

Environmental Pollution and Community Health in Resource-Extraction Regions: Evidence, Gaps, and Intervention Frameworks

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Abstract

This review examines how pollution generated by resource extraction affects community health, with particular attention to exposure pathways, vulnerable populations, evidence gaps, and intervention options. Drawing on multidisciplinary literature from environmental science, epidemiology, occupational health, toxicology, public health, and governance, the study synthesizes evidence from mining, petroleum, gas, quarrying, and related processing contexts across Africa and other regions. The review identifies air, water, soil, sediments, food systems, tailings, and toxic residues as interconnected pathways through which metals, hydrocarbons, particulate matter, silica, and other contaminants reach workers and neighbouring populations. Major health burdens include respiratory, cardiovascular, neurological, maternal, child, reproductive, occupational, and psychosocial effects, with risks intensified by poverty, livelihood dependence, age, pre-existing disease, weak healthcare access, and inadequate regulatory protection. The evidence also reveals persistent methodological weaknesses, including fragmented surveillance, inconsistent exposure metrics, limited biomonitoring, short study durations, and difficulties in causal attribution. The review finds that effective protection requires a shift from reactive remediation toward preventive, integrated governance. Priority interventions include stronger pollution controls, enforceable environmental regulation, community-based monitoring, health surveillance, transparent data systems, fair compensation, rehabilitation, and long-term clinical follow-up. Emerging digital tools and cleaner-energy systems may support these measures where they are embedded within accountable institutions and adapted to local conditions. The review concludes that safeguarding extraction-affected communities requires environmental justice, health-centred regulation, and sustained community participation. Future research should prioritize longitudinal designs, cumulative-exposure assessment, locally validated indicators, comparative governance analysis, and implementation-focused evaluation of interventions. Greater emphasis is also required on children, women, Indigenous peoples, informal workers, and remote settlements that remain systematically underrepresented in evidence.

Keywords: *Environmental pollution; Resource extraction; Community health; Exposure pathways; Environmental justice; Health surveillance*

INTRODUCTION

Resource Extraction and Environmental Health Context

Resource extraction remains a foundational component of the global economy, supplying fuels, metals and minerals required for infrastructure, manufacturing, digital technologies and energy systems. Yet the environmental-health costs of extraction are unevenly distributed because mines, oilfields and associated waste streams are frequently concentrated near rural, Indigenous, low-income and politically marginalised communities. A scoping review of mining and oil-and-gas research shows that health scholarship has traditionally emphasized occupational hazards and direct toxic exposures while giving less attention to ecosystem disruption, social determinants and cumulative community effects. This matters because extraction changes

landscapes, water security, food systems and livelihoods, creating multiple pathways through which environmental degradation becomes a population-health burden (Brisbois *et al.*, 2019).

The environmental-health context is especially visible where regulatory capacity, monitoring infrastructure and health services are weak. In Nigeria's Niger Delta, decades of petroleum extraction have generated persistent concern over oil spills, contaminated environmental media and community well-being. Evidence from exposed communities indicates that oil pollution is associated with adverse health symptoms and functional limitations, illustrating how chronic extraction-related contamination can become embedded in everyday life rather than appearing only as an acute industrial accident (Nriagu *et al.*, 2016). Environmental health in extraction regions must therefore encompass both measurable toxic exposures and the social experience of living within degraded environments.

Comparable patterns occur across sub-Saharan Africa. In Ghana, integrated evidence from artisanal and small-scale gold-mining areas documents exposure to mercury and other metals alongside injuries, noise, sanitation deficiencies and psychosocial concerns, indicating that community health risks are multidimensional rather than pollutant-specific (Basu *et al.*, 2015). In Tanzania, biomonitoring and clinical assessment among artisanal gold miners showed elevated mercury burdens among exposed groups, with amalgam burners facing particularly serious risks, demonstrating the direct link between extraction practices, toxicant exposure and preventable disease (Bose-O'Reilly *et al.*, 2010).

Evidence from Asia reinforces the transboundary character of these risks. Research in northern Indonesia identified mercury contamination in river sediments, fish and human hair around artisanal gold-mining locations, while neurological examinations detected symptoms consistent with harmful exposure among miners and nearby inhabitants (Arifin *et al.*, 2015). At a broader national scale, evidence from China shows that mining-affected soils can contain hazardous concentrations of cadmium, lead, arsenic, mercury and other metals, with risk assessments identifying serious carcinogenic and non-carcinogenic threats, particularly for children living near contaminated sites (Li *et al.*, 2014). A systematic review further demonstrates that mercury exposure remains a recurrent occupational and environmental-health problem across artisanal gold-mining settings, while highlighting weaknesses in study quality and the continuing need for stronger exposure assessment (Taux *et al.*, 2022).

Latin American evidence similarly demonstrates how extraction reshapes ecological and public-health conditions. In Peru's central highlands, mining-affected river sediments have shown elevated concentrations of toxic metals, including arsenic and lead, with risk assessments indicating significant human-health concerns through environmental contact and food-chain pathways (Custodio *et al.*, 2025). In Brazil, the Mariana and Brumadinho mining disasters illustrate the catastrophic end of the extractive-risk spectrum, where tailings failures disrupted communities, damaged ecosystems and increased pressures on health services, revealing how environmental disasters can produce immediate harm and longer-term morbidity burdens (Vidal *et al.*, 2025).

The extraction-health relationship must also be situated within debates on development, energy demand and technological transition. In Nigeria, analysis of solar integration within small-scale manufacturing demonstrates the potential for cleaner energy options to support environmentally sustainable production (Sunday and Omoegun, 2018). Similarly, research on energy efficiency and transportation-logistics optimisation in the United States provides a sustainability-oriented infrastructure perspective rather than direct evidence on polluted extraction communities, but it helps frame how demand-side efficiency can reduce resource intensity across economic systems (Opara *et al.*, 2024).

