ISSN: 2836-3655
Advances in
Hydrology & Meteorology
DOI: 10.33552/AHM.2024.02.000535
Iris Publishers

Research Article

Assessment of Groundwater Contamination and Bioaccumulation Risks Due to Mining-Induced Land Deformation in Southern Nigeria

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Received Date: October 21, 2024

Published Date: November 06, 2024

Abstract

The review evaluates the risks inherent in the mining-induced changes in the groundwater table and the accumulation of pollutants as a consequence of mining in Southern Nigeria. It particularly targets the effects of mining, for example, gold, lead, zinc, barite and others on water resources including the polluting of groundwater with such metals. Thus, through a systematic literature review method, this study synthesizes prior research drawn from different databases, for instance, Scopus and Web of Science. The authors have discussed primary contamination channels as leaching from the mine tailing, surface runoff, and fractures associated with subsidence that facilitate the percolation of toxic ions, including lead, cadmium, and mercury, into the groundwater systems. The study reveals that several mining locations in Southern Nigeria contain groundwater pollutants beyond globally acceptable standards, which put the health of the populace and the environment in considerable danger. Also, the storage of heavy metals in plants and animals is detrimental to human food safety and regional food supplies, anchored on contaminated water used in farming and for human consumption. A few gaps were noted in the course of the review; most of the studies are cross-sectional, with no follow-up results or initial rates of contamination. Future investigations are needed to fill these deficiencies, enhance mine operations, and develop treatment strategies to protect water and health. It therefore implies that there is a need to first develop strictly even more environmental standards and secondly, that effective groundwater monitoring programs should be kicked off to reverse the effects of mining on ecosystems and the communities that depend on them.

Keywords: Groundwater contamination; Bioaccumulation; Land deformation; Mining; Nigeria; Environmental Risk

Introduction

There is a need for an assessment of groundwater pollution potential and possible buildup of contaminants in Southern Nigeria, given the region's significant reliance on agriculture and freshwater sources. Consequently, the research findings of studies show that mining has detrimentally influenced water quality since lead and cadmium, for example, have been detected in water samples. These concentrations are above the WHO safety standards for human consumption, thus presenting human and agricultural products' safety hazards [1, 2]. Thus, there is a body of evidence that human activities, especially mining impact the quality of groundwater and can cause potential health risks to the population of the area [3, 4]. Furthermore, it has also been established that agricultural activities contribute to high levels of nutrients, and consequently, cause high incidences of groundwater pollution [5]. Altogether, such factors pose a great threat to food security and the welfare of the rural people in particular and the society as a whole in general. That is why, special attention should be paid to the protection of water and crops in the region, which can be contaminated by various substances [4, 5].

The findings presented here affirm that the properties to small-scale miners in Southern Nigeria have a considerable impact on the environment. Such activities have caused land deformation and in particular subsidence and surface cracking have been observed. The consequence is the destabilising of the terrain and the interference with the natural watershed and rains that are essential in sustaining groundwater quality [6, 7]. These excavation processes often lead to the informal discharge of various toxic heavy metals for example lead and barium into the environment. This is a big risk to communities that are located close distance to the plants and industries [8]. Pollutants penetrate the aquifers that provide drinking water especially to rural dwellings hence, causative agents of diseases [9]. The unsupervised and often unsafe methods of mining further contribute since such mines violate environmental measures, which in turn raises the chances of polluting natural resources [10]. These environmental and health risks should be mitigated at the earliest instance possible since current communities rely on groundwater for daily use. The inability to afford treated water also further enhances the vulnerability of such populations as explained by [10].

The farming system in Southern Nigeria is comprised of smallholder farmers and because crops are in close contact with the mining sites, the land is at a higher risk of bioaccumulation. Researches have in many ways shown that lead, cadmium, arsenic, and many other forms of heavy metal pollute the soil and water resources leading to the accumulation of the metals by crops like Telfairia occidentalis and Talinum triangulare. These crops have revealed higher concentrations of these metals than the acceptable WHO/FAO permissible limit [11]. In addition, cross-sectional studies carried out at artisanal mining areas showed that hazardous metals in common food crop varieties cause bioaccumulation, thus making them potentially dangerous to human health when ingested [12]. Consumption of such crops leads to chronic diseases such as kidney diseases and neurological disorders [13]. In addition, the animals that are usually found in such areas or those that drink such water are also affected and the toxins produced from them may find their way into the food chain through animal products [2]. Thus, carefully coordinated surveillance and outstanding intervention measures are essential to protecting the population in this area.

