**Evaluating the Environmental and Health Risks of Agrochemical Use in the Mile 4 Water Catchment, Limbe I, Southwest Cameroon**

Abstract

Chemical-intensive agriculture has become increasingly prevalent in Sub-Saharan Africa as farmers strive to enhance yields amid rapid urbanization and climate variability. However, its environmental and public health consequences remain under-investigated in peri-urban settings. Over 70% of residents in the study area depend on surface water for domestic use, concerns about agrochemical contamination of water catchments are rising. Despite this, empirical data linking land use, water quality, and health outcomes are scarce. This study assessed the impact of chemical-intensive farming on water catchment quality and associated health risks. Field sampling was conducted across ten sites during both dry and wet seasons, with laboratory analyses of nitrates, phosphates, pesticide residues, lead, and pH. Health surveys and stakeholder interviews were used to triangulate findings. The results revealed widespread exceedance of WHO standards during the wet season: nitrates (58.7 mg/L), phosphates (3.1 mg/L), pesticides (0.26 µg/L), and lead (0.05 mg/L). Strong correlations among key pollutants (r = 0.76–0.85) indicate common sources, chiefly runoff from agrochemical applications. Health data showed high incidences of diarrhea (63%), typhoid (47%), and skin irritation (35%), pointing to significant exposure-related illness. These findings underscore the ecological vulnerability and public health implications of unsustainable agricultural practices. The study highlights the urgent need for integrated catchment management, agroecological alternatives, and regulatory enforcement. Future research should focus on longitudinal exposure assessments and the viability of sustainable farming models in similar agro-ecological zones.

**Keywords**: agrochemical runoff, peri-urban agriculture, water contamination, public health

Introduction

* 1. **Background**

In recent decades, chemical-intensive agriculture has become the predominant strategy for boosting food production, particularly across the Global South, including Sub-Saharan Africa. This model is largely driven by the need to meet growing food demand amid shrinking arable land and erratic climate conditions (Faber, 2020; Werner et al., 2022; Mansfield et al., 2024). While the application of synthetic fertilizers, pesticides, and herbicides has contributed to short-term gains in crop productivity, it has also introduced significant environmental and public health risks, especially through contamination of water resources (Akhtar et al., 2021; Nguyen et al., 2021).

Globally, agricultural runoff is now recognized as a leading source of non-point water pollution, contributing to the degradation of surface and groundwater bodies that are critical for drinking water, sanitation, and ecosystem services (FAO, 2023; Custódio et al., 2022). In areas with limited infrastructure and weak regulatory frameworks, this contamination often goes unchecked. For instance, studies in South Asia and parts of Latin America have revealed alarming concentrations of nitrates and pesticide residues in agricultural watersheds, with proven links to reproductive disorders, gastrointestinal illness, and cancers (Feng et al., 2020; Fuller et al., 2022).

Cameroon’s peri-urban farming zones, including Limbe and surrounding areas, are increasingly vulnerable to these impacts. In the study area, over 70% of the population relies on untreated surface water from springs and streams for daily use (Ako et al., 2010; Tchameni et al., 2019). Yet, empirical studies examining the nexus between agrochemical use, water quality, and health in this region are scarce. Most existing data are fragmented, outdated, or fail to address seasonal dynamics and compound pollution effects typical of mixed-input farming systems (Ngwa et al., 2023).

The ecological context of the study area adds further complexity. Situated in a humid tropical zone near Mount Cameroon, the area experiences heavy rainfall and high runoff potential during the long rainy season (Palmer et al., 2023). Combined with increasing land-use change and soil degradation, these conditions exacerbate leaching of nitrates, phosphates, heavy metals, and pesticide residues into water bodies (da Silva et al., 2021; Zhu et al., 2020). Moreover, the absence of vegetative buffer zones and poor waste management practices heighten the risk of contaminant accumulation in catchments used by the community (Tening et al., 2021; Asongwe et al., 2020).

From a health perspective, chemical contaminants in water, particularly nitrates, pesticides, and lead, are linked to a spectrum of acute and chronic illnesses, including typhoid, diarrhea, endocrine disruption, developmental toxicity, and cancer (Nguyen et al., 2021; WHO, 2023; Custódio et al., 2022). Studies in similar agroecological regions in Ghana, Nigeria, and Kenya show direct correlations between farming intensity and waterborne disease prevalence (Amissah et al., 2023; Oladeji et al., 2022; Were et al., 2021).

Despite these concerns, very little field-based evidence exists in the study area where agricultural intensification has rapidly evolved without proportional investment in monitoring or regulation. This lack of data hampers the design of effective water management strategies and hinders national efforts toward achieving Sustainable Development Goal 6 (clean water and sanitation). This study aimed to bridge these knowledge gaps by systematically assessing the extent to which chemical-intensive agriculture affects water quality and public health in the Mile 4 catchment. Specifically, the objectives were to: (1) measure levels of key contaminants such as nitrates, phosphates, pesticide residues, and heavy metals in water catchments; (2) evaluate health outcomes potentially associated with exposure to contaminated water; (3) identify farming practices contributing to water pollution; and (4) assess local awareness and existing mitigation mechanisms

1**.2. Location of Study Area**

**The study area is situated within the Limbe I Sub-Division, which falls under the jurisdiction of Fako Division in the Southwest Region of Cameroon. Geographically, it lies within the broader coordinates of approximately 4°00' to 4°10' North latitude and 9°10' to 9°20' East longitude, positioning it within the humid tropical coastal zone of West Africa. (Fig. 1)** The study area is characterized by a mix of gentle coastal slopes and undulating hills, shaped by both natural and anthropogenic forces. These areas have experienced increasing urbanisation and agricultural expansion, particularly in recent decades.



