



# Climate Change, Conflict, and Resource Extraction: Analyses of Nigerian Artisanal Mining Communities and Ominous Global Trends

ORIGINAL RESEARCH

CASEY BARTREM 

IAN VON LINDERN 

MARGRIT VON BRAUN 

SIMBA TIRIMA

*\*Author affiliations can be found in the back matter of this article*

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## ABSTRACT

**Background:** The 2010 lead poisoning outbreak that claimed the lives of more than 400 children in artisanal gold mining villages in Zamfara, Nigeria is the tragic result of high gold prices, a geologic anomaly, and processing of ores in residential areas. Today, these villages face a growing crisis related to conflict and climate change. While the situation in Zamfara is unparalleled in many ways, the interactions between climate change, conflict, and mining consistently overlap a global scale. The scope of this analysis extends beyond the Nigerian crisis.

**Objectives:** Understanding the complexities of challenges faced in Zamfara provides insight into how these issues impact vulnerable communities globally, and which strategies should be considered to solve this wicked problem.

**Methods:** Analysis of the relationships between climate change, conflict, and mining in Zamfara and globally via literature review and examination of current events in the Sahel region.

**Findings:** Supporting healthy artisanal mining communities, as was prioritized in Zamfara, must be a focus of environmental, health, and mineral management policies. This includes the consideration of multiple environmental health challenges, the protection of vulnerable groups, government-supported formalization programs, and meaningful involvement of local leadership in developing, implementing, and sustaining intervention strategies to enshrine ASM as a poverty reduction, climate change adaptation strategy.

**Conclusions:** Rapidly rising metal prices and demand will continue to fuel environmental health crises associated with mining. Given Africa's growing role in the global mineral economy and the massive number of subsistence communities who will continue to be impacted by climate change, strategies that support responsible artisanal mining are both a necessity for preventing future health crises and an opportunity for promoting regional stability and peace.

CORRESPONDING AUTHOR:

**Casey Bartrem, PhD**

TerraGraphics International  
Foundation, 121 S. Jackson  
Street, Moscow ID, 83843 US

[casey@terrafound.org](mailto:casey@terrafound.org)

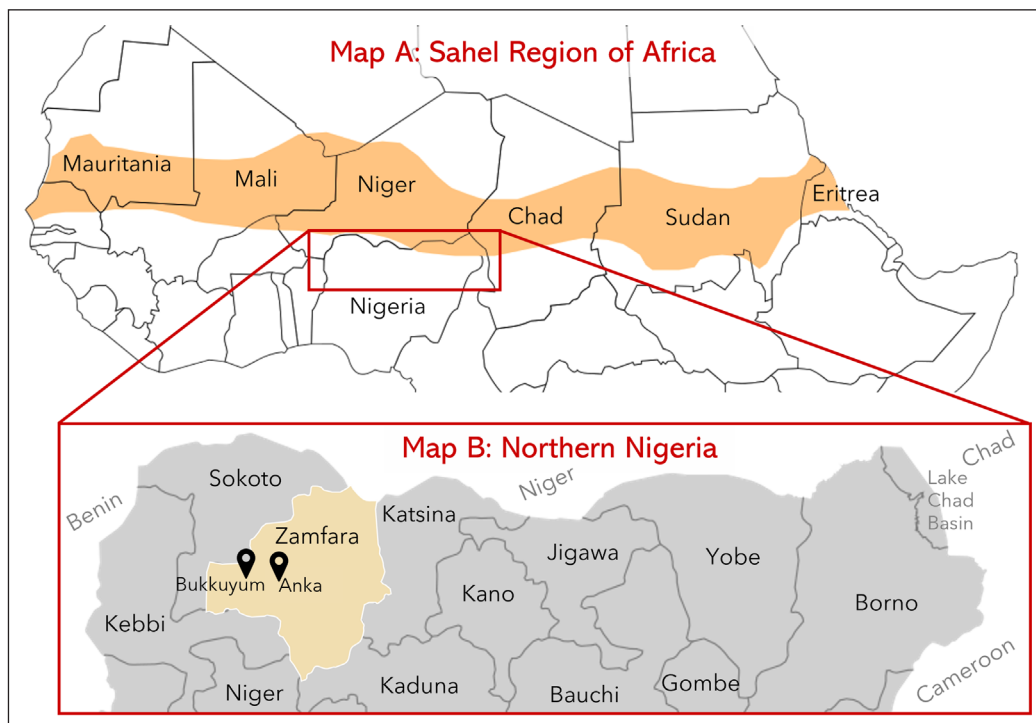
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## INTRODUCTION

