From the former UNICEM, the Lafarge corporation acquired the cement business (United Cement Company). Granite rocks, which are abundant in the Akamkpa local government, attract numerous quarrying businesses. They are renowned to be Nigeria's main producers of cocoa, rubber, and palm oil and have a good ground for agriculture. It was hypothesized that the industrial effluents and mining operations in the area may increase the prevalence of redox-sensitive metals, which will negatively affect soil fertility, biodiversity, and ecosystem sustainability. This investigation was conducted to evaluate the health risk, redox element, geographical distribution, and environmental safety.

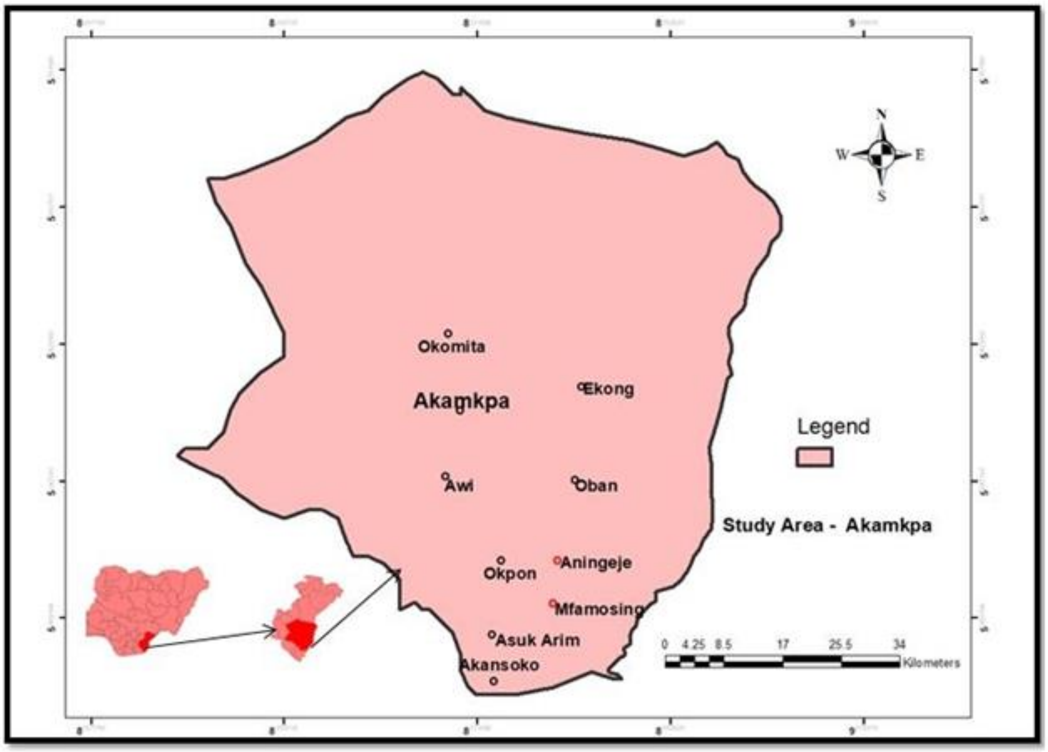


Figure 1 Map of Akamkpa Local Government

2.3. Chemicals and instruments used for the sample analysis

All chemicals and reagents used in this experiment were of analytical and trace metal grades. Fisher Malaysia products were trace metal grades of 65 per cent HNO_3, 37 per cent HCl, and 70 per cent $HClO_4$. Perkin Elmer, USA, products were stock standard solutions with a concentration of 1000 ppm for arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn), copper (Cu), iron (Fe). Throughout the investigation, deionized water was used. Merck products were sodium borohydride (NaBH4), sodium hydroxide (NaOH), L-ascorbic acid (C6H8O6), and potassium iodide (KI) (Germany). Before use, all glassware was soaked in 5 percent (v/v) HNO_3 overnight, rinsed with deionized water, and dried with a lab dryer (Okpashi, 2022).

2.4. Digestion of the soil samples

5 mL of 65 per cent HNO_3 was added to the samples, and the mixture was gently heated for 30 to 45 minutes. After cooling, the liquid was slowly heated with 2.5 mL of 70 percent $HClO_4$ until a dense white vapour formed. After allowing the mixture to cool, 10 mL of deionized water was added, followed by more boiling to expel the fumes (Hseu, 2004).

