

# Environmental Toxins and Public Health Crises of Illegal Mining in Nigeria

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## ABSTRACT

Illegal and artisanal mining has become one of the most consequential drivers of environmental contamination and public health deterioration in Nigeria, particularly across the gold and base metal belts of Zamfara, Niger, Osun, Ebonyi, and Plateau States. This research synthesises recent peer reviewed empirical evidence to examine how unregulated ore processing releases lead, mercury, cadmium, and arsenic into soil, water, and food systems, and how this contamination translates into measurable harm to human health. Drawing on soil and water assays, blood lead level studies, and health risk assessments from mining communities across the country, the chapter traces the pathway from geochemical contamination to clinical outcome, with particular attention to the disproportionate vulnerability of children. It situates this evidence within a rentier state framework, arguing that weak regulatory capacity and elite complicity in illegal mining networks have allowed environmental exposure to persist largely unabated since the 2010 Zamfara lead poisoning disaster. The research further considers the political economy of who benefits from illegal mining and who bears its health costs, before reviewing the record of remediation efforts and the policy reforms needed to break the cycle of contamination. It concludes that Nigeria's illegal mining crisis is fundamentally a public health emergency masquerading as an economic and security problem, and that any durable response must integrate environmental remediation, health surveillance, and formalisation of artisanal mining livelihoods.

**Keywords:** illegal mining, heavy metal contamination, lead poisoning, artisanal mining, environmental health, Nigeria

## INTRODUCTION

Nigeria's mineral belts have long carried a double promise: a source of livelihood for communities with few alternatives, and a source of revenue for a state that has depended overwhelmingly on oil. Gold, lead-zinc ore, tin, and columbite deposits scattered across the north west, north central, and south eastern regions have drawn hundreds of thousands of artisanal and small scale miners into informal extraction, most of it unlicensed and almost entirely unregulated (Bartrem et al., 2022). What has followed this expansion of informal mining is not simply an economic story of rural livelihoods filling a gap left by the state. It is also an environmental and clinical story, one written in the soil, groundwater, and blood of mining communities.

The clearest illustration of what is at stake occurred in 2010, when artisanal gold processing in Zamfara State triggered what remains one of the largest recorded outbreaks of acute lead poisoning in modern history, killing more than four hundred children in a matter of months (Brown & Woolf, 2021). That episode is frequently treated as a historical event, a tragedy that prompted remediation and was resolved. The evidence assembled in this chapter suggests otherwise. Contamination in Zamfara has persisted well beyond the initial emergency response, and similar patterns of heavy metal exposure have since been documented in Niger, Osun, Ebonyi, Benue, Plateau, and Kano States, indicating that the Zamfara disaster was not an isolated failure but an early warning of a much wider structural problem (Yahaya et al., 2021; Akinwumi et al., 2023; Ugochukwu et al., 2022).

This chapter examines the environmental toxins associated with illegal mining in Nigeria and the public health crises that follow from them. It draws primarily on empirical studies. Nigerian and international researchers have

produced a substantial body of soil, water, and biological monitoring data across multiple mining regions. The objective is not to catalogue every contaminated site, but to demonstrate a consistent pattern: unregulated ore processing releases toxic metals into the environment at concentrations that repeatedly exceed World Health Organization and national safety thresholds, and this contamination is measurably associated with adverse health outcomes, particularly among children. The chapter also asks who benefits from the persistence of illegal mining and who absorbs its costs, and it closes by considering what a more effective policy response would require.

## **THEORETICAL FRAMEWORK:**

### **Rentier Statehood and the Governance of Extraction**

The persistence of illegal mining in Nigeria is best understood through the lens of rentier state theory, which holds that states whose revenue derives substantially from resource rents rather than from taxation of productive economic activity tend to develop weak accountability relationships with their citizens and correspondingly weak regulatory institutions (Guj et al., 2025, as cited in the broader literature on African resource governance). Nigeria's federal and state governments have historically directed their institutional capacity toward the oil sector, leaving the solid minerals sector chronically under-resourced despite the country holding significant deposits of gold, lead-zinc, tin, and other minerals. The result is a regulatory vacuum in which artisanal extraction has expanded far faster than the state's ability, or willingness, to monitor and enforce environmental and safety standards.

