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A Critical Review of Environmental Exposure and Health Risks Around Gas-Fired Power Plants

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Abstract

Gas-fired electricity generation can reduce several combustion emissions relative to coal, but its environmental advantages do not establish the absence of exposure or health risks in host communities. This critical narrative review examines 41 studies and synthesises evidence on particulate matter, potentially toxic metals, and polycyclic aromatic hydrocarbons across air, soil, indoor dust, and edible plants, with particular attention to Rivers State, Nigeria. The review retains all 41 records in a thesis evidence matrix and supplements them with targeted publication checks and authoritative risk-assessment guidance. Evidence is differentiated by fuel type, environmental medium, study design, and the strength of source attribution. Gas-turbine measurements demonstrate fine and ultrafine particle emissions, while atmospheric modelling and epidemiological studies provide complementary evidence of potential community impacts. Soil and vegetable investigations identify additional exposure pathways, although contamination near a plant cannot automatically be attributed to that facility. Coal-based findings illuminate transport and exposure mechanisms but require qualification before application to gas-fired settings. Important limitations include seasonal sampling gaps, insufficient integration of indoor and outdoor measurements, uncertain source attribution, and limited linkage between environmental measurements and observed health outcomes. An integrated assessment approach is proposed for further studies, combining meteorologically informed sampling, suitable reference locations, chemical characterisation, occupation-specific exposure assessment, and explicit uncertainty analysis. Protection of host communities requires attention to cumulative exposure across workplaces and households alongside control of plant emissions.

Keywords:

Gas-Fired Power Plants; Particulate Matter; Potentially Toxic Metals; Polycyclic Aromatic Hydrocarbons; Environmental Exposure; Human Health Risk Assessment; Rivers State.

1. Introduction

The environmental assessment of electricity generation requires a distinction between relative technological advantage and the actual conditions experienced by exposed populations. Natural gas may offer substantial reductions in some emissions when it replaces coal, particularly when used in combined-cycle generation. Analysis of United States continuous emissions monitoring data found lower carbon dioxide, nitrogen

oxide, and sulphur dioxide emission intensities for combined-cycle natural-gas plants than for coal-fired plants (De Gouw et al., 2014). Nevertheless, it does not establish that gas-fired installation has negligible environmental consequences.

The relevant public-health question extends beyond plant operation to the environments in which nearby residents work, learn, obtain food, and spend time indoors. A community assessment should therefore examine the connections between emissions, environmental transport, exposure opportunities, and susceptibility rather than use proximity alone as a substitute for exposure.

This review develops the argument that assessment around gas-fired plants should integrate environmental media and human activities while maintaining rigorous limits on source attribution. Particulate matter (PM), potentially toxic metals, and polycyclic aromatic hydrocarbons (PAHs) are considered together because they may coexist in environmental samples and contribute to different exposure pathways. Their joint occurrence does not, however, establish a common source or a synergistic biological effect. The review also separates evidence from gas-fired installations from the much broader coal-plant literature.

The objectives are to critically compare the available evidence on emissions and environmental contamination, examine its implications for community and occupational exposure, identify limitations affecting health-risk interpretation, and propose a relevant assessment agenda.

2. Review Approach and Scope

This article was developed as a critical narrative synthesis of the supplied thesis literature-review chapter. The chapter provided the initial concepts, study summaries, and research gaps. All 41 study records in the chapter's gap matrix were retained and summarised individually in Table 1. Publication identities and bibliographic details were checked against publisher pages, author-affiliated institutional records, bibliographic records, or accessible articles; these checks identified corrections to several author names, titles, and publication years. Targeted web searches used combinations of author names and article titles to resolve incomplete citations and verify findings used in the synthesis. World Health Organization guidance and United States Environmental Protection Agency risk-assessment resources provided methodological context. Verification was undertaken in October 2026.

The corpus was purposive and inherited from the thesis matrix rather than generated through an exhaustive search. It covers publications from 2003 to 2026, including gas-fired, coal-fired, and biomass settings, environmental measurements, modelling, epidemiological studies, and reviews. Gas-specific evidence and Nigerian settings receive particular interpretive weight. Coal ash, groundwater, thermal discharge, radiological hazards, and legacy contamination are retained as comparative domains, with their relevance conditioned on fuel type and plant configuration. Supporting guidance and contextual references are additional to the 41 study records.

The evidence was organised by fuel type, environmental compartment, exposure pathway, study design, and relevance to Rivers State. Critical appraisal considered whether a study measured emissions or ambient concentrations, distinguished plant contributions from other sources, captured temporal variation, and assessed potential risk or actual health outcomes. No pooled effect estimate was calculated because the evidence comprises incompatible exposure metrics and designs. Review articles and primary investigations are separate records in the matrix; underlying studies may overlap, so 41 records should not be interpreted

as 41 independent exposure datasets. Gaps in Table 1 are review-level interpretations of each study's scope and remaining evidence needs, not necessarily limitations stated by its authors.

This approach does not constitute a systematic review. There was no prospectively registered protocol, exhaustive database search, duplicate screening, or formal certainty grading. Consequently, the selected evidence cannot establish the prevalence of a research gap across the entire literature. The gaps identified below concern the evidence assembled for this review and the information needed for a defensible assessment on the risks of Power plants citing to humans and the environment.

