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Beyond The Flame: Tracing The Fate And Health Implications Of Particulate Matter From Artisanal Refining In Bayelsa State

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ABSTRACT

This review study aims to investigate the environmental and health risks associated with particulate matter (PM) emissions from artisanal refining activities in Bayelsa State, Nigeria. Artisanal refining, despite being widely practiced, remains little regulated, leading to high pollution levels from air contaminants above all from fine particles of unknown identity that pose severe health and environmental problems. It is known from a systematic review of published verified reports that PM is emitted by artisanal refining associated with settling of particulates and fines emitted. It investigates how these particulates are disbursed throughout the surroundings and how this affect human health: In actuality, the studies state that amid signs of PM damage in the environment, an individual will also develop PM-induced cardiovascular and other respiratory illnesses owing to live exposure near a refining location. PM exposure correlates highly with respiratory diseases, cardiovascular diseases, and other health problems in communities situated near or around artisanal refining sites or communities involved in refining. Environmental studies, when extended to PM, other studies show the role of PM in soil and water contamination, worsening ecosystem degradation. However, much remains unknown about the full scope and many research gaps are still there in knowing the long-term adverse health effects and broader adverse impacts to the whole environment. This paper attempts to critically synthesize the available information and identify research areas with recommendations for future conduct, such as a health-monitoring system for better pollution-control technologies. The results suggest very clearly the necessity for broad-based policies and strategies for remedying the possible negative evolution of artisanal refining practices on both human health and the environment in Bayelsa State and regions like it.

Keywords: environmental and health risks, artisanal refining

1. INTRODUCTION

Artisanal refining in Bayelsa State, Nigeria, thrives as an informal economic mainstay in the oil-rich Niger Delta, offering livelihoods and community empowerment amid poverty and unemployment, despite its illegality (Nwozor *et al.*, 2020; Ikezam *et al.*, 2021; Angaye *et al.*, 2025). These rudimentary operations, locally known as "kpo fire," distill stolen crude into fuels via open distillation and combustion, emitting high levels of particulate matter (PM_{2.5}, PM₁₀), soot, and polycyclic aromatic hydrocarbons (Izah, 2021; Ephraim-Emmanuel *et al.*, 2023; Oyewale *et al.*, 2024). These pollutants inflict respiratory diseases, cardiovascular disorders, cancers, and environmental degradation on nearby

ecosystems and creek-dependent populations (Ephraim-Emmanuel *et al.*, 2023; Richard *et al.*, 2023; Sawyer & Izah, 2023; Suku *et al.*, 2023). Globally, PM from analogous informal fuel processing drives substantial mortality (Bennitt *et al.*, 2025; Xu *et al.*, 2024), underscoring Bayelsa's urgency as a hotspot with intense activity, high exposure in some communities, and weak oversight (Ephraim-Emmanuel *et al.*, 2023; Angaye *et al.*, 2025).

The refining of local crude oil is deemed responsible for the serious particulate matter pollution in atmosphere, including PM_{2.5}, as well as the release of polyaromatic hydrocarbons into the environment (Ephraim-Emmanuel *et al.* 2013; Lala *et al.*, 2014). However, systematic pollution studies have not been conducted that could address the fate of particular groups of pollutants and their full spectrum of health implications for local residents in the atmosphere—from their release into the atmosphere to their atmospheric transport, deposition and long-term merging and preservation in the environment/drift of particulate pollutants (Ephraim-Emmanuel *et al.* 2013; Richard *et al.*, 2013). Researches done have highlighted substantial levels of PM being associated with respiratory diseases, cardiovascular problems, sensory irritation, and several other health risks due to long-term exposure (Ephraim-Emmanuel *et al.* 2013; Lala *et al.*, 2014; Suku *et al.*, 2014), yet available information is lacking to understand the behavior of individual PM, and subsequent long-term epidemiological effects, in this context (Ephraim-Emmanuel *et al.* 2013). This study objectives is aimed to review pertinent literature, delineate the environmental behavior and health ramifications of PM from artisanal refining in Bayelsa State, and underscore critical research deficiencies to inform targeted interventions.