A tragic lead poisoning outbreak claimed the lives of 400 children and severely poisoned 30,000 more people in isolated artisanal gold mining villages in Zamfara State, Nigeria in 2010 [1–3]. In the 11 years since the outbreak was discovered, the Nigerian government and domestic and international organizations have collaborated on an environmental health response that includes medical treatment, environmental remediation, monitoring, institutional controls, and safer mining practices. Despite the severity and unprecedented nature of the crisis in Nigeria, project partners have made remarkable progress in reducing lead-related morbidity and mortality rates among children [1, 4]. Yet along with successes, both the communities and the project face increasing challenges from climate-related conflicts in the region [5].

Zamfara is located on the southern border of the Sahel, a semi-arid biogeographic zone that separates the Sahara Desert from the subtropical regions of Africa (*Figures 1 and 2*). The Sahel encompasses significant portions of Mauritania, Mali, Niger, Chad, Sudan, and Eritrea and touches smaller portions of other nations, including Nigeria. The Sahel is characterized by a short, increasingly unpredictable rainy season that punctuates an otherwise arid landscape. While droughts are typical of the region, climate change has resulted in more consistent and severe drought events [6, 7]. The frequent disappearance of the rainy season makes the area one of the most vulnerable to climate change-related impacts [8]. Traditional lifestyles such as farming and raising livestock have become increasingly difficult and fueled long-standing tensions between agrarian and pastoralist tribes. Because the Sahel is not only characterized by ecoclimatic conditions, but also by political instability, poverty, urbanization, and conflict over resources, the region has been referred to as “ground zero” for climate-related conflict [6]. In assessing areas in Africa with the greatest exposures to climate-related hazards, Busby et al. found that the Sahel repeatedly displayed higher vulnerabilities, and northern Nigeria ranked among the highest exposure quintiles [8].



**Figure 1** Map A shows the northern Africa region, with the Sahel in orange. Map B highlights Zamfara State and the two Local Government Areas (Anka and Bukkuyum) where artisanal mining communities have been impacted by lead poisoning.

Similar to the Sahel, lack of adequate rainfall and limited resources are straining already tense relations between Zamfara’s pastoralist (Fulani) and agrarian (Hausa) tribes [9–11]. The instability that characterizes much of the Sahel region is playing out in the “forgotten crisis” in Zamfara State [12]. Examining the complex relationships between conflict, climate change, and resource extraction in this region provides an opportunity to apply lessons learned to vulnerable regions beyond Nigeria.

## ZAMFARA ENVIRONMENTAL HEALTH CRISIS

### ZAMFARA STATE'S SHORT AND TURBULENT HISTORY

The area that is now Zamfara was part of Nigeria's Sokoto State until 1996, when the *Zamfara-wa* ethnic group of the larger Hausa tribe succeeded in their demand for autonomy [13]. That same year in nearby Kano State, the pharmaceutical company Pfizer Inc. launched an experimental meningitis treatment trial. At best a hastily designed trial and at worst an ethical abomination, of the 200 children given the experimental drug, five died and dozens were left with permanent disabilities [14, 15]. Imams broadcasted warnings on the radio, accusing the US company of attempting to kill or sterilize Muslim children and advising parents against seeking any form of western medicine. Polarization and distrust between tribes and religious groups flared, and vaccination rates plummeted [16]. Allegations against Pfizer were publicized in 2000 [15], the same year Sharia Law was implemented in Zamfara. A lawsuit filed in the US against Pfizer was dismissed, but a lawsuit later filed in Nigeria resulted in at least 4 families receiving compensation for their claims against the company [17].

Rates of preventable diseases soared, and polio made a resurgence [16, 18]. Aid organizations such as Médecins Sans Frontières (MSF, Doctors Without Borders) began regularly surveilling for outbreaks of cholera, malaria, measles, and meningitis. MSF was on such a surveillance mission in 2010 when health workers in remote areas of Zamfara reported high mortality rates in children in Anka and Bukkuyum Local Government Areas [1]. Acute lead poisoning was eventually identified as the cause, and a multidisciplinary response team investigated and found the affected communities were deeply involved in artisanal gold mining [2].



**Figure 2** A child walks home on the outskirts of Abare Village, Zamfara State in 2011 (photo credit: Casey Bartrem Casey Bartrem/TIFO).