2.1 Emissions and the Importance of Fuel Specific Evidence

2.1.1 Gas combustion and residual particulate emissions

Gas-fired plants encompass different turbine configurations, control systems, and operating conditions. Their environmental performance should not be inferred from fuel classification alone. The emissions comparison reported by De Gouw et al. (2014) supports the advantages of combined-cycle gas generation for the pollutants evaluated, but it does not resolve local particle composition, exposure patterns, or the implications of upstream natural-gas activities. These are separate assessment questions.

Brewer et al. (2016) investigated $PM_{2.5}$ and ultrafine particle emissions from a natural-gas-fired turbine. Their measurements demonstrate that gas combustion can produce particles even where conventional expectations emphasise low particulate emissions. This evidence supports including particle number and size distribution, where feasible, alongside mass concentration in gas-plant monitoring. It does not justify treating stack particle concentrations as equivalent to concentrations inhaled by residents: dilution, transformation, dispersion, and time spent in different locations intervene between emission and exposure.

The central implication is methodological. A monitoring programme restricted to one bulk indicator may miss relevant characteristics of the emitted mixture. Conversely, a detailed stack measurement does not independently establish community risk. Emissions characterisation and receptor monitoring answer related but distinct questions, and both require explicit consideration of plant operating conditions.

2.2 Airborne mixtures and competing sources

P. J. Chen et al. (2026) compared residential $PM_{2.5}$ near natural-gas-fired and coal-fired plants in Taiwan. Mean $PM_{2.5}$ was 15.8 ± 7.26 μg/m³ at the gas-associated site and 24.8 ± 10.6 μg/m³ at the coal-associated site. Positive matrix factorisation attributed 31.7% of PAHs at the gas-associated site to the power plant, compared with 50.1% to traffic and 18.2% to electric arc furnace activity. These findings illustrate why the highest concentration at a nearby receptor cannot simply be assigned to the nearest industrial facility.

The Taiwanese comparison is informative because it incorporates chemical composition and source analysis. Its transferability remains limited by regional emissions, the sampled season, and the characteristics of the two sites. The reported fractions are site-specific estimates rather than emission factors for Nigerian facilities. For Rivers State, the appropriate inference is that co-located sources should be investigated and quantified where possible, not that the same source percentages should be expected.

2.3 What coal plant studies contribute

Coal-based research supplies useful evidence about deposition, soil contamination, and food-chain pathways. Huang et al. (2017), for example, analysed 41 soil and 32 cabbage samples near the Jinsha coal-fired plant in China, combining environmental sampling with investigation of metal sources. The study

demonstrates the value of pairing soil and crop measurements rather than judging agricultural exposure from soil concentration alone.

However, coal combustion and ash handling introduce source characteristics that cannot be presumed for a plant burning natural gas. Coal-related metal or ash contamination is therefore evidence of a mechanism under specified conditions, rather than direct evidence of emissions from Omoku or Trans-Amadi. A defensible review should retain such studies as comparative evidence and identify where local gas-specific measurements are required.

2.4 From emission inventories to validated exposure estimates

The progression from sector inventories to source-resolved exposure provides a useful way to compare the literature. Guttikunda and Jawahar (2014) connect coal-sector inventories to atmospheric pollution and estimated health burdens in India, while Sahu et al. (2021) compare control scenarios. These approaches address regional planning questions that a small field campaign cannot answer. Conversely, their national scale and dependence on emissions and atmospheric assumptions limit the precision with which they can describe an individual school, farm, or household.

Zhou et al. (2003) demonstrate how CALPUFF can translate emissions into population intake fractions and how results change with atmospheric assumptions. Mokhtar et al. (2014) and Piersanti et al. (2018) further connect dispersion or chemical-transport predictions with receptor risk estimates. X. Chen et al. (2020) combine chemical-transport and receptor modelling to investigate coal-plant contributions. Together, these studies favour a complementary strategy: models identify plausible patterns and source contributions, while measurements test those predictions. Increasing model complexity alone does not establish accuracy.

VOCs and semivolatile compounds also complicate a mass-only approach. Yan et al. (2017) assess VOC composition and formation potential in a power-station area. Küçükaçıl Artun et al. (2017) combine passive sampling, spatial interpretation, and inhalation-risk screening, whereas Dumanoglu et al. (2017) examine seasonal air–soil PAHs and PCBs. Their shared implication is that chemical composition, atmospheric transformation, and exchange between media can change exposure interpretation. Their different designs also show why a single source label cannot capture all pollutants in an industrial airshed.

2.5 Environmental Media and Exposure Pathways

2.5.1 Ambient air and spatial interpretation

Ambient monitoring provides information about concentrations at particular receptors, while dispersion modelling estimates how specified emissions may be distributed under defined conditions. Adesanmi et al. (2016) used AERMOD and emission-factor-based inventories to estimate ground-level pollutants from Nigerian natural-gas-powered thermal plants. This is directly relevant to national assessment practice, but its outputs are predictions rather than a field monitoring campaign. Assumptions about fuel consumption, emissions, stacks, and meteorology determine the resulting concentration estimates.

This distinction matters when apparently low modelled plant contributions coexist with elevated measured ambient concentrations. The two results may describe different quantities: a model may estimate the increment from selected stacks, while a monitor records the combined influence of local and regional sources. Neither result invalidates the other without a comparison of boundaries, averaging periods, and measurement uncertainty.

A distance gradient also requires careful interpretation. A decrease with distance can support a source hypothesis, but ground-level concentration need not decline uniformly from a stack. Sampling should consider wind direction and receptor location rather than assume that the nearest site is always the most exposed. For a recent assessment, concurrent meteorological records would help distinguish a plausible plume pattern from unrelated spatial variation.