2.5. Procedure for Analysis

A Perkin Elmer atomic absorption spectrophotometer was used to test the redox elements (Analyst 800). To measure the metals in borehole water samples, three different AAS techniques were applied. Metals were measured using three distinct atomization platforms: FAAS for Cu, Zn, and Fe; GFAAS for Cd, Pb, and Ni, and HGAAS for As. The aqueous sample was inhaled into the flame atomizer of the nebulizer to determine the analyte concentration in parts per million in FAAS (ppm). GFAAS investigated lead, cadmium, and nickel Okpashi (2022). The instrument in GFAAS had a transversely heated graphite atomizer (THGA), which provided a uniform temperature distribution across the entire length of the graphite tube atomizer to avoid potential chemical interference effects. It comes with an auto-sampler system for accurate background correction (Zeeman correction). The HGAAS method was used to detect arsenic, which is based on the reaction of $NaBH_4$ with an acidified sample, which results in the total separation of the analyte as hydride from the matrix before measurement, reducing matrix interferences. The standards and samples were reduced from a pentavalent (V) to a trivalent (III) state of arsenate. This was accomplished by combining a reducing solution containing 5% (w/v) KI, 5% (w/v) ascorbic acid, and 10% HCl. The treated samples and standards were allowed to sit at room temperature for about 40 minutes before analysis, according to (Uddin1 *et al.*, 2016; Okpashi, 2022).

2.6. Data analysis and presentation

Statistical Products and Service Solutions (SPSS) version 21 was used to evaluate the data statistically. The information was presented in the form of means and standard deviations. With a significance level of ($P < 0.05$), statistical significance was calculated using an analysis of variance (ANOVA).

3.0. RESULTS

Soil samples Number and their definition

Ms1 represents soil sample 1 collected at Akamkpa, MS2 is soil sample 2 collected at Awi; Ms3 is soil sample collected at Ekong area, Ms4 is soil sample 4 collected at Okpong, Ms5 is soil sample 5 collected at Oban area, Ms6 is sample 7, collected at Mfamosing, Ms8 is sample 8 collected Asin-Okon, Ms9 is sample 9 collected at Asuk-Atam and Ms10 is sample 10 collected at Oko-ita, respectively.

Soil samples Number	*Lead (ppm)*	*Cadmium (ppm)*	*cobalt (ppm)*	*Nickel (ppm)*	*Copper (ppm)*	*Arsenic (ppm)*	*Chromium (ppm)*	*Zinc (ppm)*
Ms 1	0.1489 ± 0.005	0.0326±0.002	0.5385±0.002	1.8462±0.006	0.1617±0.012	1.8065±0.005	2.5677±0.001	1.1332±0.001
Ms 2	0.1489 ± 0.003	0.1986±0.001	0.1795±0.001	1.9487±0.011	0.0970±0.001	3.6129±0.002	2.5677±0.002	0.2165±0.002
Ms 3	0.1489 ± 0.005	0.0439 ± 0.11	0.1649±0.001	1.5128±0.002	1.0647±0.004	2.7097±0.002	1.3231±0.004	1.1818±0.001
Ms 4	0.2979 ± 0.001	0.1357±0.001	0.1648±0.003	1.7205±0.001	0.0323±0.002	1.1290±0.001	2.3231±0.002	1.1205±0.014
Ms 5	0.1489 ± 0.005	0.0357±0.006	0.1648±0.002	1.3077±0.003	1.0323±0.003	2.2581±0.012	3.3127±0.003	0.2165±0.001
Ms 6	0.2979 ± 0.001	0.0029± 0.002	0.1795±0.001	1.3154±0.003	0.0647±0.002	1.8065±0.002	1.6345±0.001	2.1475±0.001
Ms 7	0.1562 ±0.012	0.0714±0.011	0.8974± 0.005	1.7436±0.004	0.5173±0.012	0.6774±0.005	0.4667±0.011	0.8225±0.012
Ms 8	0.1275 ± 0.002	0.0000±0.000	0.3192±0.021	1.5385±0.021	1.0346±0.011	3.1613±0.001	2.4500±0.015	1.4632±0.011
Ms 9	0.2702 ± 0.004	0.0716±0.004	0.4891±0.002	1.7543±0.022	0.4850±0.013	1.8065±0.003	1.1667±0.0041	1.2727±0.021
Ms 10	0.1362 ± 0.022	0.0198±0.002	0.8792±0.001	1.3892±0.011	0.6231±0.004	1.3548±0.001	0.9333±0.022	1.2727±0.021
permissible limit	85 WHO (1996)	0.8 WHO (1996)	0.2–0.5 Mahey *et al.* (2020)	35 WHO (1996)	36 Osmani *et al.* (2015	13.12 Rahaman *et al.* (2012)	100 Osmani *et al.* (2015	50 Osmani *et al.* (2015