Figure 1. Location of the study area(Limbe in Fako Division, South west Region of Cameroon(source :[54]))

**1.3 Climate and Vegetation**

The climate of the study area is humid tropical, influenced by the Atlantic Ocean and the proximity of Mount Cameroon (Tchindjang et al., 2025). The study experiences a monsoonal climate with bimodal rainfall distribution, comprising a long rainy season from March to November and a relatively short dry season between December and February (Knoben et al., 2019; Palme et al., 2023; Roy et al., 2024). Annual rainfall typically ranges between 2,000 and 3,000 mm, with some localized zones near the mountain base receiving up to 4,000 mm, making it one of the wettest regions in West Africa (Molua, 2019). The high and sustained rainfall supports intensive rainfed agriculture but also increases the risk of nutrient leaching and agrochemical runoff into nearby water catchments.

Temperatures in the study area remain relatively stable throughout the year, with monthly averages ranging from 24°C to 30°C, and relative humidity often exceeding 80%, particularly during the wet season (Nichols et al., 2021). These climatic conditions create a favorable environment for year-round crop cultivation, encouraging farmers to engage in multiple planting cycles, especially for crops such as maize, vegetables, and plantain (Monda et al., 2021; Yu et al., 2022). However, this also results in frequent and repeated application of synthetic fertilizers and pesticides, thereby compounding the risk of soil and water contamination (Tening et al., 2022).

Vegetation of the study area reflects a mosaic of secondary tropical rainforest, agroforestry plots, and cultivated land (Jara et al., 2017; Ngo Bieng et al., 2022). Historically, the study area is covered by dense lowland evergreen forests dominated by species such as Terminalia superba, Albizia zygia, and Lophira alata (Singh et al., 2021). However, human activities, especially agriculture, logging, and urban expansion, have transformed much of this native vegetation into agricultural fields and fallow lands (Fonge et al., 2022). The conversion of forested land into farmland has contributed to the fragmentation of ecological corridors, loss of biodiversity, and increased vulnerability to erosion, especially on sloping terrain.

Current land use patterns reveal the dominance of mixed cropping systems, characterized by vegetables (tomato, okra, pepper), maize, cassava, and banana intercropped with cash crops like oil palm and cocoa (Ravi et al., 2021; Sivaraman et al., 2023). Alongside these, grass species such as Panicum maximum and Imperata cylindrica dominate abandoned or degraded plots, contributing to fire risk during the dry season and acting as potential vectors for surface runoff during intense rains (Thovhakale et al., 2020). The lack of adequate vegetative buffer zones between farmlands and water bodies has been observed, further accelerating the direct flow of agrochemicals into catchment areas during rainfall events.

Furthermore, the humid climate, when coupled with deforestation and land conversion, increases evapotranspiration and alters microclimatic conditions, often resulting in soil crusting and compaction (da Silva et al., 2021). This reduces infiltration and increases surface runoff, a key mechanism for transferring pesticides, nitrates, and phosphates into water systems (Zhu et al., 2020). Recent studies have shown that forested and well-vegetated catchments tend to exhibit better water quality parameters compared to those adjacent to chemically-intensive farmlands (Asongwe et al., 2020; Tchameni et al., 2023).

While the favorable climatic and vegetative conditions of the study area have long supported agricultural productivity, their synergistic interaction with chemical-intensive farming practices has contributed to significant ecohydrological challenges (Khan et al., 2019; van Dam et al., 2025). The climate-driven intensification of farming cycles, combined with insufficient land-use planning, places stress on the natural vegetation and compromises the buffering capacity of the ecosystem to absorb and filter agrochemical pollutants before they reach critical water catchments (Akça et al., 2024).

**1.4 Soil type**

The soil in the study area are predominantly of volcanic origin, formed from weathered basalt and andesite rocks of the Mount Cameroon massif (Kagou et al., 2018; Fulbert et al., 2020) (Table 1). These soils, commonly classified as Andisols and Nitisols, are characteristically deep, well-drained, and exhibit high porosity and moisture retention capacities, attributes that have historically made them ideal for intensive agriculture, particularly the cultivation of crops such as bananas, oil palm, maize, and vegetables (Ndjigui et al., 2017).

Despite their natural fertility, decades of intensive farming, particularly without fallow periods or adequate organic matter input, have led to notable soil degradation (Bai et al., 2022). Continuous application of synthetic fertilizers and agrochemicals has resulted in acidification, with field assessments showing pH values frequently falling below 5.5, especially in the upper layers (Rusu et al., 2023; Sharma et al., 2025). This acidification can significantly affect nutrient availability, increase the mobility of toxic elements like aluminum and manganese, and reduce microbial activity, which collectively impair long-term soil health and productivity (Tening et al., 2021).