This vacuum does not mean the absence of authority at mining sites. Rather, it has produced a parallel governance structure in which local strongmen, traditional rulers issuing informal consent, and in the worst affected states, armed groups, exercise de facto control over access to mineral deposits (Bartrem et al., 2022). Several Nigerian scholars and journalists have documented direct financial links between illegal gold mining proceeds and the banditry that has destabilised parts of Zamfara, Katsina, and Niger States, suggesting that the same institutional weakness that permits environmental contamination to go unaddressed also permits mining revenue to fund armed violence. The resource curse framework, applied at the sub-national level, thus helps explain why remediation efforts that treat lead poisoning as a purely technical or medical problem have struggled to achieve lasting results. Where the incentives that sustain illegal mining are political and economic rather than merely a matter of ignorance or poverty, health interventions divorced from governance reform are unlikely to interrupt the underlying exposure pathway.

A second, complementary strand of theory relevant to this chapter is environmental justice, which draws attention to the uneven distribution of environmental harms across populations with unequal power to resist them. Mining communities in Zamfara, Niger, and Ebonyi States are overwhelmingly rural, poor, and distant from the centres of political and economic decision making in Abuja. The contamination documented in this chapter is not randomly distributed; it falls on populations with the least capacity to demand remediation and the least access to specialised medical care once poisoning occurs.

## **METHODOLOGY**

This chapter adopts a narrative synthesis approach, drawing on peer reviewed empirical studies, systematic reviews, and case reports published primarily between 2020 and 2026, supplemented by a small number of foundational earlier sources where they establish essential historical context, such as the original clinical accounts of the 2010 Zamfara outbreak. Studies were selected for their direct relevance to illegal or artisanal mining in Nigeria and their reporting of measurable environmental contamination, such as soil, water, or food concentrations of heavy metals, or measurable human health outcomes, such as blood lead levels or clinical case series. Where Nigerian data on a specific exposure pathway were limited, comparable studies from other African mining contexts, including Zambia, Ghana, and Tanzania, are used to contextualise findings, with the geographic scope of each source made explicit.

The chapter does not present new primary data. Its contribution lies in synthesising a fragmented and geographically dispersed body of environmental and clinical evidence into a coherent account of the exposure

pathway from ore processing to human harm, and in connecting that evidence to the governance analysis set out above. As a secondary synthesis, the chapter is subject to the limitations of the underlying studies, including variation in sampling methodology, laboratory protocols, and reporting standards across the reviewed literature. No original fieldwork, human subject data collection, or interviews were conducted for this chapter, and no ethical approval was therefore required.

### **Illegal Mining in Nigeria's Metal Belts**

Nigeria's illegal mining activity clusters around several distinct geological belts. The north western states of Zamfara and Niger sit atop gold bearing ore that is frequently laced with high concentrations of lead, a geological accident that transformed a livelihood activity into a poisoning event once villagers began grinding ore with the same milling equipment used for grain (Anka et al., 2020). Artisanal gold processing in this region typically involves crushing and grinding ore near or within residential compounds, followed by amalgamation using mercury to separate gold from the crushed material, a technique that disperses both lead dust and mercury vapour directly into the domestic environment (Nota et al., 2025).

Niger State, immediately south of Zamfara, has developed a parallel artisanal mining economy in gold and other minerals, concentrated in local government areas such as Shiroro, Munya, Rafi, Mashegu, and Mariga. Contamination of drinking water sources and staple food crops around artisanal sites in Igabi-Mashegu has been documented at levels that exceed safety thresholds for household consumption (Sani et al., 2023). Niger State's mining districts have also become notorious for their overlap with banditry and insecurity, with reporting indicating that mining continues largely uninterrupted even in areas subject to repeated armed attacks, a pattern that several security analysts attribute to informal arrangements between armed groups and mining interests.