Values are presented as mean ± standard deviation in triplicate (n = 3).
Target values are specified to indicate desirable maximum levels of elements in unpolluted soils (Denneman and Robberse, 1990). SOURCE: WHO (1996) cited in Osmani *et al.* (2015). WHO permissible limits for heavy metals in the soil

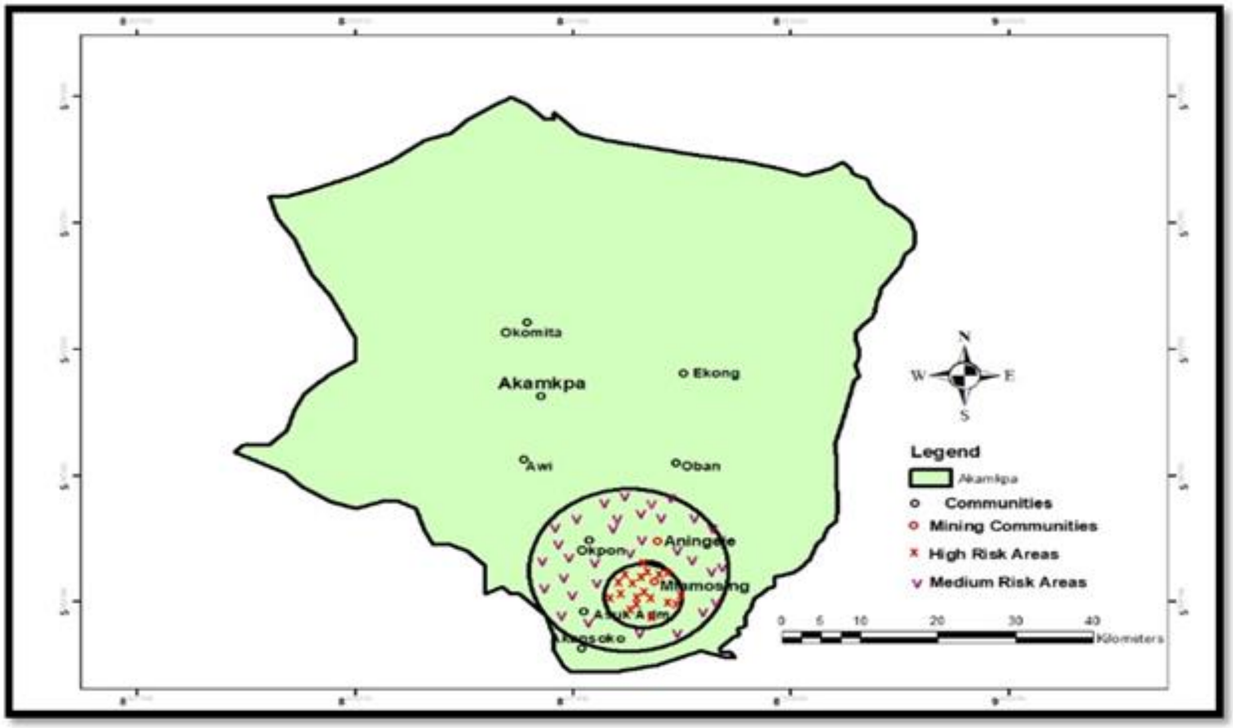


Figure 2: Health Risk Assessment

3.1. Spatial distribution and Geo-accumulation of redox-sensitive metals

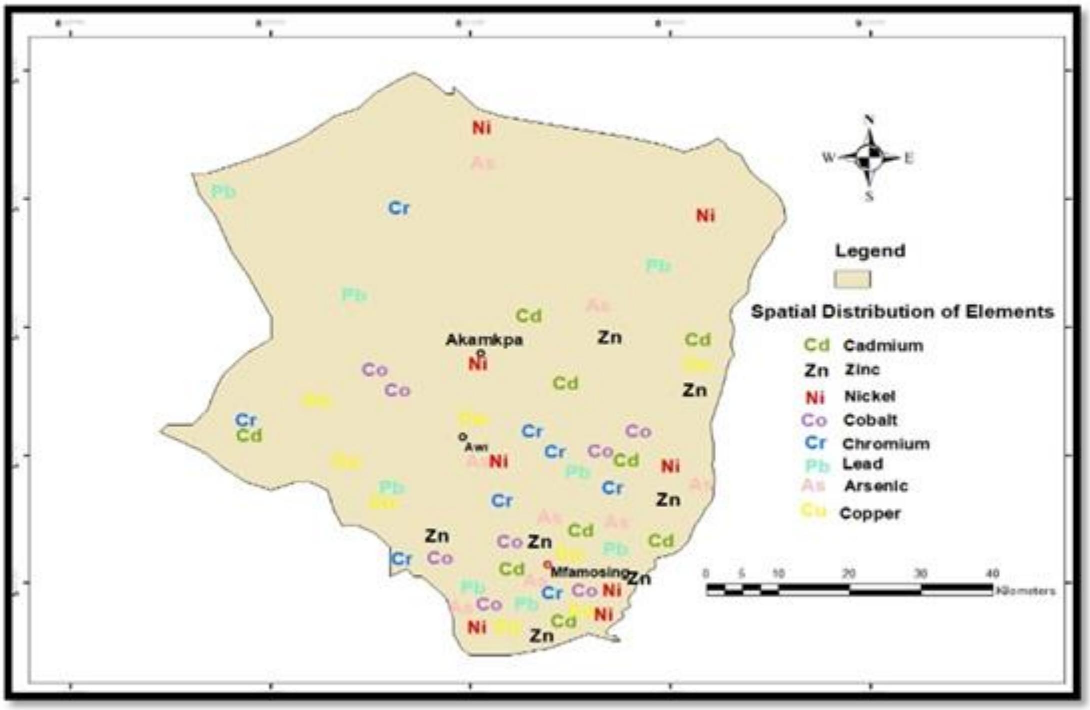
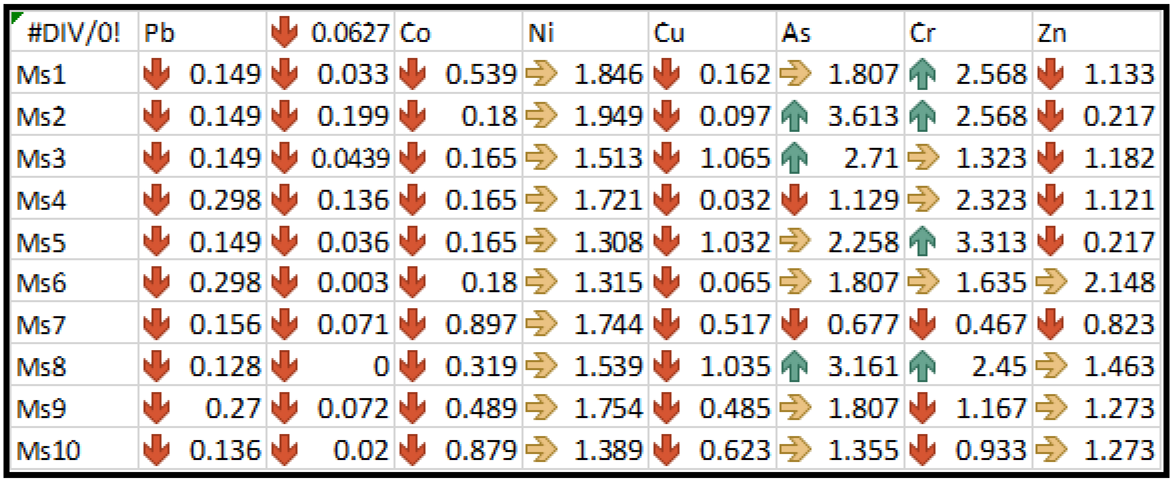


Figure 3: Spatial Distribution of redox-sensitive metals in Akamkpa Local Government