### MASS CHILDHOOD LEAD POISONING CRISIS AND RESPONSE

As in many areas of northern Nigeria, and in an increasing number of African countries, people have turned to artisanal and small-scale mining (ASM) as a major source of economic security [9]. Due to the wide variety in mining processes, organizational structures, and mineral commodities, definitions of ASM vary, but it generally encompasses mining operations without advanced technology and varying organizational structures [19]. One of the most common and rapidly growing forms of ASM is artisanal and small-scale gold mining (ASGM) (**Figure 3**).

Lead poisoning associated with ASGM is rare; typically, it is the use of mercury in isolating gold from impurities in ores that is the focus of human health risk assessments. The severe mortality and morbidity in Zamfara have three principle causes. First, small-scale mining efforts among



**Figure 3** Photo series of gold ore processing in Zamfara State, Nigeria: **a**, ore is sourced from mines across the region and transported to processing areas; **b**, ore rock is broken by hand into gravel-size pieces. **c**, modified grain mills are used to grind ore into a flour-like consistency; **d**, sluice boards are often used to gravitationally separate gold particles from silica and other contents; **e**, contents of the sluice carpets are washed into a container; **f**, mercury is added to the sluiced concentrate; **g**, a mercury-gold amalgam is obtained, which will then be heated, vaporizing the mercury; **h**, the final product is ready to be sold to dealers who visit the mine sites regularly. Photo credits: TIFO, Casey Bartrem, Simba Tirima, and Ian von Lindern.

impoverished Hausa villages rapidly increased when gold prices shot up during the 2008 economic crisis. Second, a new vein of ore was discovered late in 2009 that, in a cruel twist of geologic fate, contained 10% (100,000 mg/kg) lead [20]. And third, ore was processed in residential areas, either in public areas around the community or within the walled homes by women secluded under the Sharia Law practice of *purdah*.

Lead is a potent neurotoxin that is especially harmful to the developing brains of young children. In Zamfara in 2009–10, lead-rich ore dust covered the soil floors of homes (**Figures 4 and 5**), became incorporated into foods prepared and served on the ground, and rapidly left many children



**Figure 4** A boy plays with soil on the floor of his home (photo credit: Casey Bartrem Casey Bartrem/TIFO).

encephalopathic, leading to seizures, coma, and death [3, 21, 22]. Soil lead levels exceeded the USEPA residential soil limit of 400 mg/kg by orders of magnitude, reaching up to 100,000 mg/kg (10%) in multiple homes [23, 24]. Geometric mean blood lead levels (BLLs) were 149 µg/dL in 2010, nearly 30 times the CDC 5 µg/dL level of concern, with maximum BLLs over 700 µg/dL [1, 25]. Up to 1 of every 3 young children died in the most severely impacted villages [2, 26, 27]. More than 17,000 people were exposed to excessively high concentrations of lead in the environment [1, 28].

Over the next three years, TerraGraphics International Foundation (TIFO) worked with MSF and the Zamfara State and Nigerian federal governments to address the epidemic in eight Zamfara communities. The response was unprecedented in both Nigeria and the world. Cleanup procedures were modified to accommodate emergency medical treatment timelines, limited resources, remote location, and Sharia Law [1, 24]. Mortality rates decreased from 30% to <2% [1]. The last Zamfara village was remediated in 2013; two years later, a similar ASGM-related lead poisoning outbreak was discovered in neighboring Niger State [29]. The Nigerian government, MSF, and TIFO collaborated to respond again, addressing exposures in two remote villages. MSF has continued to treat children for lead poisoning with chelation therapy in the impacted villages, expanding the medical program to include support for local institutions to manage transient recontamination that occurs from mining camps. MSF also supports a safer mining program to reduce lead and silica dust exposures for workers in the region [30, 31].



**Figure 5** A recently remediated home in Zamfara State. Contaminated surface soils have been excavated and replaced with soils certified to be <20 mg/kg Pb (photo credit: Casey Bartrem Casey Bartrem/TIFO).

## HUMANITARIAN CRISIS IN ZAMFARA

The context has changed dramatically since 2010 when the greatest security threat in northern Nigeria was Boko Haram's terrorism of communities in Borno State in the Lake Chad region. Today, clashes between ethnic groups—principally the agrarian Hausa tribe and the pastoralist Fulani Tribe—over land use in Zamfara have resulted in more deaths and displacement than terrorism in Borno [11, 32, 33]. In Zamfara in 2018, 21,000 people had fled their homes, 10,000 people had died, and 44,000 children had been orphaned [9, 34, 35]; as of January 2021, the number of IDP from Zamfara had increased to 70,000 [36] (*Figure 6*). Despite military presence, vigilante groups patrol the area, kidnappings are rampant, and many rural villagers have fled, fearing for their lives [5, 37, 38].