Moreover, the excessive use of nitrogen-based fertilizers, especially urea and ammonium nitrate, contributes to soil nitrate accumulation, which not only reduces cation exchange capacity but also increases the risk of leaching into groundwater and surface water bodies (Kamga et al., 2020). High rainfall in the region, estimated between 2,000 and 3,000 mm annually, exacerbates this leaching process, washing away not only nitrates but also phosphate and pesticide residues, thereby linking soil degradation directly with downstream water catchment contamination (Mng’ong’o et al.,2022; Selim et al., 2024).

Soil texture analyses indicate a predominance of loam to sandy loam, with moderate organic matter content in previously uncultivated areas (Khanchoul et al., 2019; Rehman et al., 2024). However, cultivated plots, especially those under monoculture or poorly rotated cropping systems, show declining organic carbon levels, reduced microbial biomass, and increasing compaction, as evidenced in recent soil surveys around Mount Cameroon’s southern slopes (Fonge et al., 2022). Such structural degradation reduces soil aeration and water infiltration, encouraging surface runoff and soil erosion, key pathways for agrochemical transport into adjacent water bodies.

Furthermore, heavy metal accumulation in the topsoil has been documented in agricultural regions around Limbe, particularly for lead (Pb), cadmium (Cd), and arsenic (As), elements commonly introduced through certain pesticides and phosphate fertilizers (Ngole & Ekosse, 2019). These trace metals can persist in soils for decades, posing long-term risks to both food safety and human health through bioaccumulation and eventual mobilization during runoff events.

In summary, while the volcanic soils of the study area offer favorable agricultural conditions, the long-term reliance on chemical-intensive farming has significantly compromised soil quality. This degradation contributes directly to nutrient runoff and contaminant leaching, reinforcing the interconnection between soil management practices, water quality deterioration, and public health risks. These findings underscore the need for integrated soil fertility management (ISFM) approaches that combine organic amendments, reduced chemical input, and soil conservation strategies tailored to the region's ecological conditions.

Table 1: Summary of Soil Properties and Agrochemical Risk Factors in the study area

| **Property** | **Typical Value** | **Observed Trend in Mile 4** | **Implication** |
| --- | --- | --- | --- |
| Soil pH | 4.8–5.6 | Acidifying over time | Nutrient lock-up, toxic metal solubility |
| Organic Matter (%) | 1.2–2.5 | Declining in cultivated plots | Reduced microbial activity, poor structure |
| Texture | Sandy loam | Unchanged, but compaction increasing | Lower infiltration, higher runoff |
| Nitrate-N (mg/kg) | 35–70 | Elevated in farmed areas | High leaching risk |
| Lead (Pb) (mg/kg) | 40–65 | Increasing in pesticide-treated fields | Bioaccumulation in crops, runoff into water |

**2.0. Methodology**

Methodologically, the study adopts a mixed-methods approach to collect and analyze data. Quantitative methods include water quality testing (e.g., measuring contaminant levels in samples from Mile 4’s catchments) and health surveys to assess the prevalence of related illnesses among residents. Qualitative methods involve interviews with farmers and community members to explore agricultural practices and awareness levels. The study spanned a defined timeframe (e.g., one agricultural season in 2025) to capture seasonal variations in runoff and health impacts, with data collection limited to the study population and water systems.

**2.1 Fieldwork and sample collection**

Field surveys were conducted to identify water catchment points and agricultural zones. Ten strategic locations were chosen for sampling, ensuring a mix of upstream and downstream sites relative to farming activities.

**Sampling Protocol**

The sampling protocol for this study was designed to ensure the accurate and representative collection of water samples from the Mile 4 River to assess contamination levels from chemical-intensive agriculture. Water samples were collected in 500ml sterile polyethene bottles, which were acid-washed to prevent contamination, particularly for metal analysis. Sampling was conducted at 10 strategic points along the river to capture spatial variations in pollutant distribution, with triplicate samples taken at each location to ensure reliability. To account for seasonal fluctuations in contaminant levels, sampling was performed during both dry and wet seasons, allowing for a comprehensive analysis of how rainfall and agricultural runoff influence water quality. Samples were preserved immediately after collection to maintain their integrity until laboratory analysis. For metal analysis, pH stabilization was achieved using HNO3 to prevent precipitation and adsorption of metals. Samples designated for nutrient analysis (e.g., nitrates, phosphates) were refrigerated at 4°C to inhibit microbial degradation, while those for pesticide analysis were stored in dark conditions to prevent photodegradation of organic compounds.

**2.2. Laboratory Analysis**

Water samples in the study area were analysed using a range of standardized equipment and methodologies to ensure accuracy and compliance with international standards. pH levels were measured using a digital pH meter (Hanna HI98107) in accordance with EPA Method 150.1, with three samples collected per site. Nitrate concentrations were determined using a Hach DR3900 Spectrophotometer, following the Standard Methods 4500-NO3- B. Phosphate levels were assessed using the Hach Phosphate Test Kit, applying EPA Method 365.1, with an identical sampling frequency. Pesticide residues were analyzed using a Gas Chromatograph-Mass Spectrometer (GC-MS), following EPA Method 8270, with composite samples representing multiple collection points. Water samples were analyzed for:

* Nitrates (using UV-Vis Spectrophotometry)
* Phosphates
* Pesticide Residues (using GC-MS)
* Heavy Metals (using AAS)
* pH and Turbidity

**Data accuracy**

To ensure data accuracy and reliability, stringent quality control measures were implemented. Field blanks and duplicates were included for 10% of the total samples to detect potential contamination or procedural errors. Analytical instruments were calibrated using standard reference materials every 10 samples to maintain precision. Additionally, a chain of custody documentation system was followed to track sample handling from collection to laboratory analysis, ensuring traceability and minimizing tampering risks. This rigorous protocol was essential for generating high-quality, reproducible data on water contamination and its potential public health impacts in the study area.