Pollution Pathways in Extraction Communities

Pollution in resource-extraction communities develops through interconnected pathways that transport contaminants from mines, wells, processing facilities and waste repositories into environments where people live, work and obtain food. In Nigeria's Ogoniland, petroleum hydrocarbons originating from spills, leaking infrastructure, transport losses and artisanal refining have contaminated surface water, groundwater and sediments, demonstrating how persistent releases can connect industrial sources with household water systems (Lindén and Pålsson, 2013). Comparable pathway complexity is evident in Ghanaian artisanal gold mining, where mercury emissions, metal-rich sediments, degraded water quality and disturbed soils create atmospheric, aquatic and terrestrial routes of contamination (Rajaee *et al.*, 2015).

Water is important because extraction wastes may be mobilised by seepage, runoff and rainfall. In South Africa, mine-derived acidic drainage accumulated within a wetland before intense rainfall flushed contaminated water into a municipal reservoir, illustrating how hydrological events can convert stored pollution into community exposure (McCarthy and Humphries, 2013). In the D.R. Congo Copperbelt, environmental sampling indicates that cobalt reaches residents through contaminated food, fish, soil and dust, with dietary intake dominating adult exposure while incidental soil and dust ingestion is especially important for children (Cheyns *et al.*, 2014). Wind dispersal also redistributes mine residues: around Kabwe, Zambia, soil metal concentrations declined with distance from mining operations in patterns consistent with prevailing winds (Tembo *et al.*, 2006).

Airborne transport can extend contamination beyond extraction boundaries because crushing, hauling, smelting, and weathered tailings generate fine particles enriched with metals and metalloids (Csavina *et al.*, 2012). Once deposited, contaminants may enter food systems; arsenic uptake in vegetables cultivated near a former Arizona mine and smelter demonstrates a soil-to-crop ingestion pathway (Ramírez-Andreotta *et al.*, 2013). In Canada's oil-sands region, airborne and dissolved polycyclic aromatic compounds were transported into snow, tributaries and the Athabasca River,

linking atmospheric deposition with aquatic contamination (Kelly *et al.*, 2009).

Catastrophic tailings releases intensify these processes by rapidly distributing acidic water and metal-bearing sediment across river channels and floodplains, as documented at Aznalcóllar, Spain (Hudson-Edwards *et al.*, 2003). Post-disaster measurements from Brazil's Doce River demonstrate continued concern over metals in water and fish, underscoring aquatic and trophic transfer pathways (Mourão *et al.*, 2023). In Mongolia, mining-associated metals and other solutes in river systems show how extraction pressures propagate downstream through catchments, making pollution pathways spatially extensive, seasonally variable and difficult to isolate from other land-use pressures (Narangarvuu *et al.*, 2024).

Community Health Burdens and Vulnerabilities

Community health burdens in resource-extraction regions arise from the interaction of environmental contamination, occupational hazards, social deprivation and unequal capacity to avoid exposure. These burdens are rarely distributed uniformly. Children, pregnant women, older people, workers with prolonged contact, low-income households and populations dependent on contaminated local water or food systems may experience disproportionately high risks. The Zamfara lead-poisoning outbreak in north-western Nigeria illustrates this vulnerability starkly: artisanal gold-ore processing occurred within residential compounds, and young children experienced extremely elevated blood-lead concentrations and substantial mortality, demonstrating how household proximity, age-specific behaviour and livelihood practices can transform an occupational activity into a community-wide health emergency (Dooyema *et al.*, 2012).

Vulnerability is also shaped by knowledge, employment conditions and economic dependence. Among artisanal gold miners in Ghana, limited understanding of mercury-related environmental and health effects coexisted with unsafe work practices and adverse occupational conditions. Such evidence shows that exposure cannot be interpreted solely as an individual behavioural choice; miners may remain embedded in hazardous activities because income insecurity, weak regulatory protection, insufficient risk communication and limited access to safer technologies constrain feasible alternatives. Gender, age, education and duration of residence or employment can further modify both exposure and the capacity to respond to risk (Armah *et al.*, 2016).

Community burdens extend beyond acute toxic effects. Epidemiological evidence from Central Appalachia in the United States found a higher prevalence of birth defects among populations residing in mountaintop-mining areas than in non-mining areas, even after adjustment for several socioeconomic factors. This pattern underscores the importance of considering reproductive and developmental vulnerability alongside respiratory, cardiovascular and psychosocial outcomes, while recognising that socioeconomic disadvantage and environmental exposure may operate simultaneously rather than independently (Ahern *et al.*, 2011).

Pre-existing disease can further intensify vulnerability because environmental stressors act upon populations with unequal baseline health. The requested study by Ike and colleagues examines nutrition, DNA-related markers and cardiovascular health among middle-aged adults with type 2 diabetes; it does not investigate mining or extraction pollution directly and should therefore be treated only as supporting evidence that cardiometabolic status may condition susceptibility to additional environmental stressors (Ike *et al.*, 2025). Within extraction regions, health burdens are therefore best understood as cumulative outcomes produced by toxic exposure, livelihood dependence, demographic sensitivity, underlying disease, healthcare accessibility and broader structural disadvantage over extended periods.

Review Scope, Objectives, and Questions

This review examines the environmental and public-health consequences of resource extraction within communities located near mining, petroleum, gas, quarrying and related processing activities. Its scope is deliberately interdisciplinary, bringing together evidence from environmental science, epidemiology, occupational health, toxicology, community health, environmental governance and risk management. Particular attention is given to the ways pollutants are generated, transported and transformed across air, water, soil, sediments and food systems, and to how these pathways create unequal patterns of exposure among workers, households and vulnerable population groups. The review considers both chronic contamination and acute environmental events, including spills, tailings failures, dust emissions, acid drainage, heavy-metal mobilisation and hydrocarbon pollution. This framing recognizes that extraction benefits and environmental health costs are often distributed unevenly across generations.