The deteriorating security has complex roots in long-standing ethnic tensions, inadequate governance, and extreme poverty, similar to the situation in 2009 when Boko Haram's terrorism of Borno began [10, 35, 39]. Just as each of these factors alone cannot explain the acute crisis

in Zamfara, analysis of the underlying causes without consideration of how climate change has exacerbated the issues would be neglecting a crucial part of the story. Desertification in the Sahel and northern reaches of Nigeria has pushed herders south, where existing tensions over land have resulted in conflicts between pastoralist and agrarian tribes for centuries [9, 40]. Competition for agricultural land versus grazing land, and access to regions with adequate water for both, continues to fuel the Zamfara conflict [35, 41].

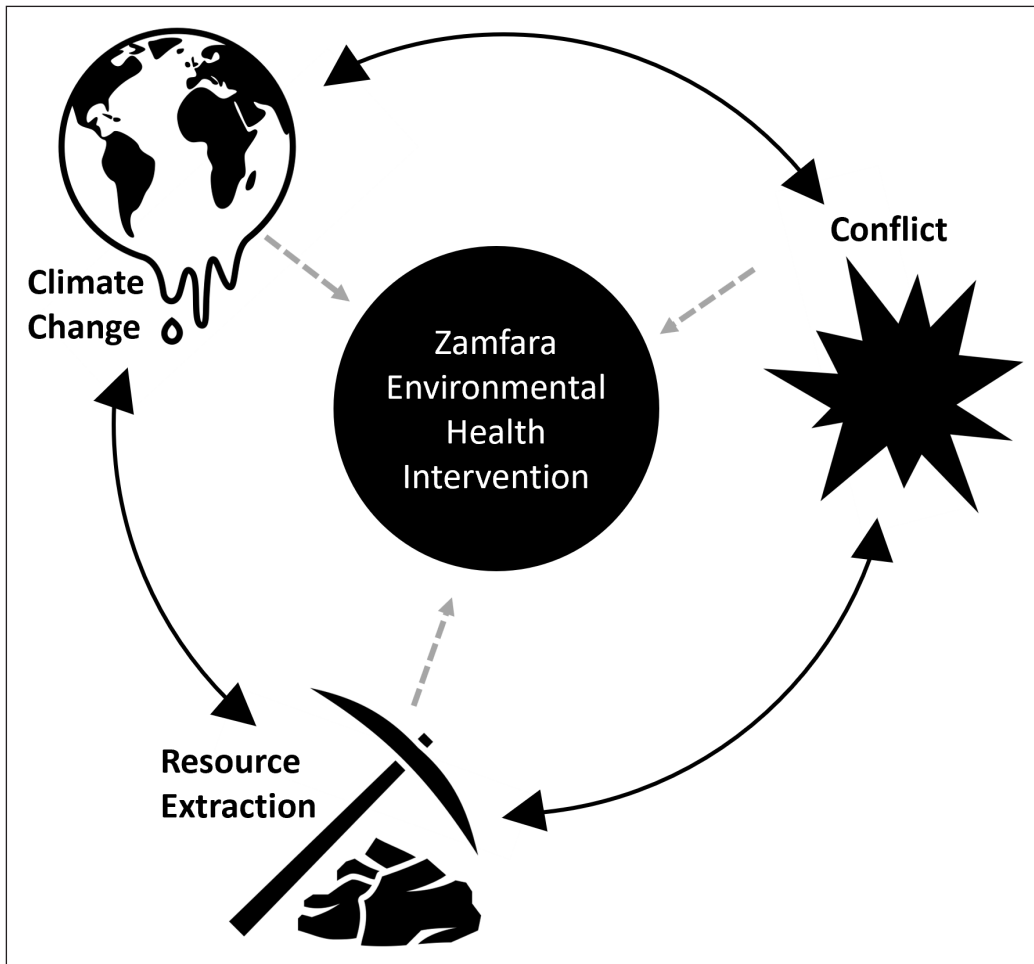
The security situation has serious implications for MSF's lead chelation treatment program. Medical teams can no longer access impacted villages to support safer mining practices or to distribute medications due to the high risk of robbery or kidnappings on the roads [5, 42]. The organization currently runs a camp in a nearby town for people displaced by the violence [43]. In response to the violence, the Nigerian federal government enacted a temporary ban on all artisanal gold mining, but many experts doubt that this will have an impact on the security situation and fear that it could force the industry "underground" and recreate unsafe ore extraction activities that caused the high mortality seen in 2010 [44].



