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Assessment of soil heavy metal pollution in the coal mining region of Ugiamwen farmland, Uhunmwonde, Edo State, Nigeria

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ABSTRACT

Exploration of coal over the past years for economic improvement has led to soil degradation, heavy metal contamination, loss of crops and vegetation and threat to existence of biota. Heavy metal contamination from coal mining processes poses significant agricultural and environmental threats due to concentration and accumulation of toxic metals in the soil. This study investigated the concentrations of heavy metals such as Lead (Pb), Copper (Cu), Chromium (Cr), Arsenic (As) and Cadmium (Cd) in soil obtained from mining area of Ugiamwen farmland using the atomic mass spectrophotometry (AAS). Soil samples were collected from six sampling points with three replicates each within the Coal Mining Soil (CMS), adjacent Farmland Soil (FS) and control soil. Control soil was collected 200m away from the mining area, where no form of mining operation was done. The concentrations of Pb, Cr, Cu and As ranged from 0.120-2.700 mg/kg, 0.246-2.213 mg/kg, 4.950-132.7 mg/kg and 0.486-3.870 mg/kg, respectively. Cadmium was below detection limits in all soil samples analyzed.Mean and standard deviation were calculated, the data obtained was subjected to one-way analysis of variance. Signiant difference in mean values was differentiated with Duncan's multiple range test (DMRT) at $P \leq 0.05$. The increase in heavy metal concentrations was linked to the leaching of wasted coal materials, use of explosive devices employed during the mining activities and emissions from heavy duty mining equipment. Findings obtained from this study confirmed the presence of heavy metal pollution in the mining area highlighting agricultural and environmental implications accompanied with the activities of coal mining.

KEY WORDS

Coal mining; Ugiamwen; Soil pollution; Metal concentration

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Introduction

Coal is an important fossil fuel which is widely used for electricity generation and industrial energy production in some countries around the world [1]. The exploration and utilization of coal resources have been going on for hundreds of years affecting the surrounding environment by polluting the nearby soil, water, air (coal dust) and agricultural lands [2]. Mining activity generates an extensive amount of waste material which is deposited on soil surface, such deposition changes nutritional and functional properties by disrupting soil microbial population, texture, organic and mineral components [3]. Most steel and cement industries use coal as fuel for extraction of iron from iron ore and for cement production [4]. Exploitation of mineral resources has been an important approach for national development globally [5]. Modern and organised mining began in Nigeria in 1903 with the Mineral Survey of the Northern Protectorate by the British colonial governments. The first legislation on mining was enacted in 1946 which was only reviewed in 1999 before the present operational Nigeria Mineral and Mining Act (NNMA) [6]. In the United States of America, United Kingdom and South Africa coal mines and its structures are called colliery. In Australia, colliery generally refers to an underground coal mine [7]. Coal mining has had a lot of development in the recent years, from the early days of men tunnelling, digging and manually extracting the coal on carts to large open cut and long wall mines. Soil contamination with heavy metals has become one of the most severe environmental hazards [8]. High levels of metals in soil decrease crop production, but also threaten human health once metals enter the food chain and increase the risk of transfer to food products [9]. Heavy metals are introduced in the environment through natural as well as anthropogenic sources. While parent rocks and metallic minerals dominate the natural sources, the anthropogenic sources range from agricultural activities such as fertilizers, animal manures and pesticides applications; metallurgy activities which include: mining, smelting and metal finishing; energy production (leaded gasoline, battery manufacture and power plants). The pollutants could be released in gaseous, particulate, aqueous or solid form depending on the mining operation [10]. The most common heavy metals found at contaminated sites in order of abundance are Pb, Cr, As, Zn, Cd, Cu, and Hg [11]. Those metals are important since they are capable of decreasing crop production due to the risk of bioaccumulation and biomagnification in the food chain. There is also the risk of groundwater contamination. Knowledge of the basic chemistry, environmental and associated health effects of these heavy metals is necessary in understanding their speciation, bioavailability, and remedial options. The fate and transport of a heavy metal in soil depends importantly on the chemical form and speciation of the metal. Soil is an important component of the biosphere because it does not only serve as a geochemical sink for contaminants but also acts as a natural buffer controlling the transport of chemical elements and substances to the atmosphere and living system.