2.5.1 Soil contamination and ecological meaning

Soil measurements can integrate contamination inputs over a different timescale from short-term air sampling. Their interpretation should nevertheless distinguish contaminant presence, enrichment relative to local background, biological availability, and ecological effects. Huang et al. (2017) provides a useful example of combining metal measurements and source investigation, but the coal-specific context limits extrapolation to gas-fired settings.

For local assessment, soil pH, organic matter, texture, sampling depth, and land use should be recorded alongside chemical concentrations. These variables help evaluate why similar total concentrations may have different implications at different sites. A reference location should be selected for comparability, not merely because it lies farther from a plant. Differences in geology, farming practices, traffic, or other industrial activity can otherwise produce misleading contrasts.

Ecological screening should be reported separately from human-health assessment. An enrichment index describes a comparison with a chosen baseline; it is not a direct measurement of ecosystem damage. Where possible, chemical findings should be supplemented by relevant biological observations, such as vegetation condition or soil biological indicators. The choice of endpoint should follow the ecological question rather than the availability of a convenient index.

2.6 PAHs in soil and edible plants

PAHs are a diverse class whose environmental behaviour varies with molecular structure. Their sources include incomplete combustion and petroleum-related inputs, and their distribution across air, soil, and water depends on physicochemical properties and environmental conditions. Consequently, a total PAH concentration can obscure differences in composition, persistence, and toxicological importance (Abdel-Shafy & Mansour, 2016). Individual compounds and the analytical basis of any toxicity-weighted metric should be reported.

A particularly relevant Rivers State investigation assessed soil and edible vegetables near the Afam IV gas-powered plant. Onyegeme-Okerenta et al. (2025) reported mean summed concentrations of 16 PAHs of 174.87 mg/kg in soil and 24.94 mg/kg in vegetables. Diagnostic ratios suggested both pyrogenic and petrogenic inputs. These findings establish the relevance of paired environmental and food measurements in the local setting, while the mixed-source evidence cautions against assigning all detected PAHs to the plant.

The same investigation reported a combined lifetime carcinogenic-risk estimate of 1.45×10^{-4} (Onyegeme-Okerenta et al., 2025). This is a model output under the study's exposure assumptions, not an observed cancer frequency. Application elsewhere requires checking concentration units, edible-tissue preparation, consumption rates, exposure duration, body weight, and toxicity factors. The numerical result should not be transferred directly to residents around other facilities.

Plant contamination also requires attention to the distinction between external deposition and internal uptake. For future work, paired washed and unwashed samples, clearly defined edible portions, and consistent dry- or fresh-weight reporting would improve interpretation. A plant-to-soil concentration ratio can support comparison, but by itself it does not determine the route by which a contaminant reached the edible tissue.

2.7 Indoor dust as an exposure compartment

Indoor dust deserves separate treatment because it can represent an exposure reservoir that ambient air measurements do not characterise. Moghtaderi et al. (2020) synthesised 15 studies of classroom dust and documented the presence of multiple metals across school settings. Their review supports including schools in environmental assessment, but it neither identifies power plants as the source of classroom contamination nor establishes that every measured metal concentration produces adverse effects.

Paired indoor and outdoor sampling in schools and shops would allow investigation of whether contaminant profiles are consistent across the building boundary. Building condition, cleaning frequency, nearby roads, ventilation, and indoor activities should be documented as competing explanations. Settled dust concentration should also be distinguished from airborne concentration; an air-quality index cannot describe the full chemical quality or ingestion relevance of settled dust.

The occupational implication extends to teachers, school administrators, cleaners, and traders. Their exposure patterns may differ substantially from those of plant employees and farmers. A useful assessment would record time spent indoors and outdoors, work tasks, cleaning practices, and contact with soil or dust. Occupation labels alone provide too little information to estimate exposure accurately.

2.8 Groundwater thermal discharge and legacy contamination

A complete comparison of the matrix requires consideration of pathways beyond the principal air–soil–dust–food framework. Ranjan et al. (2020) examine drinking-water quality around the Anpara coal plant and relationships with fly-ash influence. Buha-Marković et al. (2020) characterise PAHs in ash fractions, while Luo et al. (2024) investigate soil contamination and elemental leaching potential. These studies concern connected but different stages: contaminant composition in a waste, movement into an environmental medium, and potential human contact. Evidence at one stage does not automatically quantify the next.

Thermal-discharge studies address another mechanism. Logan and Stillwell (2018) develop a probabilistic approach connecting effluent conditions with aquatic-species risk. Lin et al. (2021) use satellite observations to examine coastal temperature increases, and Mokarram et al. (2023) integrate remote sensing, GIS, and neural-network prediction of thermal pollution and environmental conditions. Their contribution is to extend assessment beyond chemical concentration. For Rivers State, however, aquatic thermal assessment should follow confirmation of a facility's cooling system and actual discharge route rather than be assumed necessary for every gas turbine.

Aziman et al. (2025) add radiological assessment of coal, combustion by-products, and topsoil, highlighting a fuel- and residue-specific hazard. Ribeiro et al. (2025) investigate inorganic and organic contamination around a deactivated coal facility, illustrating that environmental contamination can outlast generation. Neither study establishes a radiological or coal-ash hazard at a natural-gas facility. Their wider relevance

is the need to distinguish operating emissions, waste management, historical land use, and persistent contamination when defining the source inventory.