Table 2: Pollution Matric of Redox Sensitive Metals in Lafarge area



#DIV/0!	Pb	↓ 0.0627	Co	Ni	Cu	As	Cr	Zn
Ms1	↓ 0.149	↓ 0.033	↓ 0.539	→ 1.846	↓ 0.162	→ 1.807	↑ 2.568	↓ 1.133
Ms2	↓ 0.149	↓ 0.199	↓ 0.18	→ 1.949	↓ 0.097	↑ 3.613	↑ 2.568	↓ 0.217
Ms3	↓ 0.149	↓ 0.0439	↓ 0.165	→ 1.513	↓ 1.065	↑ 2.71	→ 1.323	↓ 1.182
Ms4	↓ 0.298	↓ 0.136	↓ 0.165	→ 1.721	↓ 0.032	↓ 1.129	→ 2.323	↓ 1.121
Ms5	↓ 0.149	↓ 0.036	↓ 0.165	→ 1.308	↓ 1.032	→ 2.258	↑ 3.313	↓ 0.217
Ms6	↓ 0.298	↓ 0.003	↓ 0.18	→ 1.315	↓ 0.065	→ 1.807	→ 1.635	→ 2.148
Ms7	↓ 0.156	↓ 0.071	↓ 0.897	→ 1.744	↓ 0.517	↓ 0.677	↓ 0.467	↓ 0.823
Ms8	↓ 0.128	↓ 0	↓ 0.319	→ 1.539	↓ 1.035	↑ 3.161	↑ 2.45	→ 1.463
Ms9	↓ 0.27	↓ 0.072	↓ 0.489	→ 1.754	↓ 0.485	→ 1.807	↓ 1.167	→ 1.273
Ms10	↓ 0.136	↓ 0.02	↓ 0.879	→ 1.389	↓ 0.623	→ 1.355	↓ 0.933	→ 1.273

Redox metals with a lower concentration, distribution, and geo-accumulation across the samples are shown by arrows pointing downward. The arrows pointing upward indicate higher concentration, and the ones pointing downward show redox components with moderate geo-accumulation.