Soil productivity is one of the important functions as it forms the foundation of agricultural production and human survival [12]. However, coal mining activities can adversely affect soil quality and agricultural productivity through the release of pollutants

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including potentially toxic heavy metals. In Ugiamwen Edo State, local farmers reported increased in dust emissions associated with coal mining operations accompanied by decline in crop yield and quality. The farmers also observed symptoms of plant stress, including foliar damage and premature senescence in crops cultivated near mining area. Despite several studies on the environmental impacts of coal miming in Nigeria, information on heavy metal pollution of soils in the Ugiamwen coal mining area remains limited. Consequently, this study investigated the levels of heavy metal pollution in soils collected from the Ugiamwen coal mine region, Edo State, Nigeria. Previous studies have examined the environmental effects of coal mining in different parts of Nigeria. For example, Ezeh and Chukwu investigated heavy metal contamination of agricultural soils surrounding the Enugu coal mines, while Okafor and Onwuka assessed pollution of soils in Coal Camp and Abakpa Nike areas of Enugu resulting from coal waste disposal [13,14]. Similarly, Adaikpoh et al evaluated heavy metal concentrations in coal and sediments from the Ekulu River in Enugu State [15]. Aliyu examined the effects of coal mining on agricultural land in the Maiganga community of Gombe State, whereas Abubakar investigated the socioeconomic implications of coal mining in the same area [16,17]. Furthermore, Maina et al assessed the environmental impacts of coal mining in the Maiganga community of Akko Local Government Area, Gombe State, with particular emphasis on its socioeconomic consequences [18]. However, these studies did not evaluate the heavy metal pollution of soils in the Ugiamwen coal mining region, thereby necessitating the present investigation.

Materials and Methods

The study area

Ugiamwen village is located in Uhunmwode Local Government Area of Edo Sate. It lies between latitude: 6°40′39″ S - 5°59′40″ S and longitude: 6°40′39″ S - 5°59′40″ S. The area benefits from the tropical climate with average annual rainfall of 1475 mm. According to Aigbe and Odulami, the soils of the study area are moderately deep to very deep, well-drained sandy loam soils [19]. The area experiences a mean annual temperature of 25.5°C and mean annual rainfall of approximately 1,755 mm. Rainfall exhibits marked seasonal variation with the lowest average monthly rainfall occurring in January (10 mm) and highest in September (311 mm). While, the hottest month of the year is March [20]. The climate of the area is changing due to human activities such as mining operations, bush burning and deforestation. Human activities are thought to be having effects on food crop agriculture the study area. Incidentally, the major employer of labour in Uhunmwode Local Government Area is agriculture, which provides more than 70% of food for the people. Crops such as such as pepper, maize, cassava, potato, yam and vegetables are grown are in the area (Figure 1) [21].

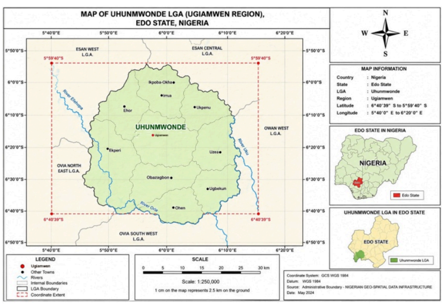

Figure 1: Map of the study area adapted from Administrative Map of Edo State obtained from the National Boundary Commission (NBC) Nigeria and the Office of the Surveyor General of the Federation (OSGOF). Geographic Coordinate System (GCS), 1984.