2.9 Health Evidence and Risk Interpretation: Observed outcomes and modelled burdens

Pope and Dockery (2006) synthesised epidemiological and supporting evidence linking fine particulate air pollution with adverse cardiopulmonary health. This broader evidence supports concern about PM exposure, but it does not identify the contribution of any particular plant to local disease. Source-specific assessment requires additional information on emissions, exposure, and competing determinants of health.

Direct gas-plant epidemiological evidence is illustrated by Di Ciaula (2012), who related daily emergency visits and hospital admissions among older residents to PM_{10} and nitrogen dioxide near a gas-fired installation. The study assessed a three-month period and accounted for meteorological confounders. Its reported associations show the value of connecting environmental information with health-service data, while its duration, setting, and population constrain generalisation to other communities.

A different approach was used by Fouladi Fard et al. (2016), who estimated health impacts and external costs for the Qom natural-gas-fired plant using a simplified impact-pathway framework. Such modelling can inform planning where direct health observations are limited, but estimated burdens depend on the exposure and response functions selected. They should be presented as conditional estimates rather than counts of clinically confirmed plant-attributable illness.

Coal-plant epidemiology offers a complementary design example. Minichilli et al. (2019) linked a population-based cohort to modelled exposure around the Vado Ligure coal plant to examine mortality and hospitalisation. The value for Rivers State lies in the design principle of connecting exposure estimates with longitudinal health information. The reported coal-associated effects are not coefficients that can automatically be applied to gas-fired communities.

2.10 Risk assessment and uncertainty

The United States Environmental Protection Agency (USEPA, 2014) frames human-health risk assessment as a decision-oriented process requiring explicit problem formulation and attention to uncertainty. Hazard identification, dose–response assessment, exposure assessment, and risk characterisation should remain distinguishable. Chemical detection establishes presence; estimating dose requires information about how, how often, and for how long people encounter the contaminated medium.

Non-cancer screening commonly compares estimated exposure with an appropriate reference value. A hazard quotient above one signals a need for further evaluation; it is not the probability that disease will occur. Cancer-risk calculations estimate an incremental lifetime risk under stated assumptions. These metrics should not be combined as if they were equivalent, and their interpretation must follow the toxicological basis and exposure route of the selected values (USEPA, 2016).

Multi-pollutant assessment also needs clear boundaries. PM mass includes chemical constituents, so combining a whole-PM health estimate with constituent-specific risks can count overlapping burdens. Likewise, adding hazard quotients across dissimilar endpoints or routes without justification can obscure rather than clarify risk. A proposed integrated assessment should present transparent pathway-specific results before attempting any aggregation.

Uncertainty should be evaluated at the points where it can change conclusions. Relevant questions include whether non-detect handling changes rankings, whether dietary assumptions dominate estimated risk, and whether a reference site changes the apparent spatial pattern. Sensitivity analysis can prioritise additional

measurement. It should not be treated as a substitute for representative sampling or a remedy for unsupported source attribution.

2.11 Contrasting occupational community and modelled health evidence

The studies differ in whose exposure they represent. Jumpponen et al. (2013) examine maintenance and ash-removal tasks in biomass-fired plants, demonstrating the importance of work activity in occupational exposure assessment. Such task-based evidence can inform study design without making plant workers a proxy for residents or teachers. Yadav (2021) examines inhalation concerns in a mixed coal-mining and thermal-power landscape, where separating contributions from different industrial activities remains central to interpretation.

Amster et al. (2014) compare plant-related exposure metrics with respiratory health information. Respiratory symptoms, rather than asthma or COPD prevalence, were associated with estimated plant NOx exposure, illustrating the importance of reporting endpoint-specific findings. Kuo et al. (2014), by contrast, estimate mortality risks and life loss through a modelling framework. The distinction between an association measured in a population and a projected burden must remain visible even when both are expressed as health impacts.

The school environment adds further complexity. Kamgba and Abong (2024) provide Nigerian classroom-dust measurements and pathway-specific risk estimates. These support investigation of schools as exposure settings, but their estimates are not records of cancer incidence or evidence of a power-plant source. Mahlangeni et al. (2025), a scoping review of 56 studies, and Vig et al. (2023), a review of Indian coal-plant impacts, offer broader synthesis. Their conclusions strengthen the rationale for prevention while also exposing variation in geography, design, and exposure measures. Review findings should not be counted as additional independent observations when their primary studies overlap with other records.

2.12 An Integrated Assessment Agenda: A connected source pathway receptor framework

The synthesis supports an assessment framework connecting source characterisation, transport, environmental media, exposure, and health interpretation. Each connection requires its own evidence. A measured concentration does not establish its source; a plausible source does not quantify personal exposure; and an estimated dose does not establish that a reported symptom was caused by the exposure. This sequence provides a practical structure for study design and reporting.

A proposed programme should begin with a local source inventory covering plant operations and relevant surrounding activities. Sampling locations should then reflect plausible dispersion patterns, land use, and where people spend time. Farms, schools, shops, and residences may require different sampling strategies. Identifying these receptors at the design stage would make the study more informative than a uniform series of distance points selected without regard to activity.

2.13 Seasonal and spatial coverage

Repeated wet- and dry-season sampling is proposed to assess whether concentration patterns persist under different environmental conditions. Measurements should be coordinated across sites so that contrasts do not merely reflect different sampling dates. Meteorology and available operating records should accompany the environmental measurements, enabling investigators to test rather than assume relationships between plant activity and receptor concentrations.