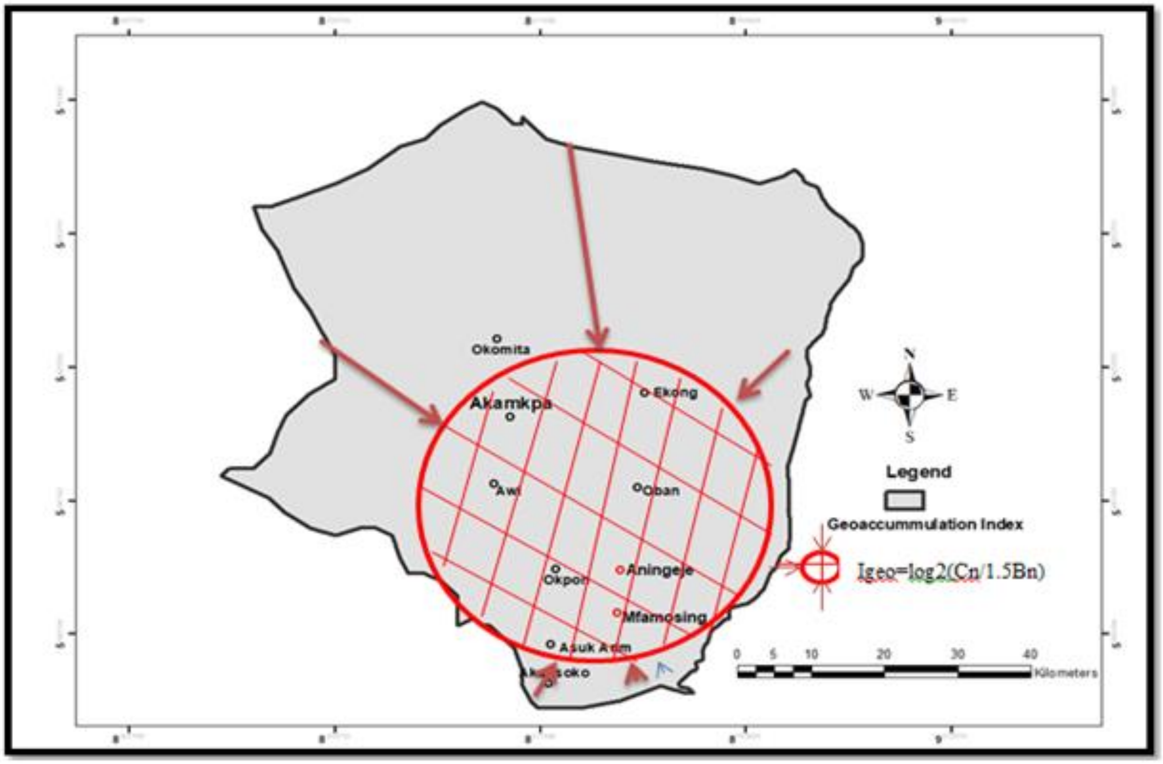


Figure 4: Map of Akampa showing Geo-accumulation Index

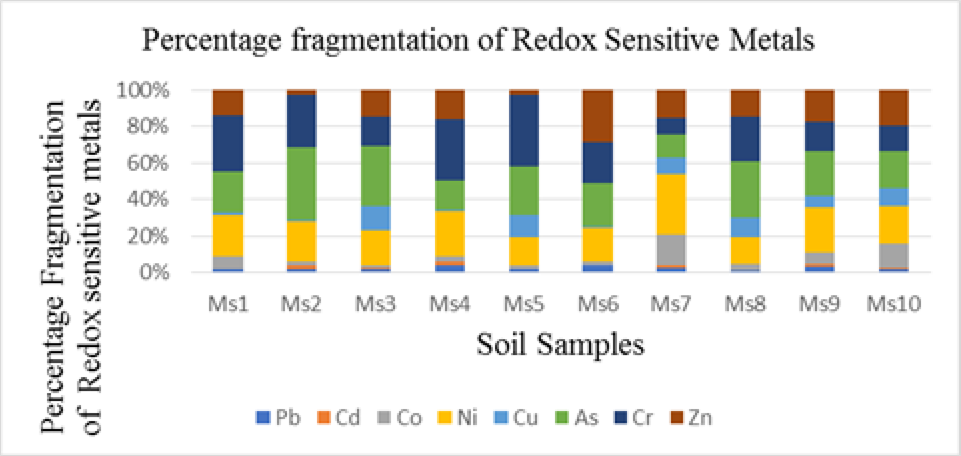


Figure 5. Percentage fragmentation of redox-sensitive metals per sample

This compares part of the whole and the percentage that each redox-sensitive metal value contributes to the total geo-accumulation in the tested samples. This also shows how a segment of the (whole) sample changes over time.

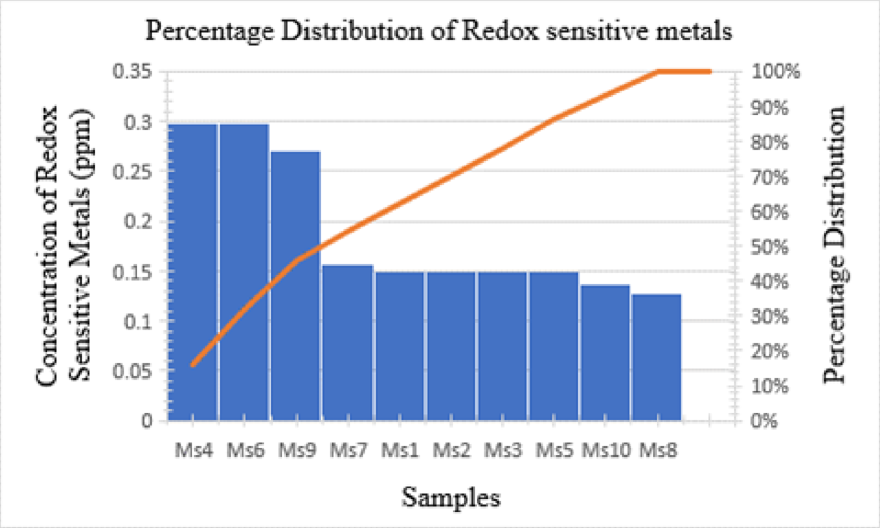


Figure 6: Percentage Distribution of Redox Sensitive Metals

DISCUSSION

Redox-sensitive metals in the soil can have a substantial impact on the soil fertility, ecological health, food safety, and food security of a certain locality due to their spatial distribution and geological accumulation. Soil samples from the Lafarge industrial area in Mfamosing, in the Akamkpa local government area of Cross River State, were used to evaluate the concentration, distribution, and geo-contamination of redox-sensitive metals (Cd, Cr, Cu, Ni, Pb, As, Co, and Zn). Several indices were taken into account to assess the impact of redox-sensitive metals brought on by Lafarge cement manufacture. An ArcMap 10:8:2 was utilized to infer the risk related to the population's health and safety, ecological sustainability, and biodiversity of the industrial area. Table 1 presents the findings on the levels of Cd, Cr, Cu, Ni, Pb, As, Co, and Zn in the soil samples. Concerning location and samples, the redox metal concentration varies. Arsenic was found to have the highest concentration in three samples—MS2, MS3, and MS8—after the examination, and chromium was found to have the second highest concentration in samples Ms1, Ms2, Ms5, and Ms8, respectively. See Table 2 for a visual representation.