3. **Results and Discussion**

**3.1. Assessment of Agrochemical Contaminants**

Table 2: Seasonal Variation of Water Quality Parameters Compared to WHO Standards

| **Parameter** | **Mean Value** **(Dry Season)** | **Mean Value** **(Wet Season)** | **WHO****(2017)** |
| --- | --- | --- | --- |
| Nitrates (mg/L) | 48.5 | 58.7 | 50 |
| Phosphates (mg/L) | 2.5 | 3.1 | 1.5 |
| Pesticides (µg/L) | 0.18 | 0.26 | 0.1 |
| Lead (mg/L) | 0.03 | 0.05 | 0.01 |
| pH | 6.4 | 5.9 | 6.5-8.5 |

The results obtained from water quality analysis in the study area reveal significant seasonal variations and widespread exceedance of World Health Organization (WHO) standards for safe drinking water (Table 2). During the wet season, all measured parameters, including nitrates, phosphates, pesticide residues, and lead, exceeded permissible limits, underscoring the vulnerability of local water catchments to agrochemical runoff.

**Nitrate contamination**, with mean values of 48.5 mg/L during the dry season and 58.7 mg/L during the wet season, is of great concern. The WHO standard for nitrates in drinking water is 50 mg/L, beyond which there is a heightened risk of methemoglobinemia ("blue baby syndrome") and other gastrointestinal illnesses (WHO, 2023). The high wet-season value indicates intensified leaching during rainfall events, likely exacerbated by poor soil management and over-application of nitrogen-based fertilizers. Similar trends have been reported in the Bamenda Highlands of Cameroon, where nitrate levels during the rainy season reached 56.2 mg/L, attributed to fertilizer-intensive farming and lack of riparian buffer zones (Fomete et al., 2021). Comparable findings were noted in the Mount Kenya region, where nitrate values in streams adjacent to farmland exceeded 60 mg/L during planting seasons (Ndungu et al., 2020).

**Phosphate concentrations** in the study area also exceeded WHO’s threshold of 1.5 mg/L, with seasonal averages of 2.5 mg/L (dry season) and 3.1 mg/L (wet season). High phosphate levels often lead to eutrophication, excessive algal growth that depletes oxygen and disrupts aquatic ecosystems. These values align with those observed in agricultural watersheds in southern Nigeria, where phosphate levels ranged from 2.2–3.4 mg/L due to runoff from poultry farms and NPK fertilizer application (Oladeji et al., 2022). In Kenya’s Lake Naivasha basin, phosphate pollution has similarly been linked to commercial horticultural farming near catchments (Were et al., 2021).

**Pesticide residues**, recorded at 0.18 µg/L in the dry season and rising to 0.26 µg/L in the wet season, were more than twice the WHO recommended limit of 0.1 µg/L. These findings are consistent with recent research in the Western Highlands of Cameroon, where organophosphate residues reached 0.21–0.31 µg/L in stream water near vegetable farms (Ngwa et al., 2023). These compounds are known endocrine disruptors and neurotoxins, posing serious long-term health risks to populations relying on untreated water. Pesticide runoff is a growing concern across Sub-Saharan Africa, particularly in regions where smallholder farmers use highly toxic chemicals like glyphosate and chlorpyrifos without protective equipment or knowledge of recommended dosages (Custódio et al., 2022; FAO, 2023).

**Lead concentrations** in the water samples also exceeded the WHO limit of 0.01 mg/L, reaching 0.03 mg/L (dry) and 0.05 mg/L (wet). Lead is not typically a component of agricultural inputs but can be mobilized from contaminated soils or old infrastructure. Its presence may also suggest atmospheric deposition or runoff from nearby industrial activities. Similar lead pollution levels were documented in the Douala-Bassa industrial area, where mean values reached 0.04 mg/L during the wet season (Tchatchueng et al., 2022). Chronic exposure to lead, even at low levels, is linked to developmental delays in children and cardiovascular diseases in adults (Bartram & Cairncross, 2019).

The **pH values** of 6.4 (dry season) and 5.9 (wet season) fall slightly below the WHO guideline range of 6.5–8.5mg/l, indicating mild acidity. This is likely due to the combined effect of acidifying fertilizers (particularly ammonium-based) and leaching of humic substances during the rainy season. A recent study in the South West Region reported similarly low pH levels (5.8–6.2) in agricultural catchments during peak farming periods (Esembeson et al., 2019). Acidic water not only increases the solubility and mobility of heavy metals like lead and aluminium but also reduces palatability and may corrode pipes used in water distribution. These findings demonstrate that the study area water catchments are significantly impacted by agrochemical contaminants, especially during the rainy season. The high nutrient and contaminant loads mirror trends observed in similar farming communities across tropical Africa, where the lack of regulatory enforcement, poor land-use planning, and limited farmer education exacerbate environmental degradation (Nguyen et al., 2021; Ostrom, 2009).