**Figure 6** A camp for people displaced by regional violence in Anka, Zamfara State, Nigeria in October 2020. Many people living in the camp were once residents of the villages impacted by lead poisoning in the previous decade (photo credit: MSF/Abayomi Akande [45]).

Where ASGM had the potential to bring economic opportunity and stability to an otherwise severely impoverished region, the current situation poses risks for Zamfara, Nigeria, and the entire region. The increase in tensions and interruption of income generating activity could easily result in a rise of extremism in Zamfara, a region where it has historically been absent [12]. Meanwhile, extremist activity is on the rise in nearby Burkina Faso, where thousands of IDP are fleeing violence and ASGM areas are now being targeted by jihadi groups [46].

The challenges Zamfara now faces—climate change, managing a booming ASGM economy, and escalating conflict—are not unique. Many governments face the daunting task of managing the same challenges. Estimates vary, but there up to 100 million people who rely on ASGM today [47]. While climate change impacts are global, certain regions of the world are known to be disproportionately impacted [6]. Countries experiencing these issues may also be dealing with other public health crises, political unrest, severe poverty, and environmental degradation [35, 48, 49]. This greatly complicates governance, adaptation and mitigation strategies, emergency interventions, humanitarian actions, and development initiatives. There is mounting evidence that conflict, climate change, and resource extraction are not only related, but fuel each other (**Figure 7**) [7, 50, 51]. This is a wicked problem because of the intractable set of interdependencies, lack of clear solution(s), and the potential for creating additional challenges when attempting to solve one aspect of the problem [52].



**Figure 7** Climate change, conflict, and resource extraction, as well as the interactions between these issues, are resulting in significant impacts on the environmental health project in Zamfara State, Nigeria.

## CLIMATE CHANGE AND CONFLICT

Domestic and international security experts recognize climate change as a critical national security concern. The increased likelihood of interstate conflict as well as violent conflicts within countries intensifies the need for both domestic and international humanitarian aid [7]. Experts first suggested a plausible link between global climate change and multiple forms of conflict in 2007 [53–55]. In the US, climate change is acknowledged as a crucial consideration for infrastructure protection, environmental degradation, public health, and conflict [56]. In 2010, the US Department of Defense stated “While climate change alone does not cause conflict, it may act as an accelerant of instability and conflict... [7]” United Nations (UN) Secretary-General Ban Ki-moon stated that “Climate change not only exacerbates threats to international peace and security; it is a threat to international peace and security [57].”

While the concept of climate-induced human conflict is not new, it has been contested [58–61]. One issue in validating the link between climate change and conflict is the complexity of climate-related changes that can fuel human conflicts. Devlin and Hendrix found that precipitation variability had a greater likelihood of resulting in conflict than overall water scarcity [62]. And yet, Raleigh et al. analyzed market food prices and the occurrence of violent conflict and found not only do elevated food costs positively correlate to risk of conflict, dry conditions are a likely culprit for the relationship [63]. A significant confounding issue is that proponents of the climate change-conflict theory have not been able to fully demonstrate mechanisms by which the effects occur [62, 64].

Despite the challenges in determining the causal relationships, reviews and meta-analyses of available literature indicate that climate-related issues are significant contributors to various types of conflict, with an abundance of articles to support the theory [64]. For example, studies investigating historical relationships between climate and conflict have found consistent patterns.

Zhang et al. found climate change to be a driver of armed conflict during a 300 year period in North America [55]. The same lead author also demonstrated a correlation between war in eastern China and temperature changes that altered food production over the course of 1000 years [54]. Analyses of more recent climate-related security issues are also compelling. Busby et al. found evidence for conflicts related to flooding, droughts, and population density [65]. They also note the exacerbation of pre-existing vulnerabilities and challenges in governments' capacity to respond to issues, ranging from inadequate infrastructure to violence [65]. In countries affected by El Nino events between 1950–2004, the chance of civil war doubled during warmer periods [66]. Other authors have amassed significant evidence for climate change-related conflict due to temperature changes, altered rainfall patterns, and sea level rise [64]. Such findings are in line with the occurrence of resource-related conflicts that occur in both renewable and nonrenewable resources globally [67].