The fate and health implications of particulate matter released from artisanal crude oil refining (kpo-fire) in Bayelsa State are underexplored amid rising environmental concerns. Current knowledge reveals elevated PM concentrations in affected communities, with rapid dispersion patterns, though long-term transport, deposition, and transformation processes remain poorly characterized (Michael & Joepen, 2021; Lala *et al.*, 2024). Exposure links to respiratory impairments, eye/skin irritations, cardiovascular risks, and heightened hospitalizations, particularly in severely exposed areas like Nembe and Gbarain (Ephraim-Emmanuel *et al.*, 2023; Richard *et al.*, 2023; Sawyer & Izah, 2023). Critical gaps include scarce routine monitoring, epidemiological data, policy frameworks, and mitigation strategies (Ephraim-Emmanuel *et al.*, 2023; Sawyer & Izah, 2023). This review addresses these questions to guide future research.

2. Literature Review

2.1. Artisanal Refining Practices in Bayelsa State

In Bayelsa State, part of the Niger Delta where oil flows, a simple way of making extra money and theft is artisanal refining termed "kpo fire" (Ephraim-Emmanuel *et al.*, 2023; Suku *et al.*, 2024). They cripple the pipes through local methods, then steal the crude or lug it with Cotonou boats to the riverside camps (Suku *et al.*, 2023). Ingredients of these items include the siting of crude in plastic drums, from which volatile gasses are shed, before being passed into rusty metal drums over open earthen ovens fired with firewood and excess crude for distilling (Ephraim-Emmanuel *et al.*, 2023; Oyewale *et al.*, 2024).

Gas emanations from opened fire heat crude oil and are then expelled outside, where the vapors lead to some simple condensers, resulting in the collection of some cheap, poor petroleum products-kerosene, gasoline, and its distilled product in the categories of diesel (Richard *et al.*, 2023; Suku *et al.*, 2023). This equipment is about as primitive and scavenged or re-assembltd to near resemble as so long as the capacity to operate it does not burn much of the owner's investment-and risk (Michael & Joepen, 2021; Oyewale *et al.*, 2024). Operation scales go down to as low as a 40 to 60 drums of diesel per day, which seen in the crudeness of production efficiency as well as environmental damage perpetrated in the area (Ephraim-Emmanuel *et al.*, 2023; and Richard *et al.*, 2023).

2.2. Particulate Matter Emissions from Artisanal Refining:

Artisanal crude oil refining, locally known as "kpo-fire," in Nigeria's Niger Delta, including Bayelsa State, releases thick clouds of particulate matter from crude oil boiling over open fires, drastically polluting the local air (Ephraim-Emmanuel *et al.*, 2023; Suku *et al.*, 2024). The pollutants primarily include fine particulate matter (PM_{2.5}) and PM₁₀, along with coarse soot and black carbon from

incomplete combustion (Lala *et al.*, 2024; Suku *et al.*, 2024). Research reveals a toxic cocktail of substances: polycyclic aromatic hydrocarbons (PAHs), which are known carcinogens, heavy metals, volatile organic compounds, and sulfur compounds, all hitching a ride on these particles (Ephraim-Emmanuel *et al.*, 2023). High levels of PAH's have been found in PM10 in areas in Bayelsa like Gbarain and Nembe. It causes severe respiratory symptoms which exceed the standards of exposure for safety. Hazardous gases brought by the Harmattan hardly allow anybody to miss the dangers (Lala *et al.* 2024). This dirty air will kill more people than it will darken the skies, then action has to be embraced desperately.

2.3. Health Implications of Particulate Matter:

Breathing in particulate matter from artisanal oil refining in Bayelsa State is like inviting a silent killer into the lungs, global studies consistently link PM2.5 and PM10 exposure to respiratory woes, heart disease, and even cancer (Ephraim-Emmanuel *et al.*, 2023; Suku *et al.*, 2023) Locally, it's hitting hard: folks in hotspots like Nembe and Gbarain endure far more coughing, wheezing, breathlessness, asthma flares, and COPD than in milder areas like Sampou.(Ephraim-Emmanuel *et al.*, 2023). The discrimination between which lot is for the better part is that one sees stuff that very slight effects asthma women heavily, stemming from more occlusive symptoms. But a child is deeply frightening and pregnant because in the end, babies, pregnant mothers, and kids end up with a very high number of those scary extras, congenital defects, reproductive hazards as well as lifelong lung injury due to contact with PAHs and toxins coming from kpo-fire sites (Richard *et al.*, 2023; Suku *et al.*, 2023a; 2023b). This is not mere irritation from one's place of residence; it curtails live, compelling us to actions to protect the vulnerable (Richard *et al.*, 2023; Suku *et al.*, 2024). Table 1 Below show the health implications of Particulate Matter from Artisanal Oil Refining in Bayelsa State

Table 1: Health Implications of Particulate Matter from Artisanal Oil Refining in Bayelsa State