A second major cluster sits in the south west, particularly around the Ilesha and Iperindo gold belts of Osun State, where artisanal mining has expanded substantially over the past decade. Soil sampling in these areas has found elevated concentrations of lead and cadmium in the immediate vicinity of processing sites, with health risk models indicating meaningful exposure risk to miners and nearby residents (Emumejaye et al., 2025; Awogbami et al., 2023). A third cluster is found in the south east, principally in Ebonyi State, where galena, the primary ore of lead, has been mined for decades, and in Benue State, where lead-zinc deposits have attracted informal extraction around abandoned and active mine sites (Ugochukwu et al., 2022; Samuel & Babatunde, 2021). A fourth, less studied but no less significant cluster exists on the Jos Plateau, where tin mining has left behind extensively disturbed land that continues to attract informal extraction and reprocessing of mine tailings (Sayyadi et al., 2025).

What unites these otherwise geographically and mineralogically distinct regions is a common absence of regulatory oversight. Licensed mining operations in Nigeria are required to conduct environmental impact assessments and implement waste management protocols; illegal and artisanal operations, by definition, do neither. The consequence, as the following section demonstrates, is a remarkably consistent signature of environmental contamination across sites that otherwise have little in common.

### **Environmental Toxins: Heavy Metal Contamination of Soil, Water, and Food**

The environmental toxicology of illegal mining in Nigeria centres on a small number of recurring contaminants: lead, mercury, cadmium, and arsenic, with each entering the environment through a distinct but overlapping set of pathways. Lead is by far the most extensively documented, owing both to its association with the Zamfara disaster and to the fact that much of Nigeria's artisanal gold ore is naturally lead rich. Soil surveys across five mining villages in Zamfara found that lead and cadmium together accounted for approximately ninety eight percent of the total ecological risk posed by six measured metals, with processing sites, where ore is crushed and ground, showing markedly higher contamination than either mining pits or residential areas (Yahaya et al., 2021). A related assessment across artisanal gold mines in the same state recorded lead concentrations reaching approximately one hundred and forty nine milligrams per kilogram at one processing site, with concentrations of lead, cadmium, and aluminium consistently exceeding both World Health Organization guidance and pre-mining background levels (Barde et al., 2024).

Airborne exposure compounds the soil contamination pathway. Personal air sampling of underground miners and ore processors in Zamfara found mean airborne lead concentrations of roughly 0.48 milligrams per cubic metre, close to ten times the permissible exposure limit set by the United States Occupational Safety and Health Administration, with gold ore processing associated with exposures exceeding allowable limits by more than thirtyfold (Nota et al., 2025). Because grinding and processing frequently take place within or adjacent to family compounds, this occupational exposure becomes a household exposure, carried home on clothing, skin, and tools in a pattern researchers have termed take home contamination. Comparative work characterising ore and tailings from Zamfara alongside a similarly affected site in Geita, Tanzania, found that lead concentrations in processing waste posed an immediate health risk warranting urgent intervention rather than long term monitoring alone (Nota et al., 2025).

Water contamination follows a comparable pattern outside the gold belts. In the lead-zinc mining communities surrounding Abakaliki in Ebonyi State, analysis of over one hundred water samples found that all but one of ten measured metals, including lead, mercury, arsenic, and cadmium, exceeded World Health Organization drinking water standards, with only copper remaining consistently within safe limits (Obasi & Akudinobi, 2020). A related study of galena mining impacts on groundwater, surface water, soil, and sediment in Ebonyi State documented sustained degradation of water quality across all four environmental media, alongside a quantified economic cost attributable to the resulting health risk (Ugochukwu et al., 2022). Comparable contamination has been documented in a Pb-Zn-F mining district in north eastern Nigeria, where water samples collected across both dry and rainy seasons showed multiple metals exceeding recommended limits, with health risk indices elevated for both adult and child populations (Adewumi & Laniyan, 2023).

Mercury contamination, while less studied in Nigeria than lead, presents a distinct and serious concern because of its use in gold amalgamation and its capacity to bioaccumulate through the food chain. A household level assessment of food contamination across mining communities in north western Nigeria found that nearly ninety eight percent of sampled households had elevated mercury levels in the food they consumed, a strikingly high prevalence that the authors linked to farming practices, including cultivation on land outside the immediate community and limited fertiliser use (Ibrahim et al., 2024). This finding is particularly significant because it demonstrates that mercury exposure in mining regions is not confined to miners themselves but extends into the general food supply, placing entire communities, including individuals with no direct involvement in mining, at risk.