Land alteration, especially due to the activities of mining, affects considerably the movement and persistence of bad things in the environment. Ground changes due to mining, such as subsidence and fractures create areas in which pollutants, including heavy metals, spread more quickly. For instance, subsidence may cause the formation of depressions that capture any incoming water and contaminants concentrating them, and deeper infiltrating into aquifers [14]. In addition, the making of soil cracks allows for contaminant flow around natural filtration processes that might normally restrain pollution [15]. It has great impact on the movement and persistence of such harmful substances in environment resulting from alteration of land, particularly as a result of mining activities. The mining caused ground changes, and they disrupt natural groundwater flow, making that water more effective at spreading pollution like heavy metals. For instance, subsidence produces depressions in which water and contaminants accumulate and then concentrate before being further infiltrated into aquifers [14]. Additionally, soil cracks that form allow contaminant flow around natural filtration processes that would normally reduce pollution [15].

In Southern Nigeria, it is highly essential to quantify the level of contamination of groundwater and health risks associated with it given the poor health care infrastructure of the country. Pervasive occurrence of heavy metals such as lead (Pb), arsenic (As) and cadmium (Cd) in groundwater were studied in several numbers and usually have exceeded the limits established by the World Health Organization (WHO). This is a massive public health issue for at risk populations such as children and the elderly [16, 17] This type of contamination may have serious adverse effects on human health, including heavy metal poisoning, and the exposure of individuals to this type of pollutant may be prolonged. [18] documented this can become a difficult condition to treat once a toxic level has been reached. Also, heavy metals from mining activities are influencing the accumulation of heavy metals in soil and water and later affecting the ecosystems, leading to biodiversity loss [19-21] have reported that heavy metals like lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) are bioaccumulating in mining affected regions of Southern Nigeria, which are a big environmental and health hazard. The degradation of the environment to which communities rely for their survival for their livelihood poses a major threat to food security. This highlights the urgent imperative of sound environmental management and regulation against exposure to the hazards under discussion [22, 18].

The aim of this review is thus to discuss the current state of knowledge regarding the influence of mining induced land deformation (including, for example, subsidence or fracture in the surfaces) on the contaminancy of groundwater and the bioaccumulation of heavy metals. This study is concerned with phenomena known to exist in southern Nigeria but which require further study, and research gaps. Further, the review provides geotechnical strategies for minimising groundwater contamination risk, and presents practical strategies to reduce land deformations and control pollutant pathways in mining regions. The end effect is that water resources will be protected and environmental health hazards will be decreased.

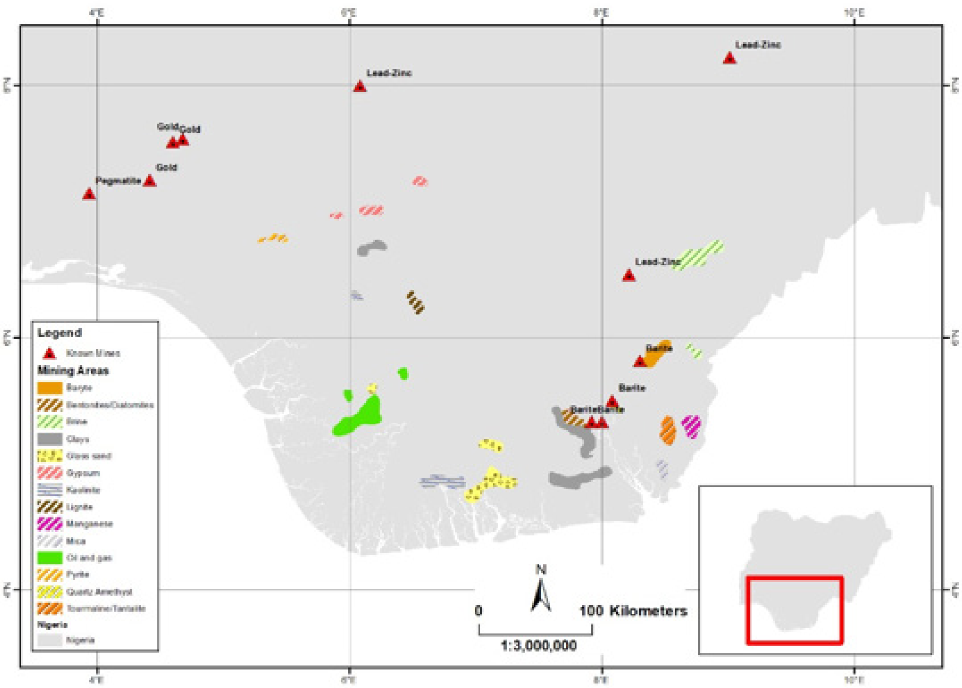

Figure 1: Geologic map showing the Mining areas in Southern Nigeria.

Methodology

A comprehensive and systematic approach to conducting a review was used using a number of databases. It was comprised of Scopus, Google Scholar and Web of Science. This study aimed at evaluating the possibility of groundwater contamination and bioaccumulation due to land deformation of mining induced nature in southern Nigeria. To identify important peer reviewed studies looking at the effects of heavy metals, like lead, zinc, cadmium and mercury, we used a combination keyword search that includes "mining induced land deformation" and "groundwater contamination." Studies which were considered to apply to Southern Nigeria and mining related contamination and which used rigorous methodology within the last decade (10 years) (2014) are considered. We excluded those which were unrelated to mining or focused on other regions.