Soil collection

Soil samples were collected from three different locations to investigate the effects of coal mining on soil quality and heavy metal concentration. The first sampling site was the CMS located within the active mining area. This site was directly influenced by mining operations including the presence of mine waste deposits making it suitable for assessing the concentration of heavy metals associated with coal extraction activities. The second sampling site was the FS located close to the mining location. These farmlands are actively used by local farmers for growing of crops. Soil samples from this area were collected to determine if heavy metals from the mining site had leached into nearby agricultural soils through runoff, erosion and atmospheric deposition of mining activities. Investigating the FS was necessary to understand the possible effects of mining activities on soil fertility in the surrounding community. Also, control soil (CS) samples were collected from an uncontaminated area located far from any mining activity. These control soils provided baseline values for comparison with the mining and farmland soils, allowing for a clearer assessment of the level of contamination associated with coal mining activities.

Preparation of experimental pots

Six (6) sampling points at a distance of 10m from each spot were mapped out for soil sample collection within the sampling sites using clean stainless-steel shovel at 0-15cm depth. Each sampling point distance was known to be; ten meters from the CMS1, twenty meters from the CMS2, thirty meters from the CMS3, forty meters from the CMS4, fifty meters from the CMS5 and sixty meters from the CMS6. The same was written for distances in farmland soil which means; ten meters from farmland soil (FS1), twenty meters from farmland soil (FS2), thirty meters from farmland soil ((FS3), forty meters from farmland soil (FS4), fifty meters from farmland soil (FS5) and sixty meters from farmland soil (FS6). The collected dried soil samples were thoroughly mixed in clean plastic bucket to obtain a composite sample. Each experimental pot contained 4kg soil.

Digestion of Soil samples

Five grams (5g) of the homogenized sample was taken and made it to fine powder and further dried in hot air oven at 70°C for 72 hrs. A weight of 0.1 g each of soil sample was taken to perform soil digestion. Added to the soil, was 9 ml of concentrated HCl and 3 ml concentrated $HNO3$ in a beaker covered with watch glasses and placed on a hot plate for 3 hr at 110°C. The digests were cooled and 20 ml 20% $HNO3$ was added. After cooling and filtering through Whatman 6 no. 42 filter paper filtrate was diluted to 100 ml with double distilled water [23,24].

Data analysis

Mean and standard deviation were calculated from data collected. One-way analysis of variance (ANOVA) was carried out using IBM SPSS Statistics for windows, version 20.0. Significance of mean values was done by using the Duncan multiple range (DMR) test at $P \leq 0.05$.

Results

Heavy metal concentration in soil

The concentrations of heavy metals detected in the soil samples are presented in Figure 2-5 for Pb, Cu, Cr, and As, respectively. The results show the differences in heavy metal concentrations across the various sampling area such as CMS, adjacent farmland soil (FS) and control soil (CS). The determination of these metals is significant because their prolonged concentration and accumulation can adversely affect soil fertility, crop growth and

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development. Additionally, increase in levels of heavy metallic substances pose threats to public and environmental health due to their constant and potential transfer across the food chain through crops that are grown. Therefore, the result presented justified evaluating the agricultural impact of coal mining and the potential environmental threats accompanied with heavy metal concentration in the study area.

The concentration of lead concentration in soil obtained from coal mining area is shown in Figure 2. The results showed that the highest Pb concentration were recorded in CMS5 and CMS6 followed by CMS4. Significantly increase in Pb concentration was noted in FS1, indicating potential dispersion of leachates of contamination from the mining source into the adjacent farmland soil.

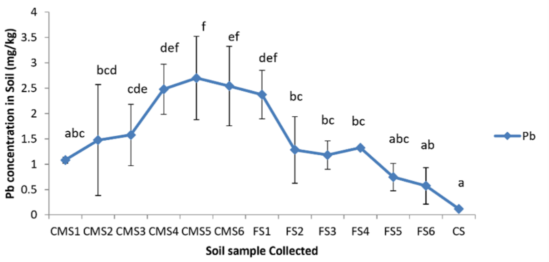

Figure 2. Lead concentration in soil obtained from coal mining area. Error bars represent standard deviation. Different alphabets indicate significant differences using DMR test (p ≤ 0.05). CMS = Coal Mining Soil, FS = farmland soil, CS = control soil.