The primary objective is to synthesize current knowledge on the relationship between extraction-related environmental degradation and community health outcomes while identifying where evidence remains fragmented, geographically uneven or methodologically weak. A further objective is to assess how demographic characteristics, poverty, livelihood dependence, pre-existing disease, limited healthcare access and weak regulatory protection can intensify vulnerability. The review also evaluates the adequacy of existing monitoring, surveillance, remediation and governance responses, with emphasis on whether interventions address pollution at source, reduce exposure, strengthen health protection and incorporate affected communities into decision-making.

Accordingly, the review is guided by several analytical questions. What major pollution sources and environmental pathways characterize resource-extraction regions? Which health burdens are most consistently associated with these exposures, and which population groups experience disproportionate risks? How effectively do existing studies measure cumulative, long-term and multi-pathway exposure? Where are the principal geographical, methodological and population-level evidence gaps? Which regulatory, technological, clinical and community-based interventions

show the greatest potential for preventing or reducing harm? Finally, what governance and research priorities are required to move from reactive management toward preventive, accountable and health-centred extraction systems?

The review therefore extends beyond documenting pollution or disease in isolation. It seeks to connect environmental processes, exposure patterns, health inequalities and institutional responses within a coherent framework capable of supporting evidence-based policy, targeted intervention and future research in extraction-affected communities across diverse economic and geographical settings.

ENVIRONMENTAL POLLUTION IN EXTRACTION REGIONS

Air Pollution from Extraction Activities

Air pollution constitutes one of the most pervasive environmental-health pressures in resource-extraction regions because drilling, blasting, crushing, hauling, ore processing, combustion and waste storage continuously generate contaminants capable of dispersing beyond operational boundaries. Unlike occupational exposure confined largely to worksites, extraction-related emissions may infiltrate neighbouring settlements, schools, farms and household environments, creating recurrent community exposure to particulate matter, crystalline silica, metals, nitrogen oxides, volatile organic compounds and combustion-derived toxicants. In the Niger Delta, analysis of indoor and outdoor dust from rural communities surrounding gas-flaring locations identified substantial polycyclic aromatic hydrocarbon contamination, with source analysis implicating gas flaring alongside biomass combustion and traffic. This demonstrates how petroleum extraction can establish an atmospheric pathway through which industrial emissions accumulate in settled dust and become available for inhalation and ingestion (Odali *et al.*, 2024).

Mining creates a different but equally important particulate burden. Wind erosion of tailings storage facilities can resuspend fine mineral particles long after active extraction has declined or ceased. In Gauteng, South Africa, dust originating from partially rehabilitated gold-mine tailings contained silica and uranium and was modelled to affect adjacent residential and commercial receptors, illustrating how poorly rehabilitated waste facilities can become persistent secondary sources of community air pollution (Mpanza *et al.*, 2020). Occupational evidence from Ghana further clarifies the biological relevance of respirable mine dust. Among underground gold miners at Obuasi, cumulative dust exposure was associated with breathlessness and reductions in selected pulmonary-function indices, underscoring the importance of particle size, silica content and exposure duration when assessing inhalation hazards associated with mineral extraction (Bio *et al.*, 2007).

The scale of emissions may extend well beyond individual sites. Australian national inventory data showed that coal mines contributed substantially to reported PM10, PM2.5, metal and nitrogen-oxide emissions, while monitoring stations recorded higher PM10 exposure in coal-mining communities than in non-mining communities. Such evidence challenges regulatory approaches that treat mine dust principally as an occupational problem, because workers may also experience continuing exposure where their homes are located within mining districts (Hendryx *et al.*, 2020). In northern Chile, source-apportionment analysis in Tocopilla, an industrial city strongly connected to copper mining, demonstrated spatially elevated particulate concentrations and differentiated contributions from industrial, soil, marine and combustion sources, highlighting the analytical difficulty of separating extraction emissions from other co-located pollution sources (Jorquera, 2009).

These atmospheric burdens are particularly consequential where communities lack paved roads, effective dust barriers, reliable health surveillance or the political leverage to secure emission controls. Seasonal dryness, strong winds and repeated vehicle movements can intensify resuspension, while children, older residents and people with pre-existing respiratory disease may experience disproportionate inhalation exposure.

Oil and gas extraction additionally releases gaseous pollutants that may vary sharply across space and time. Measurements in the Barnett Shale region of Texas detected volatile organic compounds associated with active wells and compressor facilities, with downwind concentrations declining markedly with distance. This spatial gradient shows why fixed monitoring networks may underestimate short-duration exposures experienced by households close to particular facilities and why meteorology, operational cycles and proximity must be incorporated into exposure assessment (Zielinska *et al.*, 2014).

Effective control therefore requires a source-to-receptor strategy combining dust suppression, enclosed processing, tailings stabilization, emissions capture, equipment maintenance, buffer zones and continuous community-level monitoring. The requested review of direct air capture technologies is only indirectly relevant because it focuses on removing atmospheric carbon dioxide rather than controlling particulate matter, silica, metals or toxic gases emitted by extraction activities. Nevertheless, it illustrates the broader technological principle that atmospheric remediation is generally more complex and resource-intensive than preventing emissions at source, reinforcing the priority of pollution prevention within extraction-region health protection (Liadi *et al.*, 2024).

Water and Soil Contamination Pathways

Water and soil contamination in resource-extraction regions emerges through interacting hydrological, geochemical and operational processes that transfer pollutants from active workings, waste repositories and processing zones into community environments. In the Niger Delta, crude-oil spill vulnerability is intensified by dense drainage networks, shallow aquifers, high rainfall and proximity between petroleum infrastructure and settlements. A source–pathway–receptor assessment demonstrates that spill volume, terrain, wells, pipelines, streams and population distribution jointly shape groundwater contamination risk, making subsurface migration a critical pathway of community exposure (Oyebamiji *et al.*, 2025).

Mining communities face analogous pressures where untreated effluents and waste rock are released directly onto land or into surface waters. At Kokoteasua in Ghana, artisanal mining was associated with pronounced heavy-metal contamination of soils, while elevated arsenic and zinc rendered some groundwater locations unsuitable for drinking and stream concentrations of iron and manganese exceeded relevant guideline values. Such findings illustrate the connectivity between contaminated mine sites, shallow aquifers and domestic water sources (Gyamfi *et al.*, 2019).