The food chain pathway extends beyond mercury. Studies of agricultural soils in gold mining districts of Zamfara have found elevated lead concentrations in cultivated fields, although the extent of transfer into edible plant tissue varies by crop variety, with some rice cultivars showing markedly lower lead uptake than others, offering a potential low cost mitigation strategy through varietal selection (Mandal et al., 2022; Darma et al., 2022). Vegetables grown around the Riruwai mining area in Kano State and around abandoned lead-zinc sites in Benue State have similarly shown elevated heavy metal concentrations requiring further scientific attention (Badamasi et al., 2023; Samuel & Babatunde, 2021). Even livestock have not been spared: free range chickens raised in gold mining communities in Zamfara showed evidence of lead toxicosis, indicating a probable additional route of human exposure through the consumption of contaminated poultry (Oladipo et al., 2020).

Taken together, this body of evidence describes an environment in which lead and, to a lesser documented extent, mercury and cadmium move continuously between soil, water, crops, livestock, and air across Nigeria's mining regions. A recent meta-analytical review synthesising forty studies across five Nigerian mining regions confirmed that Zamfara and the Enyigba district of Ebonyi State show the highest contamination levels nationally, with hazard indices for children exceeding safe thresholds and carcinogenic risk estimates elevated across multiple sites (Odetunde et al., 2025). The consistency of this pattern across geographically distant and mineralogically distinct regions suggests a structural rather than site specific problem, rooted in the absence of processing controls common to unregulated artisanal extraction everywhere it occurs.

## Public Health Crises: From Contamination to Clinical Harm

The clearest and most extensively documented public health consequence of environmental contamination from illegal mining in Nigeria is childhood lead poisoning. The 2010 Zamfara outbreak, in which over four hundred children died from acute lead toxicity linked to gold ore processing, established a clinical baseline against which subsequent contamination has been measured (Brown & Woolf, 2021). What the more recent literature makes clear is that the underlying exposure did not end with the emergency remediation that followed the outbreak. A cohort study of neonates with congenital lead poisoning in northern Nigeria found that elevated cord or early infancy blood lead concentrations, above approximately fifteen micrograms per decilitre, predicted adverse medium term outcomes in children under five even after environmental remediation had been carried out, indicating that early life exposure produces lasting harm that remediation alone cannot fully reverse (Thurtle et al., 2023).

Beyond Zamfara, comparable elevated blood lead levels have been documented in children living in an entirely different gold mining community in Osun State, in south western Nigeria, where researchers described the finding as an urgent call for action, noting that affected children showed significantly higher blood lead concentrations than children from a non-mining comparison area and recommending routine screening in similarly exposed communities (Akinwumi et al., 2023). A study of school children in Owerri, in the country's south east, found comparatively lower average lead burdens than in the major mining hotspots, but still identified a subset of children with blood lead concentrations above internationally accepted thresholds, suggesting that environmental lead exposure in Nigeria is not confined to the most heavily studied mining regions alone (Anyanwu et al., 2022, as reported in the Owerri school children study).

The clinical significance of these findings lies in what is now well established in the international toxicological literature about lead's effects on the developing nervous system. Childhood lead exposure is associated with irreversible reductions in cognitive development, attention, and educational attainment, with no safe threshold of exposure identified below which harm does not occur (Balali-Mood et al., 2021). This absence of a safe threshold is critical for interpreting the Nigerian evidence: even the comparatively lower blood lead levels recorded in non-hotspot communities such as Owerri represent a measurable burden of lost cognitive potential across an entire generation of children growing up near mining activity.