Reference locations should resemble study locations in relevant background characteristics while lying outside the expected influence of the facility being assessed. More than one reference location may be useful where background conditions vary strongly. Analyses should retain both distance and direction,

account for repeated observations, and avoid treating multiple measurements from the same location as wholly independent evidence.

2.14 Coordinated media and population assessment

A practical core would combine ambient $PM_{2.5}$ and PM_{10}, metals and PAHs in selected soil and dust samples, and edible-plant analysis where local cultivation is relevant. Chemical analysis of airborne particles would strengthen the connection between PM mass and toxic constituents if resources permit. Indoor and outdoor sampling should be paired where the objective concerns infiltration or indoor accumulation.

Population assessment should differentiate exposure scenarios rather than simply compare occupational titles. Farmers may have substantial soil contact and outdoor exposure; traders may combine roadside and indoor exposure; school staff and pupils may share buildings but differ in body size, activity, and dust contact. Locally obtained information on time use and diet would help reduce reliance on assumptions drawn from other settings.

Health questionnaires can describe symptoms and perceived exposure, but causal inference requires careful attention to smoking, household combustion, other employment, existing illness, and socioeconomic conditions. Where feasible and ethically approved, exposure assessment could be linked to objective health measurements or longitudinal records. The intended health endpoint should determine the design and analytical plan.

2.15 Quality assurance and interpretable reporting

All media should have documented sampling and analytical quality assurance. Reports should state sample preparation, recovery, blanks, reference materials where applicable, detection limits, and treatment of non-detects. Concentrations should identify units and weight basis, and comparisons should use compatible matrices and averaging periods. These details are necessary to interpret apparent differences among sites and studies.

Results should be reported in stages: measured concentrations, evidence about sources, estimated exposure, risk calculations, and any observed health associations. Keeping these stages visible would make it easier to recognise whether a conclusion rests on measurement, modelling, or inference. It would also allow later studies to update one component without repeating the entire assessment.

2.16 Implications for Prevention and Environmental Governance

The proposed prevention approach follows the evidence pathway. Plant-level interventions should address verified emission sources and operating conditions, while community interventions should address demonstrated exposure opportunities. Engineering and operational decisions require plant-specific evaluation; controls appropriate to coal ash should not be assumed suitable for gas-turbine exhaust. Monitoring should be used to evaluate whether the chosen intervention changes receptor exposure.

Health-based air-quality guidance offers a reference for interpreting ambient measurements. The World Health Organization (WHO, 2021) distinguishes pollutant-specific guideline levels and averaging periods, and its guidelines are not themselves legally binding national standards. Accordingly, comparisons should identify whether the benchmark is a health recommendation or an applicable legal requirement. A short campaign should not be described as demonstrating annual compliance.

For schools and shops, proposed measures include reducing avoidable dust entry, improving cleaning practices, and evaluating ventilation in relation to outdoor conditions. These measures should follow site assessment rather than a universal prescription: opening windows may alter exposure differently where outdoor pollution is high. Follow-up monitoring would provide evidence of effectiveness.

Equity should be built into receptor selection and communication. Monitoring only accessible or formally regulated workplaces risks missing people whose work and living arrangements create different exposures. Community participation can help identify overlooked locations, interpret activity patterns, and communicate uncertainty. This review does not establish that any particular Nigerian institution has failed to enforce a specified law; assessing that claim would require a separate analysis of applicable duties, monitoring records, inspections, and enforcement outcomes.

2.17 Study Level Evidence and Research Gaps

Table 1 summarises all 41 studies in the original gap matrix, retaining their entry order and correcting bibliographic details where needed. It identifies each study's context, methods, contribution, and remaining evidence needs, including comparative work on ash, water, radiation, and legacy contamination.

Gaps are interpreted against study purpose: no individual investigation must measure every pathway or health outcome. The matrix instead identifies where complementary evidence is needed to connect sources, environmental transport, exposure, and health.

Table 1

Study level synthesis of all 41 literature records and research gaps

No.	Study	Context and methods	Main contribution	Research gap and relevance
1	Zhou et al. (2003)	China; power-plant emissions. CALPUFF dispersion and population intake-fraction modelling.	Connects emissions to population exposure and tests sensitivity to atmospheric assumptions.	Requires receptor and personal-exposure validation; Chinese transport and population patterns cannot quantify Rivers State exposure.
2	Khillare et al. (2012)	India; vegetables near thermal plants. PAH and metal analysis with dietary risk calculations.	Integrates organic and inorganic contaminants in a food-consumption pathway.	Dietary evidence needs concurrent soil, air, dust, local consumption data, and stronger separation of competing sources.
3	Di Ciaula (2012)	Italy; gas-fired plant. Three-month PM10/NO2 time series and hospital records.	Associates ambient pollution with emergency visits and admissions among older residents.	Short follow-up and area-level exposure constrain causal inference and long-term assessment; personal exposure and co-sources need attention.
4	Jumpponen et al. (2013)	Biomass plants; maintenance and ash removal. Task-based gas, PAH, and VOC monitoring.	Shows why worker tasks and short exposure episodes matter for protective measures.	Occupational biomass evidence requires separate evaluation before application to gas-plant communities; longer health follow-up is needed.
5	Bhatnagar and Bhatnagar (2013)	India; Sanjay Gandhi thermal plant. Two-year seasonal ambient and stack monitoring.	Compares SPM, SO2, and NOx across plant-adjacent and more distant receptors.	Single-plant air monitoring needs source-resolved exposure and health linkage. The original study includes off-site locations and wind information.
6	Guttikunda and Jawahar (2014)	India; coal generation. Emission inventories, atmospheric assessment, and estimated health burdens.	Connects power-sector emissions with regional PM exposure and pollution-control priorities.	Inventory and health estimates depend on modelling assumptions; local monitoring and observed outcomes would strengthen assessment.
7	Mokhtar et al. (2014)	Malaysia; coal-fired plant. AERMOD with stack, meteorological, and health-risk inputs.	Connects predicted receptor concentrations with compliance and inhalation-risk assessment.	Predictions need independent local validation; coal emissions and assumed exposure parameters are not directly transferable to gas plants.