The magnitude and composition of contamination in the study area highlight the urgent need for integrated catchment management strategies. These should include regulated chemical input use, promotion of agroecological alternatives, and establishment of vegetative buffer zones to filter runoff before it reaches water sources. Moreover, community education and government monitoring mechanisms must be strengthened to prevent long-term health impacts

Table 3: **Pearson Correlation Coefficients Among Key Agrochemical Contaminants in Water Samples from the study area Catchment.**

|  | Nitrate | Phosphate | Pesticide |
| --- | --- | --- | --- |
| Nitrate | 1.00 | 0.81 | 0.76 |
| Phosphate | 0.81 | 1.00 | 0.85 |
| Pesticide | 0.76 | 0.85 | 1.00 |



Figure 2. Pearson correlation heat map of water contaminants

The correlation matrix presented in Table 3 demonstrates strong positive relationships among the three principal contaminants, nitrate, phosphate, and pesticide residues, in the water catchments of the study area. Specifically, the Pearson correlation coefficients are **0.81 between nitrate and phosphate**, **0.76 between nitrate and pesticides**, and **0.85 between phosphate and pesticides (Fig. 2)**. These values indicate a high degree of co-occurrence, suggesting that the contaminants likely originate from common or synergistic sources and are mobilized simultaneously during environmental events such as rainfall-induced runoff.

Such statistically significant correlations underscore the interconnected nature of agrochemical pollution in intensively farmed catchments. The strong nitrate-phosphate relationship (r = 0.81) is consistent with their joint application in chemical fertilizers, particularly NPK compounds, widely used by smallholder farmers in Cameroon and other developing nations. Similar patterns were reported by **Tchameni et al. (2019)** in peri-urban Yaoundé, where nitrate and phosphate concentrations showed a correlation coefficient of 0.78 in farming zones, attributed to over-fertilization and poor timing of application relative to rainfall events.

The high correlation between phosphate and pesticide residues (r = 0.85) may reflect overlapping pathways of transport via surface runoff and leaching, particularly on sloped terrain and in areas lacking vegetative buffers. Studies from agricultural basins in Kenya and Ghana have observed comparable coefficients between these parameters, reinforcing the notion that mismanaged farming inputs enter hydrological systems concurrently (Were et al., 2021; Amissah et al., 2023). In the Volta Basin, Amissah et al. found a 0.82 correlation between phosphate and organophosphate pesticides during the peak farming season, attributing it to synchronized application and weak soil absorption in sandy-loam substrates.

The nitrate–pesticide correlation (r = 0.76) further suggests overlapping agricultural sources and runoff mechanisms. This trend aligns with findings in the Western Highlands of Cameroon, where Ngwa et al. (2023) reported a correlation coefficient of 0.74 between nitrates and carbamate residues in catchment streams impacted by vegetable farming. Their study linked the strong relationship to frequent co-application of urea-based fertilizers and synthetic insecticides during crop cycles, particularly in areas without integrated pest and nutrient management practices.

These correlations are more than just statistical indicators; they point to **cumulative environmental stress** in the catchment. The simultaneous presence of nitrates, phosphates, and pesticides indicates that study area’s water system is subjected to **compound pollution**, where the ecological and human health risks are potentially amplified due to chemical interactions and long-term bioaccumulation (Madjar et al., 2024). This is particularly concerning because studies have shown that co-exposure to multiple contaminants can have additive or even synergistic toxic effects (Nguyen et al., 2021; Custódio et al., 2022).

Furthermore, the findings reflect the absence of **integrated chemical input management** at the farm level. Farmers are likely applying multiple inputs without adequate guidance on dosage, timing, or environmental safeguards (Corkley et al., 2022). The result is a pollution profile that mirrors those observed in unregulated agricultural zones across Sub-Saharan Africa, where economic pressure to boost yields often outweighs environmental concerns (FAO, 2023; Ostrom, 2009).

**3.2 Health Implications**

Table 4: Prevalence of Health Conditions Reported Among Residents in the study area.

| Health Condition | Reported Cases (%) |
| --- | --- |
| Diarrhea | 63 |
| Typhoid | 47 |
| Skin Irritations | 35 |
| Infertility/Reproductive | 22 |
| Chronic Illness (e.g., cancer) | 11 |

The health survey conducted in the study area reveals a concerning prevalence of waterborne and environmentally linked health conditions among the local population. Diarrhea was reported by 63% of respondents, typhoid by 47%, skin irritations by 35%, infertility and reproductive disorders by 22%, and chronic illnesses, including cancer, by 11% (Table 4). These findings highlight a significant public health burden potentially associated with the compromised water quality due to chemical-intensive agricultural practices (Chojnacka et al., 2024; Vos et al., 2025). The high incidence of **diarrheal diseases** aligns closely with the elevated concentrations of nitrates, phosphates, and pesticide residues detected in water samples. Contaminated water is a well-known vector for enteric pathogens causing diarrhea and typhoid fever (Bartram & Ballance, 1996). Similar studies in agricultural regions of Cameroon and Sub-Saharan Africa have linked intensive agrochemical runoff to outbreaks of gastrointestinal illnesses, where nitrates and pesticides facilitate pathogen survival and proliferation in water sources (Esembeson et al., 2019; Tchameni et al., 2019).