Because of the presence of the Lafarge cement industry and other mining operations, the accumulation of redox-sensitive metals in the fields could pollute the agricultural soils. The quality and pace of agricultural growth will be hampered once the soil is contaminated, and there is also a risk to human health throughout the food chain. Humans are mostly exposed to redox metals through soil-to-crop transfer (Okpashi *et al*., 2020). In a nation like Nigeria, where agricultural operations are intensive and food production is high, monitoring pollutant levels in the soil is essential. Redox-sensitive metals present a serious risk to human health. Many can damage internal organs or promote the growth of cancer even at modest dosages. Cadmium, cobalt, lead, and nickel are also known to affect blood cell synthesis. These metals may interact with the cell surface, weakening their elasticity and decreasing their capacity to circulate throughout the body. Food, water, or, in the case of children, lead-painted objects are the usual sources of lead exposure. Lead can be eliminated in small amounts, but high or repeated doses of lead cause bioaccumulation in plants and animal's bodies (Steffan *et al.,* 2018). Long-term cadmium exposure has been associated with renal impairment (www.atsdr.cdc.gov/csem). Human bodies retain cadmium for many years. According to www.atsdr.cdc.gov/csem/, high exposure levels can also result in bone anomalies, lung illness, and lung cancer. Thomas *et al.* (2022) discovered a link between soil pollution and human disease. They claimed that arsenic, cadmium, and lead can cause cardiovascular problems. They do so by altering zinc-sulfur complexes, preventing nitroxide-mediated vasodilation, and interfering with antioxidant responses. Cadmium causes vascular damage, endothelial dysfunction, and other adverse effects (Messner *et al*., 2009; Messner *et al*., 2010; Cuypers *et al*., 2010). According to Almenara *et al.* (2013), heavy metals have negative impacts on the epigenetic control of gene expression. According to several findings, lead causes oxidative stress, inflammation, endothelial dysfunction, and vascular cell proliferation, all of which harm heart rate variability (Navas-Acien *et al*., 2007; Vaziri, 2008). Overall, lead and cadmium have numerous biological effects that are comparable. These chemicals may come from industrial activities (such as mining, quarrying, manufacturing, and product combustion) or they may seep into the ground through surface runoff during the rainy season. These redox metals have been associated with cardiometabolic problems such as obesity, endothelial dysfunction, atherosclerosis, cancer, and apoptosis (Miguel *et al.,* 2018).

Redox metals are mostly obtained from human activity and geochemical processes. The anthropogenic sources include industrial waste, agricultural chemicals, and municipal sewage discharge. The principal routes for residual redox-sensitive metals from human activities into soil ecosystems are groundwater, and atmospheric deposition (He *et al.,* 2018). Because it may be used to assess how human activities affect ecosystems and predict changes in redox-sensitive metals' biological consequences, determining the anthropogenic or natural sources of redox-sensitive metals is essential (Wang *et al.,* 2019). The redox metals Cr were found in very high quantities in (Ms5), Co (Ms7), Cu (Ms3), Zn (Ms2), and Pb (Ms4) values, as shown in Figure 3 and Table 1. Figure 3 clearly illustrates the regional distribution of Cu, Zn, and

Pb concentrations. This variation is visible in Figure 4's Cu, Co, Ni, and As. Figure 3 shows how the dangerous metals are widely scattered throughout industrial areas, such as Aningee, Mfamosing, and Okpong, respectively. The geo-accumulation lies near the right wing of the Lafarge corporation and is situated at the Mfamosing inlet, where Lafarge's wastewater flows.

This regional distribution of redox metal content was most likely to be influenced by the industrial dynamic settings. Some elements, such as Pb, Zn, As, Cd, and Cr, showed a rising trend in content from Ms1 to Ms10 samples. Mining and other anthropogenic activities could be to blame. Some plants' enrichment response to heavy metals existing in the soil may have an impact on redox-sensitive metal contents in the soil. During the field survey, different plant development patterns were observed in diverse locations. To uphold the idea of a safe operating environment for humanity and to protect the well-being of the earth for future generations, it is envisaged that a toxic-free environment will be developed. To address soil contaminants and their consequences on human health, the connections between soil health and human health are identified and promoted.