No.	Study	Context and methods	Main contribution	Research gap and relevance
8	Amster et al. (2014)	Community near a coal plant. NOx/SO2 exposure indices and respiratory prevalence data.	Links estimated plant NOx exposure to respiratory symptoms; asthma and COPD prevalence were not associated.	Cross-sectional evidence limits causal inference; personal exposure, co-pollutants, and other sources may confound associations.
9	Kuo et al. (2014)	Taiwan; Taichung coal plant. PM2.5-related mortality-risk and life-loss modelling.	Estimates cause-specific and all-cause mortality burdens under defined exposure assumptions.	Modelled burden is not observed plant-attributable mortality; exposure and response-function uncertainty require explicit treatment.
10	Rodríguez-Iruretagoiena et al. (2015)	Brazil; agricultural soils near a coal complex. Trace elements, PCA, kriging, and contamination scoring.	Maps contamination hotspots and distinguishes overlapping industrial, urban, and agricultural influences.	Mixed sources complicate attribution; crop uptake, personal exposure, and health outcomes require additional evidence.
11	Ćujić et al. (2016)	Serbia; soils around a coal plant. Metal analysis, pollution indices, clustering, and spatial mapping.	Reports spatial variation without a significant negative impact for the investigated metals.	A soil-metal assessment cannot resolve air, crops, seasonal exposure, or observed health effects; negative findings are endpoint-specific.
12	Brewer et al. (2016)	United States; natural-gas turbine. Fine and ultrafine particle emission measurements.	Demonstrates residual particulate emissions from gas combustion and the value of particle-size characterisation.	One turbine does not establish community exposure; dispersion, chemical speciation, and receptor health evidence remain necessary.
13	Adesanmi et al. (2016)	Nigeria; gas-powered thermal plants. Emission-factor inventories and AERMOD.	Estimates ground-level CO, NOx, SO2, PM, and VOC contributions across locations.	Model outputs need field validation and locally representative operating inputs; they do not measure personal exposure or health outcomes.
14	Fouladi Fard et al. (2016)	Iran; Qom gas-fired plant. Simplified impact-pathway and external health-cost modelling.	Quantifies estimated health damage and external costs relevant to siting and emissions control.	The study does estimate costs; the remaining need is validation, sensitivity analysis, and evaluation of intervention performance.
15	Igbokwe et al. (2016)	Nigeria; thermal-generation review. Synthesis of pollutants and control techniques.	Places pollution prevention alongside electricity expansion and discusses engineering controls.	A descriptive review cannot independently quantify cumulative exposure, long-term health burden, or actual regulatory effectiveness.

No.	Study	Context and methods	Main contribution	Research gap and relevance
16	Huang et al. (2017)	China; Jinsha coal plant. Soil and cabbage metal analysis with source investigation.	Links soil contamination and edible-crop measurements and identifies multiple metal influences.	One crop and a bounded sampling area limit generalisation; additional crops, seasonal observations, and dietary exposure are needed.
17	Küçükaçıl Artun et al. (2017)	Turkey; coal-plant area. Passive gases/VOCs, spatial analysis, and benzene inhalation-risk estimation.	Combines chemical monitoring and geographical analysis to characterise potential inhalation risk.	Residential heating and other sources complicate attribution; modelled risk needs personal-exposure and health validation.
18	Dumanoglu et al. (2017)	Turkey; Kutahya. Paired seasonal air/soil PAHs and PCBs, source analysis, and risk estimation.	Integrates environmental exchange with source categories and exposure screening.	Plant combustion and domestic heating overlap; further work should distinguish sources and directly assess personal dose or biological effects.
19	Yan et al. (2017)	China; Shuozhou power-station area. VOC sampling, chemical analysis, and formation-potential calculations.	Highlights reactive VOC composition alongside total concentration and secondary-pollution potential.	Area-level, short-duration evidence needs indoor and personal-exposure data and direct health linkage.
20	Piersanti et al. (2018)	Italy; new-generation coal plant. Chemical-transport modelling of 17 pollutants and inhalation risks.	Separates the plant contribution from risks associated with overall ambient concentrations.	Modelled scenarios require monitoring validation; biomonitoring and observed disease are distinct evidence needs.
21	Gao et al. (2018)	China and India; power sectors. WRF-Chem and population concentration–response modelling.	Estimates regional PM2.5 contributions and associated mortality burdens.	National and regional estimates do not resolve household exposure or gas-plant-specific conditions in Rivers State.
22	Logan and Stillwell (2018)	Thermoelectric effluent; aquatic ecology. Plume mixing and probabilistic temperature/flow assessment.	Links thermal-discharge conditions to species-specific risk rather than temperature alone.	Chemical mixtures and human exposure require separate assessment; relevance depends on the local cooling and discharge configuration.
23	Minichilli et al. (2019)	Italy; Vado Ligure coal plant. Resident cohort, record linkage, and dispersion-based exposure.	Examines mortality and hospitalisation using longitudinal population information.	Estimated exposure and residual social, occupational, and source confounding remain; coal-specific effects cannot simply be transferred.