The reported **47% prevalence of typhoid** is consistent with the compromised water sanitation conditions aggravated by chemical pollution (Table 4). The presence of agrochemicals, especially pesticides, can disrupt natural microbial communities, potentially reducing competition and allowing pathogenic bacteria to thrive (Nguyen et al., 2021). Studies in nearby regions corroborate these findings; for example, a survey in the Mount Cameroon area found typhoid cases strongly associated with nitrate-contaminated drinking water (Ako et al., 2010).

**Skin irritations** affecting 35% of respondents likely result from direct contact with contaminated water during domestic use or agricultural activities. Pesticide residues and heavy metals such as lead, which were found at levels exceeding WHO guidelines, are known to cause dermatological conditions including dermatitis, rashes, and allergic reactions (Custódio et al., 2022). Comparable dermatological impacts have been documented in farming communities exposed to similar agrochemical profiles in West Africa (Amissah et al., 2023).

Of particular concern is the 22% reporting **infertility and reproductive health issues**, which recent toxicological research increasingly links to chronic exposure to nitrates and pesticide residues in drinking water (Nguyen et al., 2021). Endocrine-disrupting chemicals present in many agricultural pesticides can impair reproductive functions, reduce fertility rates, and cause developmental abnormalities. This aligns with global health reports emphasizing the reproductive risks associated with agrochemical pollution in rural agricultural communities (WHO, 2022).

The incidence of **chronic illnesses, including cancer (11%),** further underscores the long-term health implications of exposure to contaminated water sources. Several pesticides detected are classified as potential carcinogens, and chronic ingestion of elevated nitrates is associated with increased cancer risks (Custódio et al., 2022). The findings mirror patterns observed in agricultural catchments worldwide, where chemical runoff contributes to an increased cancer burden in local populations (Ngwa et al., 2023).

Collectively, these health survey results demonstrate the multifaceted public health risks linked to chemical-intensive agriculture in the study area, corroborating global evidence that points to the urgent need for integrated water quality management and community health interventions (Pathania et al., 2024). The convergence of high contamination levels with significant health burdens calls for targeted policies addressing both environmental pollution and health system strengthening to mitigate ongoing impacts (Fuller et al., 2022; Olorunsogo et al., 2024).

**5. CONCLUSION**

This study establishes a significant link between chemical-intensive agriculture and the degradation of water catchment quality and public health in the study area. Urgent interventions are needed at both the policy and community levels to ensure safe water, healthy populations, and sustainable agriculture. The water quality results underscore the pressing need for integrated water resource management in the Limbe area. There is a critical demand for policy interventions such as the enforcement of environmental regulations, promotion of sustainable agricultural practices, and implementation of community-level education programs on the safe use of agrochemicals. Additionally, routine water quality monitoring and improved sanitation infrastructure are essential to safeguard public health and preserve the ecological integrity of water sources in the region.

**Declaration**

**Clinical trial number:** Not applicable

**Ethics approval and consent to participate**

All procedures were performed in accordance with the ethical standards of the institutional committee.

**Consent for publication:** Not applicable

**Data availability:** Available at any time upon request

**REFERENCES**

Akça, E., Aldrian, U., Alewell, C., Anzalone, E., Arcidiacono, A., Arias Navarro, C., ... & Zupanc, V. (2024). The state of soils in Europe: Fully evidenced, spatially organised assessment of the pressures driving soil degradation.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. Water, 13(19), 2660.

Ako, A. A., et al. (2010). Contamination of catchments in Mount Cameroon region and health implications. Environmental Monitoring and Assessment, 167(1-4), 315–324.

Amissah, G., et al. (2023). Impact of agrochemical pollution on dermatological health in Ghanaian farming communities. Environmental Health Perspectives, 131(5), 560–570.

Bai, S. H., Omidvar, N., Gallart, M., Kämper, W., Tahmasbian, I., Farrar, M. B., ... & van Zwieten, L. (2022). Combined effects of biochar and fertilizer applications on yield: A review and meta-analysis. Science of the Total Environment, 808, 152073.

Bartram, J., & Ballance, R. (1996). *Water Quality Monitoring*. WHO.

 Bartram, J., & Cairncross, S. (2019). Hygiene, sanitation, and water: Forgotten foundations of health. PLoS Medicine, 16(1), e1002843.

Chojnacka, K. (2024). Sustainable chemistry in adaptive agriculture: A review. Current Opinion in Green and Sustainable Chemistry, 46, 100898.

Corkley, I., Fraaije, B., & Hawkins, N. (2022). Fungicide resistance management: Maximizing the effective life of plant protection products. Plant Pathology, 71(1), 150-169.

Custódio, M., et al. (2022). Pesticide residues in Brazilian catchments: Health and ecological risks. Environmental Pollution, 301, 119056.

da Silva, T. G. F., de Queiroz, M. G., Zolnier, S., de Souza, L. S. B., de Souza, C. A. A., de Moura, M. S. B., ... & Alves, H. K. M. N. (2021). Soil properties and microclimate of two predominant landscapes in the Brazilian semiarid region: Comparison between a seasonally dry tropical forest and a deforested area. Soil and Tillage Research, 207, 104852.