Occupational exposure among adult miners presents a related but distinct set of health concerns. Airborne lead exposures among underground miners and ore processors in Zamfara, measured at roughly ten times the permissible exposure limit, place adult miners at direct risk of acute and chronic lead toxicity, including anaemia, neurological impairment, and reproductive harm, in addition to the take home exposure risk they pose to their own households (Nota et al., 2025). A One Health assessment of artisanal and informal mining in Benue State found increased lead exposure alongside an elevated inflammatory response among exposed individuals, with women and those living closest to mining sites bearing a disproportionate share of this burden, a finding consistent with the broader pattern of gendered vulnerability documented in artisanal mining communities across the region (Paul et al., 2024).

The health burden extends beyond lead toxicity narrowly defined. Water contamination in Ebonyi and other lead-zinc mining regions carries elevated concentrations of mercury and arsenic alongside lead, exposures associated in the wider toxicological literature with kidney dysfunction, neurological disease, and increased cancer risk (Obasi & Akudinobi, 2020; Balali-Mood et al., 2021). The high prevalence of elevated mercury in food sampled across mining communities in north western Nigeria has been linked by the study's authors to a plausible contribution to chronic kidney disease, an outcome that, if confirmed by further research, would extend the public health toll of illegal mining well beyond the neurodevelopmental harms most commonly associated with lead (Ibrahim et al., 2024).

Nigeria's healthcare system carries this burden with limited capacity. Chelation therapy, the standard clinical treatment for significant lead poisoning, requires specialised staff, sustained drug supply, and laboratory capacity for blood lead monitoring, resources that are scarce outside the handful of facilities that responded to the original Zamfara emergency with international support from agencies including Médecins Sans Frontières and UNICEF.

Communities affected by contamination identified more recently, in Niger, Osun, Ebonyi, and elsewhere, generally lack comparable access to specialised toxicological care, meaning that diagnosis, where it occurs at all, frequently happens without the treatment infrastructure needed to address it. This mismatch between the geographic spread of contamination documented in the environmental literature and the concentration of clinical response capacity in a small number of historically prioritised sites represents one of the central unresolved public health failures examined in this chapter.

### **Who Profits, Who Suffers**

The distribution of costs and benefits associated with illegal mining in Nigeria is sharply unequal. At the base of the extraction chain are artisanal miners and their households, who absorb the most direct and severe health costs, including occupational lead exposure, take home contamination, and, in the case of women and children in mining communities, elevated risk of neurodevelopmental and reproductive harm, in exchange for income that rarely lifts households out of poverty (Bartrem et al., 2022). These are the populations documented throughout the environmental and clinical literature reviewed in this chapter: the children of Zamfara, Osun, and Niger State whose blood lead levels appear in peer reviewed studies, and the farming households whose food supply carries elevated mercury without their knowledge.

Above this base sit intermediaries, local buyers, transporters, and processors, who capture a larger share of the value generated by illegal mining while bearing comparatively less direct health risk, since their exposure is generally shorter in duration and less concentrated than that of miners and processors working ore on site. At the top of the chain, a smaller number of financiers, some with documented links to political and security establishment figures, capture the largest share of illegal mining's profits while remaining almost entirely insulated from its environmental and health consequences. Reporting and academic analysis on the gold trade in Katsina and Zamfara States has traced connections between local elites, security personnel, and armed groups profiting from illegal mining, arrangements that help explain why enforcement against illegal mining has remained so limited despite repeated government pronouncements against it.

Global supply chains complete this picture of asymmetric benefit and harm. Gold extracted informally in Nigeria's mining regions ultimately enters international markets, where its origin in unregulated, environmentally damaging, and at times conflict linked extraction is rarely visible to end consumers or downstream refiners. The absence of robust traceability mechanisms for artisanal gold leaving Nigeria means that the economic value generated by contaminated soil and poisoned children in Zamfara or Osun is substantially realised outside the communities and, in significant part, outside the country where the contamination occurs. This is the central asymmetry the book's framing questions point toward: those who profit from illegal mining are rarely those who suffer its environmental and health consequences, and the institutional weaknesses that allow this asymmetry to persist are the same weaknesses that have historically characterised Nigeria's management of extractive resources more broadly.