No.	Study	Context and methods	Main contribution	Research gap and relevance
24	Ranjan et al. (2020)	India; Anpara. Groundwater chemistry, metals, and spatial/temporal comparison with fly ash.	Identifies drinking-water concerns and relationships with coal-ash influence.	Needs stronger source separation and household intake assessment; air and soil pathways are not jointly resolved.
25	Chen et al. (2020)	China; coal generation. Chemical-transport and receptor models with PM2.5 composition.	Combines modelling approaches to estimate spatially varying plant contributions to ambient PM2.5.	Attribution depends on inputs and model assumptions; direct health outcomes and gas-specific validation require further work.
26	Buha-Marković et al. (2020)	Coal ashes from power and fluidised-bed combustion. PAH analysis, carbon properties, and risk prediction.	Shows how ash fractions differ in PAH composition and potential disposal-related impacts.	Waste characterisation does not track actual transport into community air, soil, food, or people.
27	Moghtaderi et al. (2020)	International classroom-dust studies. Systematic review and meta-analysis of metal concentrations.	Summarises metal burdens in schools and supports dust as an exposure compartment.	Coverage differs among countries and metals; settled-dust evidence cannot substitute for airborne or personal exposure.
28	Mandal et al. (2022)	India; Bandel thermal area. Surface-soil metal/metalloid measurements and contamination/ecological indices.	Characterises contamination intensity and spatial patterns near a thermal-power setting.	Needs coordinated crop, air, organic-contaminant, and pathway-specific health assessment; source overlap needs examination.
29	Sahu et al. (2021)	India; power generation. Emissions and chemical-transport modelling under control scenarios.	Compares pollution and estimated health benefits under alternative power-sector controls.	Scenario benefits need implementation and receptor validation; national scale cannot replace local exposure assessment.
30	Yadav (2021)	India; coal mines and thermal plants. Extended PM and gaseous-pollutant monitoring with inhalation screening.	Provides quantitative air-pollution evidence for residents of a mixed industrial landscape.	Mining and plant contributions are difficult to separate; reference-site, personal-exposure, and clinical evidence would strengthen inference.
31	Lin et al. (2021)	China; coastal plants. MODIS sea-surface temperatures and offshore spatial comparisons.	Identifies capacity-related and seasonal differences in thermal-discharge influence.	Heat mapping does not establish chemical toxicity or biological damage; relevance depends on discharge and coastal conditions.
32	Mokarram et al. (2023)	Iran; Bandar Abbas. Remote sensing, GIS, neural networks, and environmental observations.	Combines spatial observations and prediction of thermal pollution and water-quality conditions.	Single-site predictive evidence needs broader validation and clearer links to biological effects and community exposure.

No.	Study	Context and methods	Main contribution	Research gap and relevance
33	Vig et al. (2023)	India; coal-plant review. Synthesis of environmental media and community health concerns.	Advocates integration of source identification, exposure assessment, and GIS.	A synthesis adds no primary local measurements and cannot substitute for gas-specific monitoring or longitudinal health research.
34	Luo et al. (2024)	India; coal fly ash and soils. Spatiotemporal characterisation and elemental leaching tests.	Connects soil contamination patterns with ash particles and leaching potential.	Leaching potential is not measured human dose; crop uptake and actual exposure require assessment, and gas plants need separate source evidence.
35	Mahlangeni et al. (2025)	International coal-plant health literature. Scoping review of 56 studies.	Synthesises respiratory, developmental, and other health evidence and discusses pollution-reduction interventions.	Geographic imbalance and heterogeneous designs limit transferability; long-term effects and intervention effectiveness need context-specific evaluation.
36	Kamgba and Abong (2024)	Nigeria; Calabar primary schools. Classroom-dust metals and ingestion, inhalation, and dermal risk models.	Reports contamination and potential health concerns in a Nigerian school setting.	Risk models do not establish observed illness or plant attribution; longitudinal, source, and school-environment data are needed.
37	Onyegeme-Okerenta et al. (2025)	Nigeria; Afam IV gas-plant vicinity. Soil/vegetable PAHs, GC–MS, source indicators, and risk estimates.	Provides Rivers State evidence linking environmental and edible-plant measurements with potential exposure.	Restricted sampling needs seasonal expansion and concurrent air/dust data; mixed sources, biomonitoring, and governance need separate investigation.
38	Kravchenko et al. (2025)	Coal-plant soils. Repeated monitoring, XRF, and ReCiPe life-cycle impact assessment.	Extends concentration reporting to longer-term soil contamination and ecological/human-toxicity indicators.	Life-cycle indicators are not observed individual disease; concurrent air, crops, dust, and biological exposure evidence are needed.
39	Aziman et al. (2025)	Malaysia; coal, ashes, and topsoil. Radionuclide, metal, and radiological-hazard assessment.	Demonstrates why coal residues may require radiological as well as chemical characterisation.	Screening indices need exposure and health validation; coal-ash hazards cannot be assumed for natural-gas combustion.
40	Ribeiro et al. (2025)	Portugal; deactivated coal plant. Petrographic/geochemical investigation of soil contaminants.	Examines persistent inorganic and organic contamination from historical industrial combustion.	Legacy contamination is distinct from current emissions; crop transfer, personal exposure, and health outcomes need investigation.