The data extraction process concentrated on the following aspects: the location of study areas, geological properties of the areas to be studied, type of mining activities that were carried out the routes of contamination of the heavy metals detected. Although the study's limitations, including lack of long-term monitoring, are recorded, the key findings documented contamination levels which exceed WHO and FAO standards. A qualitative synthesis was performed to identify common contamination pathways: leaching, and runoff. The heavy metal concentrations were quantitatively compared against international standards. A meta-analysis was attempted when data were available in sufficient quantity. Risk assessments were also conducted to estimate health risks associated with groundwater contamination.

Mining-Induced Land Deformation and Groundwater Contamination

Mining Activities in Southern Nigeria: An Overview

Southern Nigeria has traditionally known of its diverse Geological and Mineralogical environment and thus encouraged mining activities (figure 1) (table 1). In their assessment of heavy metal pollution in the gold mining areas of southwestern Nigeria, [23] were carried out. The information includes pictures of leaching from mining sites, but without seasonal data. On the other hand, the work of [24] was directed towards the exploration of barite mining in Cross River State. Of particular value was their understanding of weathering as a conduit for contamination of mine tailings. No surface soil samples were taken, however. In a further study, [25] undertook study in soil and water contamination from lead and zinc mining in the south-eastern region of Nigeria (Ishiagu) with

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particular consideration for land subsidence and soil leaching through soil channels. But the authors did not show long term monitoring data. Another study [20] followed, identifying lead-zinc mining in Abakaliki and seepage through aquifers. In addition, the scope of the study was limited by the lack of control sites.

The study done by [26] also demonstrated that investigations on abandoned lead-zinc mines in Enyigba revealed subsidence of the mines. Nevertheless, the data set had surface water samples only. According to [21] vibration from mining activities to the earth due to seismic waves and runoff were observed in the Ebonyi State. [27] investigated the leaching of pegmatite minerals into groundwater in the vicinity of Ibadan but without specific groundwater analysis. [28] evaluated the effect of mining on the Benue Trough; formation of sinkholes and contamination of groundwater. In addition, studies by Ochelebe et al. (2020) showed environmental impacts from surface runoff from barite mining in Akamkpa and Biase.

Table 1: Case studies of Mining activities in southern Nigeria.

Author & Year	Methodology	Study Location	Geological and Geotechnical Characteristics of the Region	Mining Activity/ Mineral Mined	Geotechnical Mechanisms Leading to Subsidence	Pathways of Groundwater Contamination	Limitations of Study
Abiya, et al. (2018) [23]	Heavy metal pollution assessment, field sampling	Southwestern Nigeria	Gold-bearing schist complex	Gold mining	Not assessed in the study	Leaching from gold mining areas	Limited data on seasonal variations
Adamu, et al. (2015)[24]	Geochemical analysis, health risk assessment	Cross River State, SE Nigeria	Sedimentary terrain of barite deposits	Barite mining	Not reported	Weathering of mine tailings	Sampling limited to surface soils
Chukwu & Oji (2018) [25]	Soil and water contamination analysis	Ishiagu, SE Nigeria	Carbonate-hosted lead-zinc deposits	Lead-zinc mining	Mine-induced soil subsidence	Leaching through soil and water channels	Lack of long-term monitoring data
Obasi & Akudinobi (2019) [20]	Water sampling, hydrogeochemical analysis	Abakaliki, SE Nigeria	Lead-zinc formations in Abakaliki anticlinorium	Lead-zinc mining	Not assessed	Seepage through porous aquifers	Lack of control sites
Obasi (2020)[26]	Heavy metal concentration analysis	Enyigba, SE Nigeria	Crystalline basement rocks, lead-zinc mineralization	Lead-zinc mining	Mine collapse-related ground subsidence	Seepage from abandoned mines	Limited to surface water samples
Ugochukwu, et al. (2022) [21]	Soil, sediment, and water analysis	Ebonyi State, SE Nigeria	Lead-zinc mining zones of Abakaliki Anticlinorium	Lead-zinc mining	Seismic vibrations from mining activities	Runoff from mining activities	Economic cost analysis is limited
Okonkwo, et al. 2021 [27]	Soil contamination analysis	Olode, Ibadan, SW Nigeria	Pegmatite formations	Pegmatite minerals	None mentioned	Leaching into groundwater	Lack of groundwater analysis
Igwe, et al. 2017[28]	Environmental risk assessment	Southern Benue Trough, Nigeria	Lead-zinc deposits in fractured sedimentary rocks	Lead, Zinc	Sinkholes from mine collapse	Leaching through permeable soils	Limited spatial data on contamination
Ochelebe I, Nkebem G E, Kudamnya EA (2020) [29]	Heavy metals concentration assessment	Akamkpa and Biase, SE Nigeria	Sedimentary formations with barite mineralization	Barite	None mentioned	Surface runoff from mine sites	Lack of time-series data
Odukoya et al. (2018) [30]	Groundwater quality assessment, heavy metal pollution analysis	Ogun State, SW Nigeria	Basement complex rocks with mineralization zones	Gold mining	Not assessed	Leaching from abandoned mining sites	Limited spatial data, lack of long-term monitoring
Obiora, et al. (2019)[31]	Geochemical analysis of soils and food crops	Ishiagu, SE Nigeria	Carbonate-hosted lead-zinc deposits	Lead-zinc mining	Not mentioned	Leaching through soil and water	Focuses on specific crops and soils
Ochelebe I, Kudamnya EA, Nkebem GE (2020) [32]	Water quality assessment, heavy metal pollution analysis	Akamkpa and Biase, SE Nigeria	Barite mineralized sedimentary rocks	Barite mining	None assessed	Leaching and runoff from mine tailings	Absence of pre-mining baseline data
Wasiu, et al. (2016)[33]	Water and sediment analysis	Southwestern Nigeria	Sedimentary deposits	Gold	Erosion and sedimentation	Runoff into streams	Lack of baseline contamination data