### **Policy Pathways and Interventions**

The environmental remediation carried out in Zamfara following the 2010 outbreak, led by international agencies working alongside Nigerian federal and state ministries, achieved a reported reduction in soil lead levels of over ninety five percent in the immediately affected villages, demonstrating that large scale remediation of contaminated mining communities is technically achievable when sufficient resources and institutional will are mobilised. However, subsequent monitoring in at least one of the remediated villages found that soil lead levels were on a trajectory to approach pre-remediation concentrations again within roughly a decade and a half, driven by the continuation of unregulated mining activity in the surrounding area, a finding that underscores a central lesson of this chapter: remediation without a corresponding reduction in ongoing contamination sources is, at best, a temporary intervention.

Several policy directions follow from the evidence reviewed here. First, environmental monitoring needs to be extended well beyond Zamfara, given that comparable or in some cases more severe contamination has now been documented in Ebonyi's Enyigba district, in Osun State's gold belt, and in parts of Niger and Benue States.

A national mining health surveillance system, capable of tracking blood lead levels and soil contamination across all known artisanal mining regions rather than responding only after acute poisoning events are reported, would allow earlier identification of emerging hotspots before they reach the scale of the Zamfara disaster.

Second, formalisation of artisanal mining, rather than prohibition alone, offers a more realistic path to reducing environmental harm than repeated, poorly enforced mining bans, which the evidence from Niger State in particular suggests have done little to curb actual extraction activity while doing nothing to improve the safety of the processing methods used. Formalisation efforts that provide licensed miners with safer processing technology, including mercury free gold extraction methods and ore processing conducted away from residential compounds, address the exposure pathway directly rather than relying solely on after the fact medical treatment. Complementary technical interventions, such as the identification of lower lead uptake crop varieties for cultivation on contaminated agricultural land, offer additional, lower cost mitigation options while broader remediation is pursued (Mandal et al., 2022).

Third, given the documented links between illegal mining revenue and armed banditry in the north west, any durable policy response must integrate environmental and health objectives with the broader security and governance reforms needed to address elite capture of mining revenue. Environmental and public health interventions pursued in isolation from this governance dimension are likely to encounter the same structural resistance that has limited the effectiveness of previous mining bans and remediation efforts. Finally, expanding chelation therapy capacity and blood lead screening infrastructure beyond the small number of facilities established during the original Zamfara response, so that newly identified contamination hotspots in Osun, Niger, and elsewhere have access to comparable clinical care, would help close the gap this chapter has identified between the geographic spread of environmental contamination and the concentration of Nigeria's toxicological treatment capacity.

## CONCLUSION

The evidence reviewed in this chapter demonstrates that illegal mining in Nigeria has produced a pattern of environmental contamination and public health harm that extends far beyond the well known 2010 Zamfara lead poisoning disaster. Peer reviewed studies elevated concentrations of lead, mercury, cadmium, and arsenic in soil, water, food, and human blood across mining communities in Zamfara, Niger, Osun, Ebonyi, Benue, and Plateau States, with children consistently identified as the population bearing the greatest and most lasting harm. This contamination persists not because the underlying science is poorly understood, but because the governance failures that allow illegal mining to proceed largely unregulated, including weak enforcement, elite complicity, and in the worst affected areas, direct financial links to armed banditry, have not been meaningfully addressed.

Understanding illegal mining's environmental and health toll as fundamentally a governance problem, rather than only a technical or medical one, is essential to designing interventions capable of achieving more than temporary relief. Remediation, health surveillance, formalisation of artisanal livelihoods, and security sector reform are not separate policy tracks but interdependent components of a single response. Until they are pursued together, the pattern documented across Nigeria's mining regions over the past decade and a half, in which environmental contamination recurs, health crises are addressed only after they become acute, and the underlying extraction economy continues largely undisturbed, is likely to persist.