Contaminants may also accumulate in soils before leaching downward or being redistributed by runoff. Around mining and ore-dressing factories in northern China, cadmium, lead and arsenic were prominent topsoil pollutants, while groundwater contamination created additional health risks, demonstrating that deposition, soil retention and hydrological transport can operate simultaneously within the same extraction landscape (Zhao *et al.*, 2023). In Odisha, India, changes in soil and water quality near chromite mining similarly show how excavation, overburden disturbance and mineral-processing residues alter adjoining environmental media and create interconnected contamination pathways (Nanda *et al.*, 2022).

Legacy extraction can remain environmentally active long after production ends. At a former gold-mining site in Victoria, Australia, unrehabilitated wastes contained elevated arsenic and mercury, with contaminant mobility presenting a continuing threat to downstream water resources. This persistence shows why historical waste deposits require consideration alongside contemporary operations when characterising exposure pathways (Abraham *et al.*, 2018).

Agricultural soils provide another important interface between environmental contamination and human exposure. In Chile, copper, arsenic and antimony concentrations in soils affected by mining and associated industrial activity exceeded critical values in highly impacted areas and generally declined with increasing distance from pollution sources, demonstrating spatial transfer from extraction-related operations into productive land (De Gregori *et al.*, 2003). Together, these pathways show that water and soil function not as isolated environmental compartments but as connected reservoirs and transport media through which extraction-derived contaminants can persist, migrate and enter drinking-water and food-production systems.

Waste, Tailings, and Toxic Residues

Waste generated by resource extraction is not environmentally inert; rather, tailings, waste rock, process slurries and metallurgical residues can retain sulphides, toxic metals, processing reagents and fine particles capable of remaining reactive for decades. Globally, tailings volumes often exceed the mass of recovered commodities, and oxidation, weathering and structural instability can mobilise contaminants into groundwater, rivers, soils and atmospheric dust. Tailings impoundments therefore function simultaneously as engineered waste facilities and long-term environmental risk repositories, particularly where containment, water management and post-closure surveillance are inadequate (Kossoff *et al.*, 2014).

Evidence from southeastern Nigeria illustrates the persistence of these hazards. Analysis of mine tailings and waste rock from the Oshiri–Ishiagu mining region identified potentially toxic metals, with cadmium showing particularly high enrichment in some waste materials. Such residues can become secondary pollution sources through leaching, erosion and dispersion into surrounding environmental media, especially where abandoned or informal mine sites lack engineered containment (Igwe *et al.*, 2022).

Comparable risks occur elsewhere in Africa. At a Ghanaian gold mine, sulphide waste, oxide waste and tailings were enriched with arsenic, cadmium and lead, while calculated ecological and health risks varied according to waste type and were greatest for tailings. This heterogeneity demonstrates why waste classification and geochemical characterisation are essential before rehabilitation or reuse decisions are made (Akoto and Anning, 2021). In China, a meta-analysis of lead–zinc mine tailings similarly identified substantial contamination by multiple metals, with arsenic and lead contributing important non-carcinogenic risks and arsenic and copper contributing carcinogenic concerns (Kan *et al.*, 2021).

The consequences become more acute when containment fails. Following the Brumadinho tailings-dam collapse in Brazil, approximately 12 million cubic metres of mine waste entered the Paraopeba River system, producing major increases in turbidity, metals and nutrients and demonstrating how stored residues can be rapidly transformed into regional aquatic contamination (Thompson *et al.*, 2020).

Emerging treatment materials may assist future waste-management strategies, but their own environmental fate requires scrutiny. The requested nanomaterials study is not a mining-tailings investigation; nevertheless, its emphasis on toxicological assessment, environmental persistence and safe-by-design principles provides limited supporting justification for evaluating secondary risks before novel materials are introduced into remediation systems (Mensah *et al.*, 2024). Effective management therefore requires secure storage, geochemical monitoring, seepage control, dust suppression, progressive rehabilitation and long-term stewardship proportionate to residue toxicity and failure potential. These controls matter especially where communities depend on nearby land and water for food, livelihoods, and domestic needs.

COMMUNITY HEALTH EFFECTS AND EXPOSURE PATTERNS

Respiratory, Cardiovascular, and Neurological Outcomes

Respiratory, cardiovascular, and neurological disorders represent major health consequences of living and working within resource-extraction environments because industrial processes can generate respirable mineral dusts, toxic metals, combustion products, and contaminated wastes affecting several physiological systems simultaneously. The respiratory burden is evident where communities are exposed to silica-rich mine residues. In Johannesburg, residents living within 500 m of gold-mine waste dumps showed greater odds of upper-respiratory symptoms, wheezing, and spirometry-

defined chronic obstructive pulmonary disease than populations farther away, demonstrating that mine wastes can sustain community exposure beyond occupational boundaries (Iyaloo *et al.*, 2020).

Occupational evidence from artisanal mining reinforces this pathway. Among Mongolian gold miners, high respirable crystalline-silica concentrations were recorded during underground quarrying and grinding, while radiographic assessment identified silicosis in almost one-fifth of participants. Longer employment and dust-intensive tasks substantially increased disease risk, indicating that duration, task configuration and inadequate dust suppression shape the transition from exposure to irreversible pulmonary pathology (Dansran *et al.*, 2025). Respiratory impacts may also follow catastrophic releases rather than routine operations. After the Brumadinho tailings-dam rupture in Brazil, population-based assessment documented asthma, chronic obstructive pulmonary disease, wheezing, dry cough and nasal irritation, with symptom patterns varying according to residence and disaster-related exposure circumstances (Campos *et al.*, 2022).