Mechanisms of Mining-Induced Ground Subsidence

The occurrence of mining induced ground subsidence in Southern Nigeria has been extensively researched, to reveal different geotechnical mechanism in different geographical areas.

In Ishiagu, South-east part of Nigeria, as reported in [25] subsidence has been observed as a result of mining lead and zinc from carbonate hosted deposits which weaken the support strata due to extraction of mineral resulting to ground collapse. While there was no long term monitoring data to add to this picture, this collapse resulted in significant leaching through soil and water channels. Similarly, in Enyigba, [26] underscored the importance of mine collapses in cracks in the crystalline basement rocks in leading to subsidence during Lead and Zinc extraction. The collapse allowed the seepage from the abandoned mines and the collected data was limited to analysis of surface water samples. [28] also identified the occurrence of sinkholes caused by mine collapse in fractured sedimentary rocks within the Southern Benue Trough during lead-zinc mining and generated massive ground subsidence. Contamination of groundwater through permeable soils was exacerbated by the weakening of subterranean voids. [21] have documented an additional contributor to ground instability and subsidence due to seismic vibrations from lead zine mining activities in Abakaliki Anticlinorium and runoff from mining operations in Ebonyi State. These studies conclude that subsidence results from the collapse of underground support structures and weakening of overlying strata, frequently causing environment risk, for example, groundwater contamination.

Pathways of Groundwater Contamination

Mining activities deform the land resulting in the formation of fissures and fracture which may become a vital passage way for the leaching of heavy metals into the groundwater (figure 2). In this study it was found that gold mining has contaminated groundwater in schist complexes via leaching in southwestern Nigeria, although subsidence mechanisms were not investigated in depth. This highlights the critical role played by fractured rock systems, which allow metal to migrate into aquifers. This is similar to findings by [24] in Cross River State who noted that leaching of heavy metals from barite mine tailings into the soil as well as to groundwater was enabled by weathering of barite mine tailings in sedimentary terrains even though the limitations of their study was only surface soils. [25] found that soil subsidence induced by mining of lead-zinc ore to be a leading cause of groundwater contamination in Ishiagu, Southeastern Nigeria. We saw that subsurface structures crumbling caused pathways leading for leaching through soil and water systems. But since there was not long term monitoring data, a full understanding of how these pathways operate was not possible. Investigation of the Abakaliki anticlinorium by [20] has shown that porous aquifers are vulnerable to seepage from lead and zinc mining operations. Like in Enyigba where [26] observed seepage from abandoned lead zinc mine collpases and fractures as part of mine processes through which heavy metals entered groundwater. However, it should be stressed that this study only assessed the phenomenon on the surface water samples and not for all water.

[28] found that sinkholes created by lead-zinc mining collapses in the Southern Benue Trough lead to direct paths for contaminants to enter groundwater through permeable soil. Similarly, [32] noted that barite mining on surface runoff sites of Akamkpa and Biase have irrigated groundwater contamination. While there is an absence of pre-mining baseline data to comprehensively assess, the process of premining has been successful. Also, [30] look at the impacts of gold mining in Ogun State and found out that leaching from abandoned gold mining sites worsens the risk of groundwater contamination. In Abakaliki, a southeastern region of Nigeria, [20] carried out a hydrogeochemical analysis. The seepage pathways developed through porous aquifers due to lead-zinc mining were responded with this analysis. The issue of subsidence was not specifically addressed as it is a reasonable assumption that the induced fractures within deformation from mining are playing a role in transmitted heavy metals groundwater. [28] also recorded the role of ground instability in contaminating the groundwater through the recorded sinkholes that occurred due to mine collapse in the Southern Benue trough. Contaminants from lead-zinc mining have seeped into groundwater through permeable soils by passing through these sinkholes.