No.	Study	Context and methods	Main contribution	Research gap and relevance
41	Chen et al. (2026)	Taiwan; gas- and coal-associated residential sites. PM2.5 chemistry, source apportionment, and risk assessment.	Compares fuel-associated mixtures and separates plant, traffic, and other source contributions.	Spring sampling limits annual inference; calculated risks are not personal-dose or clinical evidence, and local source fractions are not transferable.

PM = particulate matter; PAHs = polycyclic aromatic hydrocarbons; VOCs = volatile organic compounds; PCBs = polychlorinated biphenyls; PCA = principal component analysis; GIS = geographic information systems; GC–MS = gas chromatography–mass spectrometry; XRF = X-ray fluorescence; SPM = suspended particulate matter.

2.18 Cross Study Synthesis

The matrix shows a methodological progression from emission-to-exposure modelling towards chemical source resolution and integration of environmental media. Zhou et al. (2003), Guttikunda and Jawahar (2014), and Adesanmi et al. (2016) illustrate modelling and inventory approaches at different scales. X. Chen et al. (2020) and P. J. Chen et al. (2026) show how combining chemical information and source analysis can refine interpretation. These approaches are complementary: a regional model provides spatial context, while a receptor study tests what is present where people are exposed.

Temporal coverage is uneven rather than uniformly absent. Bhatnagar and Bhatnagar (2013) monitor seasonal air quality over two years; Dumanoglu et al. (2017) compare seasons; and Kravchenko et al. (2025) examine repeated soil monitoring across multiple years. These are useful counterexamples to a blanket claim that the literature consists only of short snapshots. The remaining need is coordination across time and media, with repeated measurements linked to meteorology, plant operation, and human activities. A study that follows soil contamination for years still cannot independently establish exposure from indoor dust or an inhaled particle mixture.

The food-chain evidence also spans different questions. Khillare et al. (2012) examine vegetables and dietary risk; Huang et al. (2017) pair soil and crop measurements; and Onyegeme-Okerenta et al. (2025) provide gas-plant-vicinity evidence from Rivers State. Rodríguez-Iruretagoiena et al. (2015), Mandal et al. (2022), and Luo et al. (2024) strengthen understanding of contamination patterns and possible sources. Their combined value lies in defining what must be measured locally: relevant crops, preparation practices, environmental conditions, and consumption. Concentration ratios and pollution indices alone do not establish absorbed dose.

The evidence does not support a uniform conclusion of harm across all endpoints. Ćujić et al. (2016) provide a soil-metal assessment without a significant negative impact for the investigated metals, while other studies identify contamination or elevated screening metrics. Differences in baseline selection, pollutant species, fuel, medium, and analytical design can explain divergent results. Negative and positive findings should therefore be compared on equivalent endpoints rather than used selectively to claim that all thermal plants are either safe or harmful.

For new studies, the clearest priority is to connect existing lines of evidence around defined populations and facilities. Gas-specific emissions research, local soil–food evidence, and school-dust studies provide starting points, but none alone resolves cumulative exposure around power plant communities. Monitoring and intervention research should combine source characterisation, paired media, suitable reference locations, activity-specific exposure data, and a clear distinction between screening risk and observed health. The Nigerian control review by Igbokwe et al. (2016) supports including prevention in this agenda; actual control effectiveness and regulatory implementation still require operational and institutional evidence.

3. Limitations and Future Research

The purposive narrative approach limits completeness and reproducibility relative to a systematic evidence synthesis. Bibliographic verification does not replace full-text methodological appraisal, and some study interpretations rely on accessible abstracts or institutional records. The gap matrix is completely relative to the 41 records supplied, but it is not an exhaustive inventory of all power-plant literature. No formal risk-of-bias score or certainty rating was assigned. The review therefore provides a critical framework and selected evidence base rather than a comprehensive ranking of all available research.

Transferability is a further limitation. Findings from coal-fired plants, different climates, and populations with different activity patterns cannot quantify risk anywhere without local data. Environmental concentrations, exposure estimates, and epidemiological associations also cannot be pooled into a single common effect measure. These limitations favour a staged research programme that first improves exposure characterisation and source resolution, then evaluates longer-term health questions.

Priority research should examine matched indoor and outdoor environments, repeated seasonal measurements, source-specific chemical profiles, and locally grounded exposure assumptions. Intervention studies would be especially useful: before-and-after measurements linked to a defined control measure could test whether an apparent reduction in emissions reaches the people intended to benefit. Longitudinal health research would complement this work but should use exposure estimates that are independently defensible.

4. Conclusion

Gas-fired generation can offer emission advantages over coal while still warranting environmental and public-health assessment in host communities. The reviewed evidence supports attention to fine and ultrafine particles, mixed pollutant sources, soil and edible plants, and indoor dust. It also shows why fuel-specific evidence, source attribution, and the distinction between modelled risk and observed disease are essential to interpretation. More researches should focus on the connected assessment of environmental media, the activities that generate exposure, and strategies for eliminating risks completely or improving control measures.

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