Cardiovascular effects are increasingly recognised as another component of extraction-related morbidity. Analysis of Appalachian communities in the United States found that mortality from heart and respiratory diseases increased with coal-mining intensity even after adjustment for demographic, behavioural and socioeconomic covariates, suggesting that environmental and occupational burdens can intersect with structural disadvantage to amplify chronic disease risk (Hendryx, 2009). Evidence from Chinese coal miners provides a plausible vascular pathway: cumulative coal-dust exposure showed positive dose-response associations with arterial stiffness and estimated ten-year atherosclerotic cardiovascular disease risk. These findings broaden the conventional understanding of mine dust from a predominantly pulmonary hazard toward a systemic exposure capable of contributing to vascular dysfunction (Huang *et al.*, 2024).

Neurological outcomes are consequential where extraction mobilises lead or mercury. During the Zamfara artisanal-gold-mining emergency in Nigeria, clinical assessment of 972 lead-poisoned children showed that neurological abnormalities became progressively more likely as venous blood-lead concentrations increased; younger children were particularly vulnerable. This evidence demonstrates that extraction-related contamination can produce severe neurotoxicity when ore processing occurs within residential environments and exposes developing nervous systems to highly bioavailable lead (Greig *et al.*, 2014). Mercury-intensive gold extraction creates a parallel risk. In Ghana's Western Region, artisanal miners displayed substantial urinary mercury burdens, and neuropsychological assessment showed meaningful differences associated with mining formalisation and exposure patterns, supporting the importance of neurological surveillance alongside conventional occupational monitoring (Ovadje *et al.*, 2021).

Community neurotoxicity is not confined to workers. Children living near the open-pit mining complex of Cerro de Pasco, Peru, had higher concentrations of several heavy metals than children from a comparison area, with chronic exposure associated with mood alterations, reduced visual field and other adverse symptoms. The coexistence of arsenic, cadmium, lead, chromium and other metals illustrates the challenge of attributing neurological effects to a single contaminant when extraction communities experience complex mixtures over time (Piñeiro *et al.*, 2021).

Taken together, these findings show that extraction-related health burdens cannot be compartmentalised neatly by organ system. Respiratory injury may coexist with vascular stress and neurotoxicity because particulate matter, silica and metals move through shared environmental and occupational pathways. Risk is intensified by cumulative exposure, proximity to waste facilities, informal processing, inadequate protective controls and delayed diagnosis. Effective health protection requires integrated surveillance combining spirometry, cardiovascular risk assessment, biomonitoring and neurological evaluation, supported by exposure reduction at source and long-term follow-up of workers and surrounding communities over extended periods.

The Nigerian neurological evidence directly links increasing blood-lead concentrations with neurological abnormalities, while the South African, Ghanaian, Chinese, Brazilian, Peruvian, Mongolian and U.S. studies provide complementary outcome evidence.

Maternal, Child, and Reproductive Health

Maternal, child, and reproductive health outcomes in resource-extraction regions reflect heightened biological sensitivity during pregnancy, fetal development, infancy, and childhood. In Nigeria's Niger Delta, a prospective cohort study found that women residing in highly oil-polluted areas experienced greater risks of premature rupture of membranes and postpartum haemorrhage than women in lower-exposure areas. These findings show how petroleum contamination may interact with pregnancy-related vulnerability and increase pressures on maternal-health systems (Oghenetega *et al.*, 2022).

Mining-related metal exposure creates comparable concerns across the maternal–infant continuum. In Ghanaian gold-mining communities, toxic metals including mercury, arsenic and lead were detected in breast milk, and estimated intakes for substantial proportions of infants exceeded provisional tolerable levels. Biomarker patterns suggested that fetal exposure during pregnancy could exceed subsequent exposure through breastfeeding, emphasising protection before conception and throughout gestation rather than reliance on postnatal interventions (Bansa *et al.*, 2017).

Evidence from Peru further demonstrates the reproductive significance of mixed-metal exposure. In the Madre de Dios artisanal and small-scale gold-mining birth cohort, maternal and cord-blood measurements were used to evaluate associations between toxic metals, birth weight and gestational age. The study demonstrates the value of prospective biomonitoring while recognising that pregnant women in mining regions encounter complex mixtures

through occupational, dietary and environmental pathways (Berky *et al.*, 2023).

Population-level evidence from Brazil indicates that reproductive vulnerability extends beyond mine workers. In municipalities surrounding the Candiota coal-mining region, gestational and neonatal outcomes varied in relation to residence within an established pollution hotspot, reinforcing concern about community exposure during critical developmental windows (Soares *et al.*, 2022). Maternal and child protection in extraction regions therefore requires reproductive-health surveillance, prenatal exposure assessment, accessible antenatal care, contaminant biomonitoring and targeted risk communication, particularly for women dependent on extraction-linked livelihoods and infants whose developmental vulnerability can convert comparatively brief exposures into lifelong health consequences.

Occupational and Psychosocial Health Burdens

Occupational and psychosocial burdens in resource-extraction regions arise from the interaction of hazardous work, insecure livelihoods, demanding production systems and social pressures. Workers may face traumatic injuries, excessive workloads, shift schedules, isolation, precarious employment and chronic concern about accidents, while households may experience income volatility and strain. Among artisanal and small-scale miners in Ghana, work-related stress was associated with poorer self-rated health, with anxiety and depressive symptoms mediating much of this relationship. The evidence demonstrates that occupational risk in informal mining extends beyond physical injury to psychological well-being (Nyaaba *et al.*, 2025).

Psychosocial pressures are also evident in formal mining systems. A study of coal miners in Xinjiang, China, found that occupational stress and job burnout were significant risk factors for psychological symptoms, while burnout partly mediated workplace stress. Long hours and limited control can generate psychological strain alongside conventional occupational hazards (Fu *et al.*, 2022). In Australia, remote mining and construction workers reported elevated psychological distress compared with the general population; relationship difficulties, financial concerns, shift rosters, social isolation and mental-health stigma were prominent stressors. Roster design and geographical separation can transmit occupational pressures into family life (Bowers *et al.*, 2018).