The concentration of Cu analysed in soil collected from coal mining area is presented in Figure 3. The highest concentration Cu was found in CMS5. The elevated concentration of Cu noted at CMS is associated with accumulation of coal waste, release of Cu from coal associated materials and persistent mining disturbances. Ecological processes which include erosion and runoff also contributed to the dispersion of Cu within the mining environment. Conversely, the least Cu concentration was recorded in the CS signifying minimal contamination and indicating that mining processes are the major source of increased copper levels in the soil.

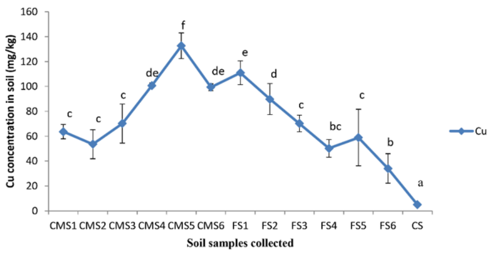

Figure 3. Copper concentration in soil obtained from coal mining area. Error bars represent standard deviation. Different alphabets indicate significant differences using DMR test (p ≤ 0.05). CMS = coal mining soil, FS = farmland soil, CS = control soil.

Figure 4 shows the concentration of chromium (Cr) in soil obtained from CMS and adjacent farmland soil. The results revealed noticeable variation in Cr concentration across the different sampled points, indicating the influence of coal mining activities on Cr distribution within the study area. The highest mean Cr concentrations were recorded in CMS in the order CMS1 > CMS2 > CMS3 > CMS4 > CMS5 > CMS6. In contrast, the pattern of Cr in FS was on the decrease considering distance (70m) away from the mining point, but with clear accumulation.

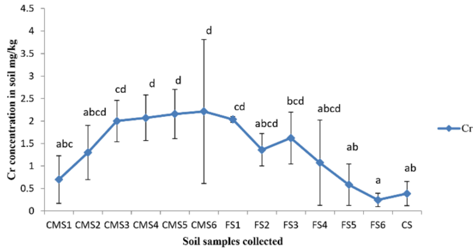

Figure 4. Chromium concentration in soil obtained from coal mining area. Error bars represent standard deviation. Different alphabets indicate significant difference using DMR test (p ≤ 0.05). CMS = Coal Mining Soil, FS = Farmland Soil, CS = Control Soil.

Arsenic concentration in soil obtained from coal mining area is shown in Figure 5. The gradual decrease in arsenic concentration from CMS2 - CMS6 may indicate dilution effects and increasing distance from the major contamination source within the mining area. On the contrary, a different pattern of arsenic concentration was observed in the FS samples from FS1 - FS6.

In contrast to the relatively consistent decrease in pattern observed in the mining soil the distribution of Arsenic (As) in FS showed heterogeneous trend indicating variation in concentration across FS. This variability was attributed to differences proximity of adjacent farmland to source of contamination particularly eroded materials from coal mining activities and soil hydrological properties.

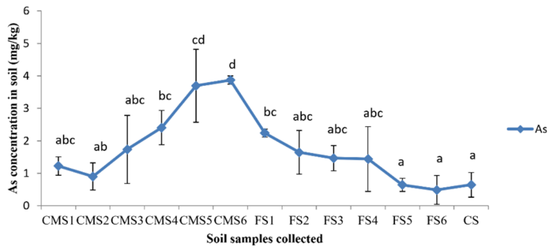

Figure 5. Arsenic concentration in soil collected from coal mining area. Error bars represent standard deviation. Different alphabets indicate significant difference using DMR test (p ≤ 0.05). CMS = coal mining soil, FS = farmland soil, CS = control soil.