A parent chart was plotted to illustrate the distribution and concentration of redox-sensitive metals in descending order of frequency, with a cumulative line on the secondary axis as a percentage of the total geo-accumulation. This perhaps shows the samples with higher geo-accumulation of redox-sensitive metals. Observation shows that samples Ms4 and Ms6 were the highest, closely followed by sample Ms9. Samples Ms7, Ms1, Ms2, Ms3, and Ms5 were moderately distributed, relative to samples Ms10 and Ms 8. In the soil samples, eight redox-sensitive metals (As, Cd, Cr, Cu, Co, Ni, Pb, and Zn) were examined. The results indicated that several redox-sensitive metals had maximum concentrations that were over the acceptable level, but the overall redox-sensitive metal content of the soils was modest and did not surpass 40%. Redox-sensitive metal concentrations displayed substantial regional differentiation, except for samples Ms4, Ms6, and Ms9. The concentrations of redox metals varied little between the soil samples. Except for Cr, Pb, and As, a distinct vertical partition in the soil was seen, providing more proof of external influence in these soil samples, look at Figure 5. Except for fragmentary soil, samples from Ms8 and Ms10, which showed the degree of pollution in all other soil samples, it was deemed to be above the safe range. Consequently, the Mfarmosing area as well as both the adjacent districts are severely contaminated. As a result, the Lafarge cement industry and other mining activities such as quarrying in the Mfarmosing region pose a significant risk to the environment. The findings of the present investigation revealed that the main anthropogenic sources of redox-sensitive metal pollutants in the soils of Akamkpa were mining and cement manufacturing is progressively taking place.

Chromium only results in skin irritation and ulcers at low concentrations. However, prolonged exposure can cause cancer, damage to the renal tubules, and problems with the liver Okpashi, (2022). Like chromium, it may build up quickly in aquatic life (ATSDR Web site at URL: http://www.atsdr.cdc.gov/csem/csem.html). Arsenic exposure can result in respiratory issues, lung and skin cancer, decreased cognitive quotient, nervous system problems, and even death at high levels. Groundwater and soils can quickly get contaminated with arsenic through industrial processes and natural sources. Some plants can absorb arsenic through irrigation or other sources. In this case, the percentage distribution of the redox-sensitive metals was examined and present in Figure 6 which depicts the wide distribution of redox-sensitive metals across the samples. For instance, samples MS4 and MS6 had about 88%, MS9 had 80%, and MS7 had 42%. The percentage distributions for the other samples, Ms1, Ms2, Ms3, Ms5, Ms8, and Ms10, are, respectively, 40% and below. For illustration purposes, Figure 2 represents the health risk analysis of the study area, where neighbouring communities like Aningee, Mfamosing, Okpong, and Asin Oko are perceived to be at risk of redox-sensitive metal effects.

Conclusion

Lafarge Cement Company and other mining and quarrying activities in Akamkpa Local Government Area have prompted concerns about redox-sensitive metals that contaminated the farmlands. In the current investigation, 10 soil samples were taken from a location with a lot of industrial activity. To explore their spatial distribution patterns and geo-accumulation, eight redox-sensitive metals, including Cd, As, Co, Cu, Ni, Pb, Zn, and Cr concentrations, were typically identified. To examine source apportionment and potential threats to humans and ecological health, a geographical information system (GIS) was combined with Arc Map component analysis, matrix fragmentation (MF), and the geo-accumulation index. Several indices were taken into account to assess the impact of redox-sensitive metals. An ArcMap version of 10:8:2 was utilized to infer the risk related to the population's health and safety, ecological sustainability, and biodiversity of the industrial area. Concerning location and samples, the redox metal concentration varies. Arsenic was found to have the highest concentration in three samples—MS2, MS3, and MS8—after the examination, and chromium was found to have the second-highest concentration in samples Ms1, Ms2, Ms5, and Ms8, respectively. While exhibiting various patterns, the concentrations of As, Cu, Ni, and Zn were higher than those of Cr, Cd, Co, and Pb. The Asuk, Atim, Kagsoko, Oban, Mfamosing, and Aningee regions are in the general vicinity of the spatial distribution. The geo-accumulation index covers the following places: Awi, Oban, Mfamosing, Aningee, Okpon, and Ekong, respectively. One can reasonably imply the basis for the widespread distribution and geo-accumulation of redox-sensitive metals and their potential harm to humans and ecosystems by taking into account the mining and quarrying activities in these areas along with the presence of cement manufacturing at Mfamosing. As a way of advancing this investigation, some organisms within the area can be used to verify a metal's hazardous impact on the ecosystem and monitor the rise in redox-sensitive metals to determine the danger.

Declaration of Competing Interests

The author declares that he has no competing financial interests or personal relationships that could influence the investigation presented in this article.

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