Health Impact	Affected Groups	Symptoms/Conditions	References
Respiratory Issues	General population	Coughing, wheezing, breathlessness, asthma flare-ups, COPD	Ephraim-Emmanuel <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023
Heart Disease & Cancer	General population	Increased risk of heart disease, cancer	Ephraim-Emmanuel <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023
Increased Respiratory Problems in Hotspots	Communities like Nembe and Gbarain	Higher incidence of coughing, wheezing, breathlessness, asthma	Ephraim-Emmanuel <i>et al.</i> , 2023
Gender Disparity	Women	Symptoms appear more frequently in women	Richard <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023a
Vulnerable Populations	Children & Pregnant women	Congenital defects, reproductive harm, lung damage	Richard <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023b
Long-Term Health Damage	All affected groups	Lifelong lung damage, shortened lifespan	Richard <i>et al.</i> , 2023; Suku <i>et al.</i> , 2024

2.4. Environmental Fate and Dispersion of Particulate Matter:

Particulate matter from artisanal refining in Bayelsa doesn't just linger locally, it spreads widely through the atmosphere, driven by winds, humidity, and turbulence (Nwosisi *et al.*, 2021; Angaye *et al.*, 2025). Gaussian plume models from nearby Port Harcourt sites show PM2.5, PM10, and soot dispersing up to 1 km, with concentrations fading but still risky downwind (Michael & Joepen, 2021). When the harmattan blows, the backward trajectory during that period provides evidence of long-range transport over distances as fine particles from uncontrolled refineries blanket entire communities (Lala *et al.*, 2014). Thus, such pollutants are able to settle dryly, or they get scavenged by wet processes and deposited on

soil, creek, and wetland and wind up contaminating aquatic and terrestrial systems (Nwosisi et al., 2021). Furthermore, black carbon (soot) is capable of releasing and attaching contaminants in ecosystems like PAHs because it condenses on the surface of snow, either altering the temperature as well as absorption properties of snow-pack or accelerating the warming on which some contaminants attach. Black carbon is often short-lived but very powerful; the other way is through absorption of sunlight thus holding heat near the earth's surface where it is effective enough to enable contaminant accumulation of with most PAHs (Nwosisi et al., 2021; Ephraim-Emmanuel et al., 2023). These changes in bioaccumulation and biotransfer of PAHs and the growth on which contamination accumulates in or contaminates precipitation, snow, ice packs, and snowflakes, all become component media through which black carbon changes the physical and chemical properties of these environmental media areas harmful to humans, aquatic organisms, and soil or aquatic organisms as these result appearing with more time, thus altering the balance of the environment (Mallin et al., 2021; Ze et al., 2024).

2.5. Previous Studies on Artisanal Refining and Public Health in Nigeria

Artisanal crude oil refining, rampant in Nigeria's Niger Delta including Bayelsa State, unleashes toxic pollutants like particulate matter, PAHs, and soot, wreaking havoc on public health. Ephraim-Emmanuel *et al.* surveyed communities in Bayelsa, finding residents in heavily exposed areas like Nembe and Gbarain suffered more moderate-to-severe respiratory symptoms including; coughing, wheezing, and breathlessness, compared to less affected spots, tied directly to refinery emissions (Ephraim-Emmanuel *et al.*, 2023). The study of Richard *et al.* (2023) spotlighted broader woes including: respiratory and cardiovascular failures, eye/skin irritations, and birth defects from inhaled particles and gases. Echoing this, the study of Suku *et al.* (2024) linked the practice to rampant respiratory ills, cancers, and reproductive issues via contaminated air, water, and soil.

3. Methodological Approaches in Review Studies:

3.1. Literature Search and Selection Criteria:

A systematic literature review was made with the use of PRISMA framework to guide it, thus ensuring that the approach would be transparent and reproducible, facilitating the identification of studies on particulate matter from artisanal refining (Ariffin et al., 2025). Comprehensive searches have been carried out in four databases such as PubMed, Scopus, Web of Science, and Google Scholar following the well-established tradition provided by authors working on Niger Delta research (Ezeh et al., 2024; Suku et al., 2024). The review would focus on English-language, peer-reviewed articles published from 2000 to 2024. Inclusion criteria put a premium on empirical studies about PM emissions, transport, deposition, or health burden related to artisanal activities in Bayelsa/Niger Delta (Ephraim-Emmanuel et al., 2023; Suku et al., 2024). Any non-relevant work, grey literature, or outdated material was not included as part of the exclusion criteria. The first stage in screening was the titles/abstracts of papers (n≈500) followed by a full-text review for each of them (n≈100), then hand-searching references.