Discussion

Ogbonna et al. reported that coal mining area is known to be a major source of contamination with heavy metals because of the release and accumulation of toxic elements in the surrounding soil [25]. In this study, the increase in concentration of heavy metals is attributed to mining activities such as use of explosive devices, excavation, distribution and transport of coal dust on the surfaces of the soil. Particles of suspended particulate matter produced during mining activities also led to the deposit of heavy metal into surrounding soil during rainfall. Also, the topography of the study area facilitated the transfer of contaminated runoff from the mining source to adjacent farmlands thereby enhancing the distribution of heavy metals. Lead (Pb) concentration recorded in this study were highest at CMS5 located 50m from the coal mining point. Similar findings have been reported in previous works of Freitas et al., stating that elevated Pb concentration in soil nearby Sao Domingos coal mine in Portugal [26]. While, Ogbonna et al noted highest Pb levels near the Oyeama coal mine site in Enugu State, Nigeria [25]. The elevated Pb levels contributed to the contamination of

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surrounding farmlands, negatively affecting growth, quality and safety of agricultural produce thereby posing risks to the food chain and human health. Relatively, elevated Pb concentration detected in FS1 resulted from contamination associated with the mobility of heavy duty vehicles and tractors employed for transportation of coal. Increase and occurrence of Pb in nearby farmland soil are worrisome due to its toxicity. Hence, it has been linked to poor crop growth and productivity [27]. Coal mining activity generates large number of unwanted materials such as wastes coal ash and rocks resulting in high deposition of metals such as Cu in soil. Matthews et al noted that Cu concentrations are high in coal mining area [28]. Results obtained in this study also showed similar pattern of copper concentration in soil. High concentration of Cu in soil plays cytotoxic role induces injury to plant. This leads to plant growth retardation and leaf chlorosis [29]. In this study, it was observed that Cu was found high in FS6 and CMS5. The highest concentration of Cu in soil samples was found in CMS4 and CMS5 which is injurious when in contact with plant roots at these levels. Arsenic (As) concentration varied in soil obtained in this study. Elevated concentration of as was detected in CMS5 and CMS6. The high increase of as concentration can be related to presence of the mine explosive devices employed during mining process and vehicular contamination too. This report is in tandem with the report of Zhou et al who described elevated concentration of As in soil nearby the Dobaoshan mining area in China [30]. Arsenic is not essential to plant growth. Inhibition of flowering, retarded fruit development and loss of fertility and reproductive characters of plants compromised by contamination. Chromium (Cr) concentration was also found to be elevated in soil obtained from farmland soil. The distribution trend showed that Cr have been disperse via flood water movement and overflow from mining area into adjacent agricultural soil. Several studies like Ishtiaq et al. reported the toxic effects of Cr is associated with coal waste pollution [31]. Also, Kazakis et al. reported that Cr leachates provided for over 90% of total Cr contamination in the Sarigkol mine basin in Northern Greece [32]. Synonymously, the present study findings indicated that coal mining activities in Ugiamwen mine site contributed significantly to Cr concentration and accumulation in boarding farmland soil. In general, findings from this study showed that coal mining processes contribute greatly to heavy metal concentration in soil nearby Ugiamwen mining area, hence posing potential agricultural and ecological risks.

Conclusion

This study confirmed the presence of toxic heavy metals in soils surrounding the Ugiamwen coal mining area, indicating the significant environmental impact of mining activities within the region. The elevated concentrations of metals observed in the coal mining and adjoining farmland soils suggest potential risks to soil quality, agricultural productivity, and ecosystem health. Furthermore, the topographic characteristics of the area favour intense gully erosion and the rapid accumulation and dispersal of contaminants. These conditions may enhance the mobility of heavy metals into surrounding agricultural lands and water bodies. Therefore, continuous environmental monitoring and the implementation of appropriate pollution control measures are strongly recommended. Further studies are also necessary to evaluate the extent of heavy metal uptake by crops cultivated within the area and the associated implications for food safety and public health.

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Disclosure Statement

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