The Nigerian study is indirectly rather than extraction-specifically aligned. It shows that economic challenges and marital disagreement influenced changing breadwinner roles among husbands in Ibadan, showing that livelihood instability can produce household psychosocial strain. It should therefore support interpretation of extraction-dependent income insecurity, not claims about mining workers themselves (Ezeani and Sabboh, 2021).

Technological intensification adds another dimension. Contemporary extraction increasingly relies on automated equipment, control systems and human–machine interfaces, potentially reducing some physical exposures while creating cognitive demands involving vigilance, information processing and rapid decision-making. The requested multimodal workload framework is not mining-specific, but its integration of physiological, behavioural and performance indicators provides a methodological basis for assessing cognitive load in technology-intensive extraction workplaces (Adamolekun *et al.*, 2025). Occupational-health strategies should integrate injury prevention, psychosocial assessment, fatigue management, confidential mental-health support, livelihood security and cognitive-ergonomic monitoring rather than treating worker health as a purely physical safety problem across workers and their families alike.

EVIDENCE GAPS AND ASSESSMENT CHALLENGES

Exposure Measurement and Causal Attribution

Exposure measurement is a central methodological challenge in resource-extraction health research because communities are rarely exposed to a single contaminant through one stable pathway. Dust, metals, hydrocarbons, contaminated water, food-chain transfer and take-home exposure vary across space, season and work cycle, making one-time sampling an incomplete proxy for biologically effective dose. Across African artisanal and small-scale gold-mining settings, evidence remains fragmented, with environmental measurements, biomonitoring and health outcomes often collected separately; this weakens source-to-exposure-to-disease linkage and constrains causal inference (Ondayo *et al.*, 2024).

Improving measurement requires integration of environmental monitoring with biomarkers, geospatial information, exposure histories, and outcomes. Advanced biosensing illustrates how field-deployable detection can combine measurement with algorithmic interpretation. Although developed for antimicrobial-resistant foodborne pathogens rather than mining contaminants, AI-enabled biosensors demonstrate principles applicable to extraction communities, including real-time signal processing, on-site detection and reduced diagnostic delay; their relevance here is methodological (Olorunkosebi *et al.*, 2023).

Digital twins offer a complementary approach by linking physical systems with virtual models capable of detecting deviations and predicting abnormal conditions. The smart-substation framework developed by Shittu and colleagues shows how multisource sensor data, simulation and predictive analytics could support exposure surveillance around extraction infrastructure if adapted to pollutant transport and community receptors (Shittu *et al.*, 2023). Similarly, vibration-based condition monitoring demonstrates how continuous sensor streams can identify operational deterioration before failure, suggesting a transferable model for detecting equipment states preceding leaks, dust releases or other hazards (Omoegun *et al.*, 2023).

Sensor-based fault detection also highlights the importance of data quality, calibration and anomaly discrimination. The HVAC study by Sunday and Omoegun, its treatment of sensor drift, incomplete measurements and model-based diagnostics, illustrates why exposure systems must

distinguish environmental change from instrument error (Sunday and Omoegun, 2020). Causal attribution requires more than detecting pollutants: studies must establish temporality, characterize dose and duration, control confounding, account for co-exposures and connect environmental concentrations with internal dose and health outcomes. Longitudinal designs, repeated biomonitoring, personal sensors and harmonized protocols are therefore essential for moving extraction-health research from spatial association toward causal explanation.

Data Inequities and Vulnerable Populations

Data inequities are a constraint on understanding environmental health burdens in resource-extraction regions because the populations most exposed are often the least systematically represented in surveillance, biomonitoring, and longitudinal research. Children in artisanal gold-mining communities illustrate this problem. In Osun State, Nigeria, children living in a mining community had higher blood-lead concentrations than those in a comparison community, demonstrating both heightened vulnerability and the importance of community-based screening where formal exposure datasets are sparse (Akinwumi *et al.*, 2023).

Measurement inequity is also methodological. Instruments developed in other cultural settings may not capture psychosocial vulnerability accurately among African populations. The revised self-esteem scale developed for Nigerian adolescents and youths demonstrates the value of culturally adapted, psychometrically evaluated measures when assessing dimensions of well-being that conventional environmental surveillance may overlook (Sabboh, 2022). Similarly, item-response modelling of emotional vacillation among Nigerian undergraduates shows how testing differential item functioning and construct validity can reduce measurement bias across population subgroups (Sabboh, 2025).

Gender constitutes another major source of invisibility. Across artisanal and small-scale mining in sub-Saharan Africa, women are disproportionately concentrated in lower-value activities and face intersecting disadvantages involving limited capital, education, land access, occupational protection, health risks, and social discrimination. Yet evidence remains geographically concentrated, particularly in Ghana and the Democratic Republic of Congo, limiting generalisation across the region (Paschal and Kauangal, 2023).

Comparable inequities affect Indigenous populations in high-income countries. Native American communities in the western United States experience legacy exposure from abandoned mines alongside poverty, infrastructure deficits, undercounting, and limited environmental-health research. Standard exposure scenarios may inadequately represent traditional diets, water use, and land-based practices, thereby obscuring culturally specific pathways (Lewis *et al.*, 2017). More equitable evidence systems therefore require disaggregated data, participatory monitoring, culturally valid instruments, repeated biomonitoring, and intentional inclusion of children, women, Indigenous peoples, informal workers, and remote communities.

INTERVENTION FRAMEWORKS AND POLICY RESPONSES

Pollution Prevention and Regulatory Enforcement

Pollution prevention in resource-extraction regions requires regulatory systems that intervene before contaminants enter air, water, soil and food chains, rather than relying principally on remediation after damage occurs. Effective prevention begins with licensing, environmental impact assessment, baseline characterization, emission and discharge limits, waste-management plans, financial assurance and enforceable closure obligations. Nigeria illustrates the consequences of weak implementation: illicit mining has persisted despite statutory controls, with inadequate oversight limiting public authorities' capacity to contain environmental, health and economic harms. Stronger inspection capacity, institutional coordination and sanctions are essential to convert legal requirements into preventive practice (Olujobi and Irumekhai, 2024).