## REFERENCES

1. Adewumi, A. J., & Laniyan, T. A. (2023). Contamination, ecological, and human health risks of heavy metals in water from a Pb-Zn-F mining area, north eastern Nigeria. *Journal of Water and Health*, 21(10), 1470-1488. <https://doi.org/10.2166/wh.2023.132>
2. Akinwumi, I. A., Adegoke, S., Oyelami, O., Akinwumi, A. E., & Adedeji, T. A. (2023). High blood lead levels of children in a gold mining community in Osun State, Nigeria: An urgent call for action. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 117(9), 615-621. <https://doi.org/10.1093/trstmh/trad035>

3. Anka, S. A., Bello, T., Waziri, A. F., Muhammad, A., Bello, I., & Nasiru, A. (2020). Environmental effect of lead combination of mining communities in Zamfara State, Nigeria: A review. *Journal of Biology and Today's World*, 9(11), 1-6.
4. Awogbami, S. O., Solomon, O. A., Sawyerr, H., & Raimi, M. (2023). Comparative assessment of seasonal variations in the quality of surface water and its associated health hazards in gold mining areas of Osun State, south west Nigeria. *Advances in Environmental and Engineering Research*, 4(1), 1-20. <https://doi.org/10.21926/aeer.2301011>
5. Badamasi, H., Hassan, U. F., Adamu, H., Baba, N., & Adamu, D. (2023). Heavy metals contamination levels in the vegetables grown around Riruwai mining area, Kano State, Nigeria. *Turkish Journal of Agriculture - Food Science and Technology*, 11(6), 1032-1037. <https://doi.org/10.24925/turjaf.v11i6.1032-1037.5663>
6. Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. *Frontiers in Pharmacology*, 12, Article 643972. <https://doi.org/10.3389/fphar.2021.643972>
7. Barde, B. G., Adeleye, A. O., Oladeji, A. A., & Duhu, Y. B. (2024). Heavy metals pollution and ecological risk assessment around artisanal gold mines in Zamfara, Nigeria. *Environmental Analysis, Health and Toxicology*, 39, Article e2024016. <https://doi.org/10.5620/eaht.2024016>
8. Bartrem, C., von Lindern, I., von Braun, M., & Tirima, S. (2022). Climate change, conflict, and resource extraction: Analyses of Nigerian artisanal mining communities and ominous global trends. *Annals of Global Health*, 88(1), 82. <https://doi.org/10.5334/aogh.3547>
9. Brown, M., & Woolf, A. (2021). Zamfara gold mining lead poisoning disaster, Nigeria, Africa, 2010. In *History of Modern Clinical Toxicology* (pp. 149-158). Academic Press. <https://doi.org/10.1016/b978-0-12-822218-8.00012-0>
10. Darma, A., Ibrahim, S., Sani, A., Zandi, P., & Yang, J. (2022). Appraisal of lead (Pb) contamination and potential exposure risk associated with agricultural soils and some cultivated plants in gold mines. *Environmental Systems Research*, 11, Article 12. <https://doi.org/10.1186/s40068-022-00259-3>
11. Emumejaye, K., Okpara, E. C., Olaoye, M., Ishola, S. A., Biere, P., Mustapha, O. A., Banks, C. E., Onwudiwe, D. C., Makinde, V., & Gbadebo, A. (2025). A health risk assessment of the heavy metal levels in soil from Itagunmodi and Iperindo mining belt, southwest Nigeria. *Discover Environment*, 3, Article 45. <https://doi.org/10.1007/s44274-025-00326-3>
12. Ibrahim, U., Karkarna, M., Babura, S. M., Matazu, M. A., Jibo, A., Umar, M. L., & Aliyu, M. (2024). Correlates of food contamination by heavy metals in northwest Nigeria. *Environmental Health Insights*, 18. <https://doi.org/10.1177/11786302241301700>
13. Mandal, J., Bakare, W., Rahman, M., Rahman, M., Siddique, A. B., Oku, E., Wood, M. D., Hutchinson, S., & Mondal, D. (2022). Varietal differences influence arsenic and lead contamination of rice grown in mining impacted agricultural fields of Zamfara State, Nigeria. *Chemosphere*, 305, Article 135394.
14. Nota, M., Gottesfeld, P., Mbuligwe, S., Kassenga, G., & Anka, S. M. (2025). Airborne lead exposures during artisanal lead mining and gold ore processing in Zamfara, Nigeria. *Journal of Occupational and Environmental Hygiene*, 22(9), 623-634. <https://doi.org/10.1080/15459624.2025.2491490>
15. Nota, M. M., Tirima, S., Anka, S. M., Kassenga, G. R., & Mbuligwe, S. E. (2025). Comparative characterization of lead and other heavy metal contamination in ore and tailings: Environmental health risks in small-scale mining communities in Zamfara, Nigeria, and Geita, Tanzania. *Mitteilungen Klosterneuburg*, 75(2). <https://doi.org/10.61586/ucia3>
16. Obasi, P., & Akudinobi, B. (2020). Potential health risk and levels of heavy metals in water resources of lead-zinc mining communities of Abakaliki, southeast Nigeria. *Applied Water Science*, 10, Article 184. <https://doi.org/10.1007/s13201-020-01233-z>
17. Odetunde, S. K., Yusuf, A., Sunmon, O., Oladetuyi, A. P., & Godspower, O. I. (2025). Ecological and human health implications of heavy metal pollution in Nigerian artisanal mining communities: A meta-analytical review (2010-2024). *Journal of Sustainability and Environmental Management*, 4(1). <https://doi.org/10.3126/josem.v4i1.89879>
18. Oladipo, O., Ekong, P., Uchendu, C., & Ajani, O. (2020). Lead toxicoses in free-range chickens in artisanal gold-mining communities, Zamfara, Nigeria. *Journal of Health & Pollution*, 10(26), 200606. <https://doi.org/10.5696/2156-9614-10.26.200606>