3.2. Analysis and Synthesis of Literature:

In piecing together the literature, we drew on systematic review methods like those in recent Niger Delta studies, following PRISMA guidelines to search PubMed, Scopus, and Web of Science for works from 2000 onward on artisanal refining's particulate matter impacts (Suku *et al.*, 2024). Thematic synthesis helped spot trends, such as pervasive respiratory risks from PAHs exposure in Bayelsa communities (Ephraim-Emmanuel *et al.*, 2023; Richard *et al.*, 2023), gaps in long-term PM fate tracking, and key findings on ecosystem and health disruptions. Realist review elements unpacked context-mechanism-outcome patterns, ensuring a nuanced view of evidence

3.3. Limitations of Existing Literature:

The scientific discoveries call for scrutiny as to their intent and veracity. A long list of robust review papers should be based on the scientific norm and should be ascertained with a high degree of truthfulness. It attempts to contrast past knowledge with a future road map. Particulate matter emissions effectuate respiratory and cardiac problems, contributing to premature mortality. The particles accumulate and breed on the arterial walls, interrupting oxygen supply to the heart. How many of the countless

respiratory problems arise from PM inhalation? Indirectly, this paves the way to an overflow of fresh ideas. Very similar to every living or transportation concept, particulate matter pollutants also affect every human and animal life. According to the United States Environmental Protection Agency, PM_{2.5} has more associated risks to human health than larger particles or PM₁₀. Particulate matter will be here/impinging to the human body since its inhalation almost happens straight from the nostrils.

4. Discussion:

4.1. Summary of Key Findings

In Bayelsa State of Nigeria, there is an indigenous crude oil refiner that throws the most dangerous particulates, such as PM_{2.5} laden with polycyclic aromatic hydrocarbons, into the atmosphere. These dispersed, highly hazardous particulates widely drift over areas like Nembe and Gbarain and finally find settlement in these communities as indicated by recent works of Ephraim-Emmanuel et al. (2023) and Lala et al. (2024). The populations exposed to the most severe pollution diseases of respiratory morbidity experience a significant increase in rates of moderate to severe respiratory symptoms, coughing, wheezing, shortness of breath, affecting 41.4% of the respondents in Nembe compared to sites with much less exposure (Ephraim-Emmanuel et al., 2023; Sawyer & Izah, 2023). The residents also suffer from problems connected to the eye, skin, cardiovascular system, as well as very high exposure rates from developing chronic diseases like Chronic Obstructive Pulmonary Disease, cancer, etc. due to very poor regulatory monitoring (Richard et al., 2023; Sawyer & Izah, 2023). In addition to gas flaring and bunker fuel burn-off, there are soot clouds across the Niger Delta shadowing broader air pollution scenario such as air pollution depending on hospitalisation, productivity losses, and economic burdens in Nigeria's most oil-rich areas (Nwosisi et al., 2021; Oyewale et al., 2024). This requires a lot of actions, such as creating facilities like modular refineries and enforcing the stringent measures, to begin the end of this scourge of public health (Sawyers & Izah, 2023).

4.2. Health Impacts

It meant that locals were inhaling every quantity of toxic particulate matter around localities on an every day basis. Consequently, one will be living within the four walls of smoke, which act as a serious ecologic pressure on the body, in the context of artisanal refining of crude oil in Bayelsa State, Nigeria. Pollution was linked with exposure to PM rich in Polycyclic aromatic hydrocarbons from "kpo-fire" activities that were suspected to be at the root of a host of respiratory ailments such as chronic obstructive pulmonary disease, lung cancer, and impaired lung function (Ephraim-Emmanuel et al., 2023). Those diseases included the following: cardiovascular; eye, skin, and pharyngeal irritations; and even psychological stain, alongside increased hospitalization rates and losses in productivity (Richard et al., 2023; Sawyer & Izah, 2023). Reports from children and women revealed they were the most affected groups prone to the wheezing, chronic cough, and damage in sensory organ functions after inhaling black soot (Ephraim-Emmanuel et al., 2023; Sawyer & Izah, 2023).