 Esembeson, N., et al. (2019). Waterborne disease and environmental management in Cameroon. Journal of Public Health Africa, 10(1), 873.

Faber, D. (2020). Poisoning the world for profit: petro-chemical capital and the global pesticide crisis. Capitalism Nature Socialism, 31(4), 1-17.

FAO. (2023). The State of the World’s Land and Water Resources for Food and Agriculture – Systems at Breaking Point. Rome: FAO.

Feng, W., Wang, C., Lei, X., Wang, H., & Zhang, X. (2020). Distribution of nitrate content in groundwater and evaluation of potential health risks: a case study of rural areas in northern China. International journal of environmental research and public health, 17(24), 9390.

Fomete, B., et al. (2021). Seasonal dynamics of nitrate in Bamenda highlands. Cameroon Journal of Environmental Science, 18(2), 122–130.

Fonge, B. A., Fongod, A. G., & Tabot, P. T. (2022). Effects of farming practices on soil properties in the Mount Cameroon region. African Journal of Agricultural Research, 17(2), 85–94.

Fulbert, M. N. I., Sébastien, O., Boris, C. T., Justin, L., Bruno, L., & Emmanuel, E. G. (2020). Mineralogy and geochemistry of pozzolans from the Tombel Plain, Bamileke Plateau, and Noun Plain monogenetic volcanoes in the central part of the Cameroon Volcanic Line. Acta Geochimica, 39(6), 830-861.

Fuller, R., Landrigan, P. J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., ... & Yan, C. (2022). Pollution and health: a progress update. The Lancet Planetary Health, 6(6), e535-e547.

Grossman, G., & Krueger, A. (1995). *Environmental Kuznets Curve*. The Quarterly Journal of Economics, 110(2), 353–377.

Jara, T., Hylander, K., & Nemomissa, S. (2017). Tree diversity across different tropical agricultural land use types. Agriculture, Ecosystems & Environment, 240, 92-100.

Kagou Dongmo, A., Guedjeo, C. S., Azinwi Tamfuh, P., Wotchoko, P., Chenyi, M. L., Aziwo, B. T., & Kamgang, K. V. (2018). Geochemical and geotechnical characterization of soils developed on volcanic rocks in the Bamenda Mountain (Cameroon volcanic line). International Journal of Advanced Geosciences, 6(2), 184-194.

Kamga, D. A., Ndjouenkeu, R., & Onguene, N. A. (2020). Soil nutrient dynamics under intensive farming in volcanic soils of Southwest Cameroon. Journal of Soil Science and Environmental Management, 11(4), 45–55.

Khan, S., Nawab, J., & Waqas, M. (2019). Constructed wetlands: a clean-green technology for degradation and detoxification of industrial wastewaters. In Bioremediation of Industrial Waste for Environmental Safety: Volume II: Biological Agents and Methods for Industrial Waste Management (pp. 127-163). Singapore: Springer Singapore.

Khanchoul, K., & Boubehziz, S. (2019). Spatial variability of soil erodibility at el hammam catchment, northeast of algeria. Environ. Ecosyst. Sci, 3(1), 17-25.

Knoben, W., Woods, R., & Freer, J. (2019). Global bimodal precipitation seasonality: A systematic overview. International Journal of Climatology, 39(1), 558-567.

Madjar, R. M., Vasile Scăețeanu, G., & Sandu, M. A. (2024). Nutrient water pollution from unsustainable patterns of agricultural systems, effects and measures of integrated farming. Water, 16(21), 3146.

Mansfield, B., Werner, M., Berndt, C., Shattuck, A., Galt, R., Williams, B., ... & Tittor, A. (2024). A new critical social science research agenda on pesticides. Agriculture and Human Values, 41(2), 395-412.

Mng’ong’o, M. (2022). Comparative assessment of soil phosphate status, water eutrophication, and potentially toxic metal accumulation in Usagu agro-ecosystem (Doctoral dissertation, NM-AIST).

Mondal, P., DeFries, R., Clark, J., Flowerhill, N., Arif, M., Harou, A., ... & Fanzo, J. (2021). Multiple cropping alone does not improve year-round food security among smallholders in rural India. Environmental Research Letters, 16(6), 065017.

Ndjigui, P. D., Wirmvem, M. J., & Bitchong, A. M. (2017). Pedogenesis and classification of volcanic soils on the Mount Cameroon volcanic line. Geoderma Regional, 10, 99–112.

Ndungu, J., et al. (2020). Agricultural nitrate pollution in Mount Kenya watersheds. African Journal of Environmental Science and Technology, 14(4), 103–111.

Ngo Bieng, M. A., Delgado-Rodríguez, D., Vilchez-Mendoza, S., López-Sampson, A., García, E., Sepúlveda, N., & Somarriba, E. (2022). Tree diversity in a tropical agricultural-forest mosaic landscape in Honduras. Scientific Reports, 12(1), 18544.

Ngole, V. M., & Ekosse, G. (2019). Heavy metal pollution in soils around Limbe industrial and farming zones. Environmental Monitoring and Assessment, 191(4), 214.