19. Paul, S. N., Frazzoli, C., & Orisakwe, O. (2024). Towards a one health assessment of artisanal and informal mining in Benue State, Nigeria. *Medical Sciences Forum*, 25(1), Article 2. <https://doi.org/10.3390/msf2024025002>
20. Samuel, P., & Babatunde, B. (2021). Risk assessment of heavy metals in food crops at abandoned lead-zinc mining site at Tse-Faga, Logo, LGA, Benue State, Nigeria. *Journal of Environmental Protection*, 12(9), 636-652. <https://doi.org/10.4236/jep.2021.129038>
21. Sani, A. H., Musa, A., & Achimugu, M. D. (2023). Assessment of heavy metal pollution of drinking water sources and staple food cultivars around artisanal mining site in Igabi-Mashegu, Niger State, Nigeria. *World Journal of Biology Pharmacy and Health Sciences*, 14(2), 190-201. <https://doi.org/10.30574/wjbphs.2023.14.2.0162>
22. Sayyadi, M. G., Chindo, I. Y., Manasseh, J., & Sani, A. K. (2025). Comparative analysis of concentrations of heavy metals in mining sites and community soils, Jos Plateau State, Nigeria. *Journal of Basics and Applied Sciences Research*, 3(4). <https://doi.org/10.4314/jobasr.v3i4.27>
23. Thurtle, N., Kirby, K. A., Greig, J., Bil, K., Dargan, P., Ntadom, G., & Buckley, N. (2023). Neonatal blood lead concentration predicts medium term lead-related outcomes in children five years old with congenital lead poisoning: A retrospective cohort study in northern Nigeria. *PLOS Global Public Health*, 3(2), Article e0001644. <https://doi.org/10.1371/journal.pgph.0001644>
24. Ugochukwu, U. C., Chukwuone, N., Jidere, C., Ezeudu, B., Ikpo, C., & Ozor, J. (2022). Heavy metal contamination of soil, sediment and water due to galena mining in Ebonyi State, Nigeria: Economic costs of pollution based on exposure health risks. *Journal of Environmental Management*, 315, Article 115143.
25. Yahaya, S. M., Abubakar, F., & Abdu, N. (2021). Ecological risk assessment of heavy metal-contaminated soils of selected villages in Zamfara State, Nigeria. *SN Applied Sciences*, 3, Article 435. <https://doi.org/10.1007/s42452-021-04175-6>
26. Yahaya, S. M., Mahmud, A. A., & Abdu, N. (2022). Heavy metals source apportionment and human health risk assessment of contaminated soils of Zamfara State, Nigeria. *Agro Bali: Agricultural Journal*, 5(2), 372-386. <https://doi.org/10.37637/ab.v5i2.897>