## CONFLICT AND RESOURCE EXTRACTION

In 1993, Richard Auty used the term “resource curse” in reference to the paradoxical relationship between a country's high-value natural resources and that country's low social, economic, health, and environmental development indicators [50]. Because resource extraction, unlike other sectors, can occur without the development of domestic, political, or economic governance, conflicts are more likely to occur over these commodities [68]. These conflicts may be large-scale (e.g., civil war) or small-scale (e.g., among individuals or groups) [6]. From 1970 to 2008, roughly half of global armed conflicts were related to high-value natural resources [69]. In Africa, three of the most violent wars in recent years were related to extractive industries [70]. More recently, ASM has been linked to violent conflict in multiple countries, including Columbia, Democratic Republic of the Congo (DRC), and in the Sahel [46, 71].

ASM can also stabilize a region when well-managed and supported [72, 73]. In Sierra Leone, diamond mining transitioned from fueling violent civil war to being instrumental in peacebuilding by reducing extreme poverty and boosting government revenues to fund social programs [74]. Responsible, bottom-up strategies for formalizing, supporting, and regulating ASM have proven economic and environmental benefits when governance puts human health and welfare as the policy focus [75–79]. ASM has been proposed as both a development strategy and a climate change adaptation strategy [75, 79]. Yet policies that promote healthy ASM communities and generate revenue to support sustainable practices are scarce [80]. In 2016 alone, the United Arab Emirates reported over 15 billion USD in gold imported from Africa, a 10-fold increase from 2006. More than 10 billion USD of this import went unrecorded by African nations, highlighting not only a massive loss in potential revenue, but a missed opportunity to fund health initiatives for mining communities [81].

While there are clear associations between ASM, conflict, and adverse environmental health outcomes, banning the activity has consistently proven to be both ineffectual and counterproductive [75, 77, 78, 82]. ASM is a poverty-driven activity; outright bans negatively impact ASM communities by disrupting or completely severing sources of income, further destabilizing communities and regions [73, 75, 76, 83, 84]. Responsible regulation that goes beyond simply taxing miners is a more effective way to reduce adverse impacts of ASM [77]. These support strategies are best developed at the local level and include miners, community leaders, vulnerable groups, and multiple levels of formal leadership and governance [76, 85, 86]. Such strategies will be more effective at curbing negative impacts, and will also improve overall programmatic sustainability.

## RESOURCE EXTRACTION AND CLIMATE CHANGE

Both informal and formal mining industries impact and are impacted by climate change. Mine operations, and associated deforestation, are contributors to greenhouse gas emissions [87, 88]. Climate change impacts associated with mineral extraction and production doubled between 2000 and 2015 [89]. But large scale mining companies are also evaluating climate change operational



impacts and implementing adaptation strategies related to infrastructure improvements, water scarcity predictions, and special considerations in northern climates where permafrost is melting [87, 90–93]. In 2017, El Salvador named climate change concerns as a major reason in the decision to ban all mineral mining in the country, citing concerns over water scarcity and increasing threats to tailings dams from extreme weather events [93].

The evidence of a link between climate change and informal sector mining is more limited. Nonetheless, the potential relationship is important due to the extensive occurrence and explosive growth of the sector. ASM is often referred to as informal, but ranges from the individual level to highly organized systems, and is found throughout mineral-rich regions of Africa, the Americas, and Asia [94]. As of 2017, an estimated 40 million people worked in ASM globally, compared to 7 million employed in industrial-scale mining [80]. It is estimated that 15–20% of global minerals, including 80% of sapphires and 30% of gold, are produced by small-scale artisanal miners [95]. An estimated 14–19 million people globally are directly employed by ASGM alone [48, 96], but the economy supports more than 100 million people, ten times more than before the 2008 world economic crisis [47]. In some countries, ASM production exceeds industrial mining. For example, in the DRC, more than 50% of coltan (an ore containing tantalum, a component used widely in electronics) and more than 90% of gold are informally produced [77].