[30] studied impact of abandoned gold mining site on Ogun state Southwestern Nigeria. While little was known about how subsidence occurred, the study found that abandoned sites increased the likelihood of heavy metal leaches from fractures and cracks in the rock, which further contaminated the local groundwater quality. In addition, [33] stated runoff from gold mining sites in Southwestern Nigeria, which caused erosion and sedimentation to contaminate groundwater.

Results

The water and soil contamination levels in mining areas of Southern Nigeria were compared to the permissible limits set by World Health Organization (WHO) and the Food and Agriculture Organization (FAO) with respect to heavy metals such as lead (Pb), cadmium (Cd) and iron (Fe) (table 2). A number of studies have found lead concentrations in water tests consistently to exceed the WHO standard concentration of 0.01mg/L (figure 3). [20] reported a shocking concentration of 11.42 mg/L, while [31] found 4 mg/L, which is several hundred times overload than where it is allowed. The quantity of lead is substantial in addition to the high levels of cadmium being reported by [20] which exceeded the permitted limit (0.003 mg/L) with 15.67 mg/L. Also, other metals next to this, including iron, have potentially harmful concentrations to human health. For instance, [31] recorded concentration of 13.951 mg/L, more than the WHO guideline (0.3 mg/L). However, these elevated levels are a major health hazard and can include neurological damage, organ failure, and cancer. There is the accumulation of these metals over time through the consumption of contaminated water or affected fish or, crops.

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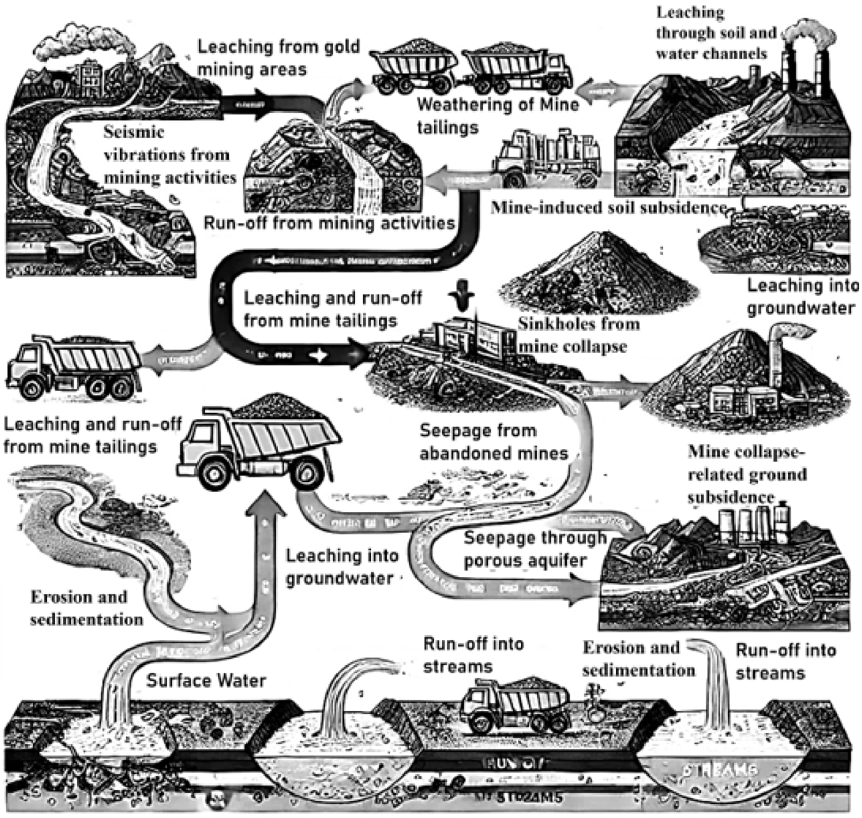

Figure 2: Impact of Land Deformation on Groundwater Flow and Contamination.