Ghana presents a governance challenge. Although its mining legislation establishes environmental and institutional controls, weaknesses in the regulatory framework and environmental management of illegal mining continue to undermine sustainability. Regulatory effectiveness depends not merely on legislation but on clear institutional mandates, adequate resources, routine monitoring, transparent permitting and enforceable reclamation requirements (Asumda *et al.*, 2024). Experience shows prevention must extend across the mine life cycle. In Western Australia, integrating environmental impact assessment with mine-closure planning improved early consideration of closure risks and encouraged learning and behavioural change, although coordination between regulatory agencies remained important (Getty and Morrison-Saunders, 2020).

The three requested governance studies are indirectly aligned because they address enterprise and supply-chain governance rather than environmental regulation in extraction regions. Nevertheless, their transferable principles can strengthen enforcement architecture when applied cautiously. A supply-chain governance model emphasizing policy alignment, compliance monitoring, data intelligence and traceability supports the proposition that environmental obligations should be embedded across contractors, suppliers and operational units rather than confined to corporate headquarters (Akin-Oluyomi and Akhigbe, 2022). Similarly, enterprise risk management integrating operational analytics demonstrates how continuous risk indicators and cross-functional oversight can shift organizations from reactive compliance toward anticipatory control, a useful principle for monitoring spills, tailings risks and permit deviations (Falemi *et al.*, 2024).

Regulatory legitimacy additionally requires transparency and accountability. A governance model linking audit trails, compliance analytics, reporting pathways and strategic oversight provides a transferable basis for ensuring that environmental responsibilities are traceable to identifiable decision-makers and measurable performance indicators (Akhigbe *et al.*, 2025). For extraction communities, prevention is strongest when regulation combines stringent

standards with independent inspection, real-time monitoring, disclosure, community reporting channels, proportionate penalties and financial guarantees. Such an architecture reduces opportunities for regulatory evasion while ensuring that pollution control, rehabilitation and community-health protection remain enforceable obligations throughout exploration, production, closure and post-closure stewardship.

Community Monitoring and Health Surveillance

Community monitoring and health surveillance are essential in resource-extraction regions because conventional regulatory datasets often fail to capture localized, intermittent and cumulative exposures. Effective systems should connect environmental measurements with clinical indicators, biomonitoring and community-reported events so that emerging hazards can be detected before they become entrenched disease burdens. In Nigeria's Niger Delta, integrated assessment combining air, soil and surface-water sampling with questionnaires and health-facility records demonstrated the value of linking environmental conditions with observed morbidity rather than treating pollution monitoring and health surveillance as separate exercises (Ana *et al.*, 2009).

Participatory monitoring can strengthen this linkage where institutional capacity is limited. In Zimbabwe's Hwange coal-mining area, trained community monitors and scientists collected hundreds of water samples and helped maintain automated sensors, identifying acid mine drainage, illegal mine-water discharges and metal concentrations of public-health concern. The approach illustrates how standardized citizen-science protocols can expand spatial and temporal coverage while giving affected communities a defensible evidentiary role in environmental governance (Ruppen *et al.*, 2021).

Biomonitoring adds evidence of internal dose. In Peru's Madre de Dios gold-mining region, measurements of mercury in human hair and locally farmed fish differentiated community-level exposure patterns and showed that residence in artisanal mining areas was associated with elevated hair mercury. Such surveillance is particularly valuable because environmental concentrations alone cannot establish how much contaminant has entered the human body (Langeland *et al.*, 2017). Community science can also broaden air-quality surveillance: near a former mining and smelting site in Arizona, comparison of foliar surfaces with conventional dust collectors demonstrated the potential for locally accessible sampling methods to characterize metal-bearing aerosols and support repeated monitoring (Zeider *et al.*, 2021).

Digital infrastructure can strengthen these systems when adapted responsibly. Blockchain-assisted SCADA architectures offer transferable mechanisms for tamper-resistant records, secure exchange and auditable data provenance, although the study concerns power systems rather than extraction-health surveillance and should be interpreted methodologically (Shittu *et al.*, 2022). Likewise, smart SCADA automation demonstrates how continuous sensing, predictive analytics and real-time process control can support early warning (Omoegun *et al.*, 2024). A robust surveillance framework should therefore combine community observers, calibrated environmental sensors, biomarker testing, interoperable health records, geospatial mapping and transparent reporting thresholds, with referral mechanisms ensuring that abnormal findings trigger investigation, exposure reduction and appropriate clinical follow-up. This integration improves comparability over time, supports targeted screening, and helps authorities prioritize vulnerable settlements during emergencies.

Remediation, Compensation, and Health Protection

Remediation, compensation and health protection constitute complementary obligations in extraction-affected regions because environmental cleanup alone cannot restore lost health, livelihoods or social security. Effective remediation should begin with source removal, containment and exposure interruption, followed by verification that contaminant concentrations have fallen to health-protective levels. The Zamfara response in northern Nigeria demonstrates the value of integrating environmental and clinical action: contaminated soils and mining wastes were removed or capped, safer ore-processing practices were introduced, and exposed children received chelation treatment, producing substantial reductions in soil lead and blood-lead concentrations (Tirima *et al.*, 2016).

Remediation also requires diagnosis of why contamination or infrastructure failure occurred. Although developed for industrial equipment rather than extraction communities, design-of-experiments and root-cause analysis provide transferable methods for distinguishing failure mechanisms from superficial symptoms, testing corrective options and reducing recurrence. Applied to mining or petroleum systems, such logic can strengthen investigations of repeated spills, tailings instability, treatment-system failure and ineffective rehabilitation measures (Akanbi *et al.*, 2023).

Compensation must extend beyond payment for visible property damage. Mining-induced displacement in Ghana shows that compensation and resettlement arrangements can undermine livelihoods when valuation practices fail to account for land access, income generation and long-term socioeconomic security. A rights-based approach therefore requires transparent valuation, meaningful participation, accessible grievance mechanisms and restoration of livelihood capacity, particularly for households whose economic survival depends on land and natural resources (Twerefoo, 2021).