While ASM is largely fueled by commodity prices and lack of viable economic alternatives [97], other environmental factors also contribute to shifts in this informal sector work. Some authors suggest that environmental degradation has contributed to the growing artisanal mining economy [75, 93, 94]. In the face of decreasing crop yields, unpredictable precipitation, droughts, and increasing demands on grazing and agricultural lands, both agrarian and pastoralist groups are increasingly unable to pursue traditional livelihoods [9, 75, 98]. In rural areas, mining represents an important means of income diversification for many farmers, and addressing both agriculture and mining issues is necessary for lasting impacts on development [51, 99]. In areas with distinct dry and rainy seasons, ASM allows farmers to generate income during the dry seasons while farming during the rainy season. Due to declining value of many export crops, loss of agriculture input subsidies (e.g., fertilizers), and changing weather patterns (rainfall), off-season workers increasingly rely on ASM [51]. Despite these relationships, there is limited research on the potential impacts of climate change on the growing ASM economy [93].

Climate change will fuel both the formal and informal mining sectors in another important manner. Demand for alternative energy options is expected to significantly alter the global mineral economy [89, 100]. Demand for cobalt, copper, and rare earth elements used in batteries, electric vehicles, wind turbines, and other “renewable” energy components will increase by several orders of magnitude [100]. This suggests that such low-carbon alternatives should not be referred to as “green” or “renewable” technologies given the environmental, social, and health impacts associated with sourcing their components, which are finite resources.

## **ADDITIONAL CONSIDERATIONS AND RECOMMENDATIONS**

During a national conference on lead poisoning associated with ASGM in Abuja in 2018, the Nigerian Vice President stated “As Nigeria traverses the road to shared mining prosperity, we must ensure that we do not do it in a way that harms our health or environment. Those who say the option is death by poisoning, rather than poverty, offer a cynical choice [101].” The worrisome destabilization of Zamfara since the 2018 conference serves to highlight the importance of supporting healthy ASM communities in Nigeria. Accomplishing this requires attention to several key issues.

First, assessing and addressing environmental health challenges associated with ASM cannot focus on a single risk. The most often cited environmental health risk related to ASGM is from the use of elemental mercury in isolating gold particles. Mercury is a highly toxic metal that impacts the brain and kidneys of workers and communities [96, 102], and it is also a global pollutant distributed via atmospheric and hydrologic pathways [103–105]. ASGM now is the largest source of global mercury pollution [106, 107]. However, focusing solely on mercury in ASGM neglects other substantial occupational and environmental health risks. ASM workers experience exposures to silica dust, multiple heavy metals, and cyanide, musculoskeletal injuries, hearing damage, and mine collapses

[48, 104]. Mining communities face increased risk of water and vector borne diseases, higher rates of sexually transmitted diseases, and alcohol and drug abuse [48, 108]. Many ASM-related health crises place burdens on governments or humanitarian actors to respond to violence or disease outbreaks [49]. Comprehensive strategies must be developed in consideration of all of these risks.

In assessing and mitigating the impacts of and interactions between climate change, conflict, and resource extraction, special consideration must be given to vulnerable groups. Women experience more severe climate change impacts due to financial inequalities, barriers to property ownership, and neglectful or discriminatory agricultural extension programming resulting in limited access to improved seed varieties, land credit, and fertilizers, all of which are essential in managing climate-related challenges [109]. Children are more vulnerable to malnutrition resulting from climate-related decreases in crop yields, increased rates of vector-borne diseases, and increased levels of air pollution [110]. Female miners are also marginalized or neglected from ASM formalization efforts [111]. During conflict, women are subject to sexual assault, psychological abuse, and lack of access to reproductive care, and they experience higher maternal mortality rates [112, 113]. At mining sites, women often experience violence, abuse, and discrimination, and pregnant women are more vulnerable to chemical and physical hazards [114, 115]. Children often suffer from abuses related to child labor [104, 116] and are particularly sensitive to chemical exposures during sensitive periods of neurodevelopment. Toxicants such as mercury and lead can pass the blood-brain and placental barriers, impacting critical neurodevelopment and resulting in impacts ranging from IQ deficits to severe brain damage [102, 117, 118].

Some of the direct adverse outcomes associated with ASM are addressed by industrial-scale mining operations. Proponents of formalization point to better occupational health and safety practices, banning of child labor, and improved job security for workers. There is some merit to these claims, but there are significant economic, environmental, and social costs to these types of formalized mining operations. The inherent nature of formal mining includes efficiencies related to mechanization rather than human-powered operations. Hence, the economic benefits are limited to a smaller number of mostly male miners, often resulting in mining communities where few people benefit monetarily [111, 119]. Yet everyone in these communities suffers from the environmental degradation associated with the operations [120]. Further, large-scale operations tend to be foreign-owned, further reducing the distribution of wealth. Formalization should therefore focus on legalization and support of equitable ASM, not on shifting ASM practices towards industrial-scale mining.