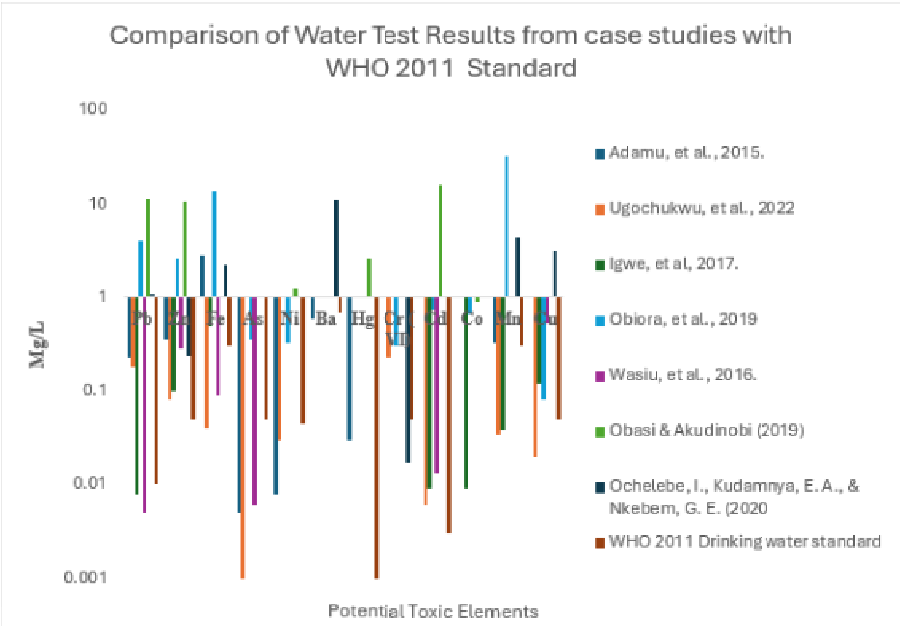

Figure 3: Comparison of Water Test Results from case studies with WHO 2011 Standard.

Table 2: Contamination levels of heavy metals in water from the included studies.

Water Test (mg/L)												
	Pb	Zn	Fe	As	Ni	Ba	Hg	Cr (VI)	Cd	Co	Mn	Cu
WHO 2011 Drinking water standard	0.01	0.05	0.3	0.05	0.045	0.7	0.001	0.05	0.003		0.3	0.05
Adamu, et al. (2015) [24]	0.226	0.36	2.811	0.005	0.008	0.604	0.03	NA	NA	NA	0.33	NA
Obiora, et al. (2019) [31]	4	2.612	13.951	0. 35	0.332	NA	NA	0.3	0.75	0.652	31.503	0.08
Ugochukwu, et al. (2022)[21]	0.18	0.08	0.04	0.001	0.03	NA	NA	0.23	0.006	NA	0.035	0.02
Igwe, et al. 2017[28]	0.008	0.1	0.49	NA	NA	NA	NA	NA	0.009	0.009	0.039	0.12
Wasiu, et al. (2016) [33]	0.005	0.28	0.091	0.006	NA	NA	NA	NA	0.013	NA	NA	0.54
Obasi & Akudinobi (2019) [20]	11.42	10.53	NA	4.13	1.26	NA	2.6	14.60	15.67	0.9	63.45	NA
Ochelebe et al. 2020 [32]	1.067	0.237	2.233			11.173		0.017			4.43	3.087

Similarly, soil contamination levels are a major issue in soil analysis (table 3). According to the Food and Agriculture Organization (FAO) and World Health Organization (WHO), there is a standard for lead in soil as 100 milligrams per kilogram (mg/kg) (figure 4). Nevertheless, [31] found lead levels above this threshold, at 3,870 mg/kg. This represents a serious extensive contamination ascribed to mining activities. Likewise, Zn with a limit of 300 mg/kg, had also correlating elevated values in numerous studies, such as 302 mg/kg reported by [26]. This is of particular concern as arsenic (As), a known carcinogen, exceeds the 1.5 mg/kg limit and as this has been reported by [29] at 4.34 mg/kg. In addition, the cadmium concentration in the soil is high, while [26] recorded a value of 40.51 mg/kg, exceeding the allowable limit of 3 mgd/kg.

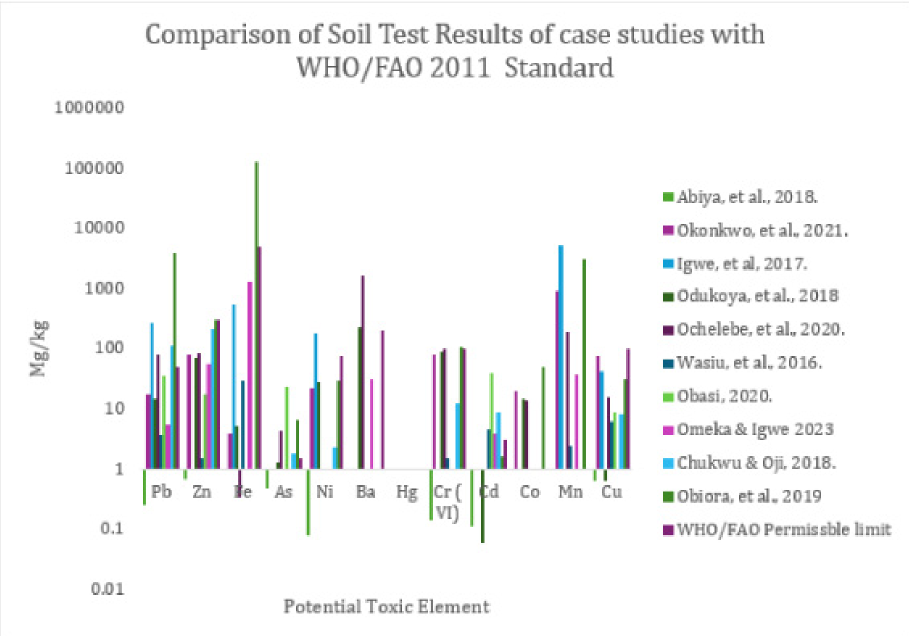

Figure 4: Comparison of Soil Test Results of case studies with WHO/FAO 2011 Standard.