Health protection must operate concurrently with environmental and economic restoration. Mining disasters in Brazil demonstrate that health consequences evolve beyond immediate fatalities to encompass changing disease patterns, mental-health needs, water and food insecurity, disrupted services and population surveillance. Public-health preparedness should consequently remain active through emergency, recovery and post-remediation phases rather than ending when acute rescue operations cease (Freitas *et al.*, 2019).

Clinical systems must also accommodate complex and overlapping needs among affected residents. The requested multidisciplinary emergency-care review is not extraction-specific, yet its emphasis on coordinated decision-making, shared accountability and integrated medical and psychosocial care provides a defensible model for treating communities presenting with toxic exposure, trauma and disaster-related illness (Ohunyon *et al.*, 2023). Similarly, evidence-based wound-care principles are indirectly applicable where extraction accidents produce injuries requiring infection prevention, systematic assessment and advanced treatment; the study should not be interpreted as evidence from mining populations (Ohunyon *et al.*, 2024).

Governance Priorities and Future Research

Governance priorities in resource-extraction regions must move beyond episodic compliance toward institutions that integrate environmental protection, public health, community rights and transition planning across the full project life cycle. In Nigeria's Niger Delta, environmental inequality has been linked to governance arrangements that distribute ecological costs unevenly and weaken conflict management, indicating that accountability, access to environmental resources and enforceable corporate obligations should remain central policy priorities (Umukoro, 2012). In Ghana, mining governance still gives insufficient regulatory weight to public health, supporting institutionalisation of health impact assessment within licensing, environmental assessment and monitoring systems (Proksik *et al.*, 2025).

Future governance should also redistribute decision-making power. Participatory environmental monitoring in Peru demonstrates that community involvement can reshape how mining impacts are interpreted and contested, although participation alone does not eliminate knowledge or power asymmetries (Himley, 2014). Comparative evidence from Canada and Sweden likewise indicates that legitimate mining governance requires transparent assessment, consultation and stronger recognition of Indigenous rights and self-determination (Lindahl *et al.*, 2024). Legal reform should therefore address structural inequalities embedded in contracts and dispute-resolution systems, while strengthening environmental, human-rights and community safeguards (Phillips, 2025).

Technological transition represents a complementary, but not substitutive, governance priority. Hydrogen-system modelling offers pathways for decarbonising national energy systems, yet future research must assess affordability, infrastructure requirements and environmental trade-offs rather than assuming technological neutrality (Shittu *et al.*, 2019). Hybrid-solar optimisation similarly demonstrates the relevance of decentralised renewable systems for developing economies, supporting research on whether reduced fossil-energy dependence can lessen extraction pressures while improving energy access (Sunday and Omoegun, 2019). Blockchain-enabled peer-to-peer microgrids may strengthen transparency and decentralised participation in energy markets, but regulatory interoperability, equity and data governance remain unresolved (Shittu *et al.*, 2021).

Digitalisation also warrants careful evaluation. AI-enabled digital twins can strengthen predictive maintenance and system optimisation, suggesting transferable applications for anticipatory environmental-risk management, provided that algorithmic accountability and data quality are secured (Shittu and Shittu, 2024). IoT-enabled microgrid and battery integration further illustrates how climate-resilient distributed infrastructure may support lower-carbon development, although governance research must examine cybersecurity, accessibility and institutional capacity (Shittu *et al.*, 2025). Emerging ocean-wave energy research extends this diversification agenda, but simulation-based innovations require field validation, lifecycle assessment and ecological safeguards before large-scale deployment (Ganiu, 2025; Ayinde,2025). Future research should therefore combine longitudinal health evidence, cumulative-exposure modelling, participatory governance, comparative regulatory evaluation and justice-oriented transition analysis so that technological innovation complements, rather than displaces, protection of extraction-affected communities.

CONCLUSION

This review has achieved its central aim by integrating evidence on environmental pollution, exposure pathways, health burdens, methodological limitations, and intervention priorities across resource-extraction regions. The analysis demonstrates that mining, petroleum production, quarrying, and associated processing activities generate complex mixtures of airborne particulates, toxic metals, hydrocarbons, contaminated effluents, tailings, and persistent residues that move through air, water, soil, sediments, and food systems. These pathways create cumulative and uneven exposures that extend beyond workers to households and surrounding communities.

The review further shows that respiratory, cardiovascular, neurological, maternal, child, reproductive, occupational, and psychosocial outcomes are shaped not only by contaminant intensity but also by age, poverty, livelihood dependence, pre-existing disease, weak infrastructure, and limited access to healthcare. Children, women, informal workers, Indigenous populations, and economically marginalised communities therefore experience disproportionate vulnerability. At the same time, the evidence base remains constrained by fragmented surveillance, inadequate biomonitoring, short-term study designs, inconsistent exposure metrics, and persistent difficulties in causal attribution.

The study also establishes that effective responses require more than post-contamination remediation. Stronger pollution prevention, enforceable regulation, transparent governance, community participation, real-time monitoring, clinical surveillance, compensation mechanisms, and long-term health protection are essential. Technological innovations, including digital monitoring, predictive systems, cleaner energy alternatives, and decentralised infrastructure, can strengthen these responses when embedded within accountable institutions.

Accordingly, policy should prioritise preventive regulation, independent environmental and health monitoring,

mandatory rehabilitation and financial assurance, equitable compensation, and community-centred decision-making. Future research should expand longitudinal cohort studies, cumulative-exposure modelling, locally validated health indicators, biomarker integration, and comparative governance evaluation. Progress will depend on aligning extraction policy with environmental justice, public-health protection, and transparent accountability so that economic benefits do not continue to be secured at the expense of the health, livelihoods, and ecological security of host communities. This requires durable institutions capable of translating scientific evidence into timely, enforceable, equitable, and socially legitimate action.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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