In all of these efforts, any viable solution will be interdisciplinary, and any sustainable solution will be locally implemented. In Zamfara, the environmental health response was modeled on an approach similar to that used at a US Superfund Site [1]. Those validated scientific methods were adapted and implemented by local institutions. This is crucial for all environmental health interventions but is highlighted by the subsequent humanitarian crisis in Zamfara. When international aid organizations are no longer able to regularly access impacted communities, it is local authorities who will be responsible for managing ASGM in a way that prevents future health crises.

While understanding the geo-political realities in a region is important, hundreds of frameworks have been developed for analyzing relationships between health and climate change, climate change and the environment, and even mining and climate change, yet none capture the full scope of the interactions between all the challenges. Further, existing models are not appropriate for situations where the dominant extractive industry is in the informal sector, a growing reality in many countries [70, 93, 121]. The climate change, conflict, mining nexus is a wicked problem because it is inherently interdisciplinary, has complex interdependencies, crosses international borders, is geographically and temporally dynamic, and is difficult to both define and solve [56]. In the face of these challenges, involvement from local stakeholders in designing site-specific adaptation and intervention strategies is paramount.

It is encouraging to see more recent research into the impacts of climate change on formal sector mining, but the relationship between climate change and informal mining needs further investigation. The interactions between climate change and ASM include direct effects, such as people giving up increasingly tenuous subsistence lifestyles for more reliable income and indirect effects, including the shift in mineral demand due to increasing use of alternative energy options.

## CONCLUSIONS

Environmental health crises related to ASM will continue to occur in marginalized communities for as long as global markets demand coltan, gold, and other minerals. This was clearly demonstrated in Zamfara, where the dramatic increase in gold value was partially responsible for the lead poisoning outbreak [1, 3, 24]. Demand for metals is expected to intensify with the production of low-carbon energy alternatives. The World Bank estimates a 585% increase in the demand for cobalt by 2050 in order to meet demand for renewable energy alone [122]. Most of the world's cobalt comes from mining in the DRC, a country that has been embroiled in violent conflict for decades and where other mineral resources, such as coltan, are used to fund multiple armed groups [123, 124]. With increased global demand for and production of mineral resources, there is a risk that conflicts over nonrenewable resources will amplify if environmental and health impacts are not mitigated and economic benefits are not equitably distributed [9, 67, 125].



**Figure 8** Residents of Bagega Village in Zamfara State, Nigeria at a mass prayer for peace (2020, photo credit: Simba Tirima).

A combination of explosive population growth, pervasive climate change impacts, and vast quantities of unexploited mineral resources place the African continent in an especially precarious position in coming decades [126, 127]. By the end of this century, Africa will be home to half of the world's children and 40% of the global population [128]. Nigeria is one of nine countries where the largest increase in population is expected to occur and it is no stranger to conflict: the Niger Delta region has been plagued with intractable conflict related to oil and gas extraction for decades [129, 130, 131]; the devastating Biafra conflict in the late 1960s was the impetus for several French physicians to form what is now MSF [132]; and the unethical Pfizer drug trial and its effects are still apparent in today's polio survivors [14, 15]. Zamfara exemplifies a region grappling with managing the challenges of conflict ([Figure 8](#)), climate change, and resource extraction against a regional backdrop of extreme poverty, a rapidly increasing population, health crises, and environmental degradation. Locally driven, sustainable climate change adaptation strategies inclusive of responsible ASM could be a foundation for stabilizing impacted communities and promoting peace.

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## COMPETING INTERESTS

The authors have no competing interests to declare.

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## AUTHOR AFFILIATIONS

**Casey Bartrem, PhD**  [orcid.org/0000-0001-7534-7103](https://orcid.org/0000-0001-7534-7103)

TerraGraphics International Foundation, Moscow Idaho US

**Ian von Lindern, P.E., PhD**  [orcid.org/0000-0002-5104-0155](https://orcid.org/0000-0002-5104-0155)

TerraGraphics International Foundation, Moscow Idaho US

**Margrit von Braun, P.E., PhD**  [orcid.org/0000-0001-5922-3645](https://orcid.org/0000-0001-5922-3645)

TerraGraphics International Foundation, Moscow Idaho US; University of Idaho, Moscow Idaho US

**Simba Tirima, PhD**

TerraGraphics International Foundation, Moscow Idaho US; Médecins Sans Frontières, Abuja, NG

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