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Table 3: Contamination levels of heavy metals in soil from the included studies.

Soil Test (mg/Kg)												
	Pb	Zn	Fe	As	Ni	Ba	Hg	Cr (VI)	Cd	Co	Mn	Cu
WHO/FAO Permissble limit	100	300	5000	1.5	50	200	1	100	3	50		100
Abiya, et al. (2018) [23]	0.257	0.664	NA	0.478	0.081	NA	NA	0.141	0.11	NA	NA	0.629
Odukoya, et al. (2018) [30]	14.61	72.32	5.1	1.27	28.29	232.22	NA	89.78	0.06	14.41	983.22	36.96
Okonkwo, et al. (2021) [27]	17.92	81.67	3.77	NA	22.33	NA	NA	77.92	NA	19.21	924.21	76.33
Igwe, et al. (2017)[28]	268.195	NA	549.5	NA	177.3	NA	NA	NA	NA	NA	5350.3	42
Ochelebe, et al. (2020) [29]	78.05	85.2	0.33	4.34	NA	1584.5	NA	99.8	NA	14	192.25	15.38
Obiora, et al. 2019[31]	3870	302	128900	6.6	30	NA	NA	106.3	1.6	50.5	3040.3	31
Wasiu, et al. 2016[33]	3.63	1.5	29.8	NA	NA	NA	NA	1.5	4.6	NA	2.47	6.05
Obasi (2020)[26]	36.2	17.24	NA	23.27	NA	NA	NA	NA	40.51	NA	NA	8.62
Omeka & Igwe (2023) [34]	5.6	56.52	1304.16	NA	NA	32.21	NA	NA	3.95	NA	37.93	NA
Chukwu & Oji (2018) [25]	109.55	210	NA	1.83	2.34	NA	NA	12.66	8.57	NA	NA	8.24

Discussion

Soil and water contamination resulting from mining activities are examined in different African regions and the types of pollutants, their origins and extent of land degradation are examined. Pb, Zn, Fe, and Cr(vi) are the most commonly identified contaminants in water samples from several studies. [24] and [31] reported lead level of 0.226 mg/L and 4 mg/L respectively, both are very higher than WHO standard of 0.01 mg/L. Research has shown that in mining areas in Ghana, concentrations of lead (Pb) in the Bonsa River exceed 1.5 mg/L, particularly in the Bonsa River. In this region, heavy metal analysis revealed high concentrations of pollution [35]. Additionally, investigations in the Nsuta manganese mining region indicated exceedingly high levels of Pb in mine pit water, which also leads to contamination of groundwater [36]. As documented by [20], contamination levels were recorded to be exceedingly elevated; pH= 3.2, Pb = 11.42 mg/L, and Cr (VI) = 14.6 mg/L clearly exceeding WHO limits. On the contrary, [28] also recorded Pb contents of 0.008 mg/L, values that were within permissible limits and guided for less serious contamination in their investigation area.

Pb and Zn contamination of surface water is a problem of common occurrence in many African regions due to mining activities. For example, as reported in [31], Zn levels in Nigeria at 2.612 mg/L exceed the WHO standard of 0.05 mg/L and similar is found in the Copperbelt Region of Zambia from high contents of trace metals especially zinc and arsenic. High levels of Zn have been found in studies to be heightened in areas affected by mining due to runoff from mining operations and tailing facilities [37]. For instance, some mining affected areas have recorded arsenic content exceeding 4.13 mg/l/ accounting for one of the big impacts to the environment [38].

Pb and Cr(VI) have been well documented as the most commonly occurring contaminants in soil. Concentrations of Pb reported as alarmingly high by [28] and [31], exceeded the WHO limit of 100 mg/kg at 267.195 mg/kg and 3870 mg/kg respectively. The studies in the Kabwe mining region of Zambia observe really high soil Pb concentration over 3000 mg/kg which is accounted to improper disposal of mine tailings and to the dust fall out from the mining operations [39, 37]. Reports of elevated Cr(VI) levels, like 12.66 mg/kg, higher than the allowable limit of 100 mg/kg, have been made in other areas too [40]. Health concerns have been raised on how to address soils and crops contamination in the Zambian Copper belt affeted by mining activities [37, 40]. Similar heavy metal pollution issues are being faced in South Africa's mining zones as a result of elevated chromium and other pollutants, as a result of which there is also broader regional environmental degradation by mining practices [41].