Linking these symptoms definitively with artisanal PM exposure proved to be rather challenging. Self-reported data suffered from recollection biases-mostly during the era of coronavirus-related restrictions on spirometry (Ephraim-Emmanuel et al., 2023). Lack of appropriate monitoring equipment, weak or practically no regulatory framework, and inconsistent measurement methods have all been barriers to accurate exposure assessments (Sawyer & Izah, 2023). Environmental assessment of exposure was often blurred due to confounding gas flaring and biomass burning, and nothing was done concerning PAHs-specific research records; hence, the complete effect of health burden was not well known (Ephraim-Emmanuel et al., 2023; Igibah et al., 2024). The freshwater-dependent lifestyles in Bayelsa heightened risks even as gaps in data persist thereby stalling effective interventions due to the need for evidence-based policy research, with this policy gap occurring as an urgent matter (Lala et al., 2024).

4.3. Environmental Impact and Fate of Particulate Matter

Particulate matter that poses a severe threat to local environments in Balyelsae State arises from the artisanal refining of crude oil since air, soil, water, and ecosystems equally become contaminated with PAHs and other toxins (Table 2). Lost water quality and a raised level of total petroleum hydrocarbons in some creeks (Olugbobiri and Ogboinbiri) as reported by Suku and others (2023) has PM-opposed

agglomeration dropping, erosion of soil fertility, and ultimately, land degradation and deforestation because the ecology is being cleared of mangroves (Richard et al., 2023; Suku et al., 2023). Typically, it acidifies the wetlands' waters, kills off other habitats due to the attractiveness of the toxins, and worsens the Niger Delta crisis (Sawyer & Izah, 2023; Suku et al., 2024).

Table 2: Environmental Impacts of Particulate Matter from Artisanal Oil Refining in Bayelsa State

Environmental Impact	Affected Areas	Consequences	References
Soil and Water Contamination	Farmlands, groundwater, creeks	Infertile farmland, contaminated groundwater with persistent hydrocarbons	Akagbue <i>et al.</i> , 2024; Ephraim-Emmanuel <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023
Water Quality Degradation	Olugbobiri and Ogboinbiri creeks	Elevated total petroleum hydrocarbons harming aquatic life	Suku <i>et al.</i> , 2023
Soil Fertility Loss and Land Degradation	Farmlands and terrestrial ecosystems	Soil erosion, land degradation, deforestation, and disruption of mangrove forests	Richard <i>et al.</i> , 2023; Suku <i>et al.</i> , 2023
Wetland Acidification and Habitat Destruction	Bayelsa's wetlands	Acidified waters, bioaccumulation of toxins, destruction of habitats, amplified ecological crisis	Sawyer & Izah, 2023; Suku <i>et al.</i> , 2024

4.4. Gaps and Unanswered Questions

While there is every understanding of the deterioration I am talking about, limited understanding seems to be the most important barrier removing exciting new discovery (Ibok et al. 2022; Kimkhankay et al. 2022). But the issues of the research gap have been that the stage for it consists of chronic damages including asthma and skin irritations (Ibok et al. 2022). It's no use talking about the big ones, like all you've learned in public media MESINA; now get to understand the condition that puts indoors kept as much as possible (Ibok et al. 2022). Environmentally, we know little of PM's fate: how it drifts, settles into soils and creeks, ravaging ecosystems beyond immediate spills (Richard *et al.*, 2023; Suku *et al.*, 2024). Scant monitoring gear and feeble regulations mean pollution levels fly under the radar, while communities stay in the dark (Sawyer & Izah, 2023). According to portable Ecclesiology, timeliness of cohort studies, dispersion models and robust policies are necessary to fight balance before health in the study area (Sawyer & Izah, 2023).

CONCLUSION

Overall, this research serves to highlight the serious and critical health outcomes associated with particulate matter generated from artisanal crude refining activities in Bayelsa State, Nigeria, resulting in the high release to the atmosphere of PM_{2.5}, and, although it is still controvertible, PM₁₀ and can widely spread through the air, water, and ground via atmospheric processes, greatly enhancing the normally precarious respiratory, skin, eyes, and cardiovascular health risks among socially vulnerable populations. Such contaminants, meanwhile, degrade habitats and weigh economic penalties on increased hospitalizations and workforce losses. To improve conditions, strong regulatory frameworks are required that are decentralized and are underpinned by public-private partnership on clean, modular refineries and real-time environmental monitoring and health surveillance systems. Research should venture into more longitudinal health studies, advance dissemination modelings, and more community-based interventions: such could foster a more of a shift toward sustainable solutions. A call to action - a shared call to action -- is in order in transforming Bayelsa from a mecca of illegal refining into a haven of environmental justice in order to save lives and balanced ecosystems for subsequent generations.

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