Lead (Pb), zinc (Zn), iron (Fe) and chromium (Cr (VI)) are among the common pollutants found in various parts of Africa where mining works take place or are associated with the operations, poor waste management and soil erosion. Regional mining practices and land disturbance affect the degree of contamination. As reported in [31, 28], in Southern Nigeria land subsidence is often correlated with increasing levels of heavy metals. On the other hand, in Eastern and Southern Africa including Tanzania and Zambia, high contamination levels occur respectively, Hg and As due to artisanal mining practices [42, 43].

Environmental and Health Implications

Groundwater contamination and heavy metals bioaccumulation pose serious environmental and health risks to mining regions of Southern Nigeria. The WHO/FAO defined limits of heavy metals such as lead (Pb), cadmium (Cd) and so on have also been found in the concentrations above the water test results. As a matter of fact, a study by [20] recorded lead level of 11.42 mg/L above the 0.01 mg/L limit and cadmium level of 15.67 mg/L above the WHO limit of 0.003 mg/L. Thirdly, studies such as [31] recorded raised levels of iron (Fe), ranging from 0.315 to 13.951 mg/L, above the acceptable limit of 0.3 mg/L and concerns also arise from very high arsenic (As) readings reported by [20] of 4.13 mg/L indicating that this value exceeds the WHO limit of 0.05 mg/L. This increased metal concentration in the water disrupts the aquatic ecosystems, causes bioaccumulation in fish and other aquatic life, which are important local community food sources.

The soil test results reveal significant amounts of heavy metal pollution chief among them lead (Pb) and cadmium (Cd). The WHO/FAO recommended limit for soil lead is 100 mg/kg, stated in many studies but also shown to be greatly exceeded in [31] with a value of 3870 mg/kg. Studies by [29] and [27] show high concentrations of zinc (Zn) with levels of about 85.2 mg/kg and 81.67 mg/kg, respectively, which is beyond permissible limit of 300 mg/kg. [29] also reported arsenic (As), but at hazardous levels of 4.34 mg/kg. Long term health risks to human populations has resulted because these heavy metals accumulate into crops and livestock.

Heavy metals like lead, cadmium, arsenic, and iron accumulate on the food chain and pose great health risks for humans in communities which use contaminated water and soil for their sustenance. These metals can be hazardous to health arising from prolonged exposure as necessitated in several studies [44-46]. These non-biodegradable metals persist in the environment, increasing the threat of long term exposure, which results in higher incidences of cancer and developmental problems in children [47], Jonson, et al. 2024. Additionally, during bioaccumulation, these metals become more concentrated throughout the food chain, which makes human health hazardous [45]. Because of this, it is important to undertake effective environmental monitoring and remediation as a way of reducing these risk and ensure that the mining regions of Southern Nigeria [44, 46] are protected from both the ecosystems and human health.

Mitigation Strategies

Mitigation strategies for mining-induced contamination in Southern Nigeria, as detailed in the attached document, can focus on three main areas: They include land reclamation, improved mining regulations and water treatment. Reclaiming the land should focus on stabilising subsided land and replanting indigenous vegetation to restore ecosystems and reduce pollutant pathways, for example in the cracks of the soil and aquifers. Successful examples in other developing regions, i.e. barite and lead zince mining areas, have shown the benefits from such practices to reduce heavy metal mobility. The improved mining regulations are essential. Risk mitigation can include enforcement of strict environmental monitoring and requires that miners use sustainable practices, like customised waste disposal and periodic testing of land, water and air. Particular importance is in regions such as Ebonyi and Cross River states where artisanal and small scale mining – which is often unregulated – has contributed greatly to contamination and land deformation.

There should be water treatment programs that are set up for contaminated ground water. By working in collaboration with industries, local governments could install purification plants to remove lead, cadmium and other metals from the water before it's used in communities. After that, public awareness campaigns should be started to educate the residents on the health risk if you consume contaminated water and food, which can be done either written or orally. These could be workshops on safe agricultural practices and good waste management to prevent further bio accumulation of metals.

Limitations of the Review

Several limitations of the review research have to be acknowledged. A major limitation is that it relies upon available literature, which often does not provide comprehensive or long term data especially on seasonal variations in groundwater contamination. This restricts the depth of the review's analysis to variations in contamination levels for which seasonality is not fully allowed. Furthermore, the research is also restricted to certain areas within Southern Nigeria where and case studies are available. Such bias is created because areas not studied may not suffer from severe contamination issues – and not represented in the findings.

A second drawback is that methodologies employed in the reviewed studies are inconsistent, and thus the synthesis of results is difficult. Variations in sampling technique, analytic method and reporting standard hamper direct comparisons and call into question the reliability of the review's conclusions. Additionally, few studies have baseline data on pre-mining groundwater conditions to make a full assessment of the impact of mining activities on groundwater quality. The review neglects bioaccumulation by limited data on how heavy metals accumulate in food chains and human populations. This limits understanding of long term health risks. In addition, studies that were limited to recent times did not allow for the long term views on mining impacts on groundwater and ecosystems.

Acknowledgement

None

Conflict of Interest

No conflict of interest.

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