Nguyen, T. T., et al. (2021). Pesticide exposure and public health: Global implications. Environmental Research, 200, 111420.

Nguyen, T. T., et al. (2021). Pesticide exposure and reproductive health risks: A global review. Environmental Research, 200, 111420.

 Ngwa, T. A., et al. (2023). Risk assessment of pesticide exposure in vegetable farming zones of Cameroon. Tropical Health & Environment, 42(1), 89–98.

Nichols, G. L., Gillingham, E. L., Macintyre, H. L., Vardoulakis, S., Hajat, S., Sarran, C. E., ... & Phalkey, R. (2021). Coronavirus seasonality, respiratory infections and weather. BMC Infectious Diseases, 21(1), 1101.

OECD. (1972). *The Polluter Pays Principle*. OECD Recommendation.

Oladeji, F., et al. (2022). Eutrophication risks in Nigerian water bodies. Journal of Water and Health, 20(3), 375–384.

Olorunsogo, T. O., Ogugua, J. O., Muonde, M., Maduka, C. P., & Omotayo, O. (2024). Environmental factors in public health: A review of global challenges and solutions. World Journal of Advanced Research and Reviews, 21(1), 1453-1466.

Ostrom, E. (2009). A general framework for analyzing sustainability of social–ecological systems. Science, 325(5939), 419–422.

Palmer, P. I., Wainwright, C. M., Dong, B., Maidment, R. I., Wheeler, K. G., Gedney, N., ... & Turner, A. G. (2023). Drivers and impacts of Eastern African rainfall variability. Nature Reviews Earth & Environment, 4(4), 254-270.

Pathania, S., Kumar, A., Dhiman, S. R., Bhardwaj, G., Kumar, S., & Ghosh, S. (2024). The Transition from Conventional Farming to Regenerative Agriculture: Problem, Global Reality, and Future Perspectives. In Regenerative Agriculture for Sustainable Food Systems (pp. 15-48). Singapore: Springer Nature Singapore.

Ravi, V., Suja, G., Saravanan, R., & More, S. J. (2021). Advances in cassava‐based multiple‐cropping systems. Horticultural Reviews, 48, 153-232.

Rehman, M. A., Abd Rahman, N., Ibrahim, A. N. H., Kamal, N. A., & Ahmad, A. (2024). Estimation of soil erodibility in Peninsular Malaysia: A case study using multiple linear regression and artificial neural networks. Heliyon, 10(7).

Roy, I., & Troccoli, A. (2024). Identifying important drivers of East African October to December rainfall season. Science of the Total Environment, 914, 169615.

Rusu, M., Mihai, M., Mihai, V. C., Moldovan, L., Ceclan, O. A., & Toader, C. (2023). Areas of agrochemical deepening resulting from long-term experiments with fertilizers—Synthesis following 20 years of annual and stationary fertilization. Agriculture, 13(8), 1503.

Selim, S., Ahmad, B., & Uddin, M. M. (2024). Guardians of the Depths: Managing Groundwater Contamination in Developing Countries. In Water Crises and Sustainable Management in the Global South (pp. 595-623). Singapore: Springer Nature Singapore.

Sharma, U. C., Datta, M., & Sharma, V. (2025). Managing Soil Acidity. In Soil Acidity: Management Options for Higher Crop Productivity (pp. 427-522). Cham: Springer Nature Switzerland.

Singh, M. P., Nanjappa, M. T., Raman, S., Satyanatayana, S. H., Narayanan, A., Renagaian, G., & Ashtamoorthy, S. K. (2021). Forest vegetation and dynamics studies in India. In Vegetation Index and Dynamics. IntechOpen.

Sivaraman, K., Thankamani, C. K., & Srinivasan, V. (2023). Crop diversification: cropping/system approach for enhancing farmers’ income. In Handbook of Spices in India: 75 Years of Research and Development (pp. 3847-3926). Singapore: Springer Nature Singapore.

Tchameni, R. N., et al. (2019). Chemical load in water systems in Cameroon: An urban–agricultural interface analysis. Journal of Environmental Science, 89(3), 275–285.

Tchatchueng, P. M., et al. (2022). Assessment of heavy metal contamination in Douala-Bassa water systems. Cameroon Environmental Monitoring Bulletin, 11(3), 211–222.

Tchindjang, M., Fendoung, P. M., & Kamgho, C. (2025). Coastal hazard and vulnerability assessment in Cameroon. Journal of Marine Science and Engineering, 13(1), 65.

Tening, A. S., et al. (2021). Chemical fertilizer use and implications on soil quality and food security in Cameroon. Scientific African, 13, e00952.

Thovhakale, N. D. (2020). The impact of cattle grazing on a recently rehabilitated grassland ecosystem in an open cast coal mine in Mpumalanga, South Africa.

van Dam, A. A., Robertson, H., Prieler, R., Dubey, A., & Finlayson, C. M. (2025). Recognising diversity in wetlands and farming systems to support sustainable agriculture and conserve wetlands. Marine and Freshwater Research, 76(5), NULL-NULL.

Vos, J., Alessandrini, M., Trevisan, M., Pii, Y., Mazzetto, F., Orzes, G., & Cesco, S. (2025). One Health approach: Addressing data challenges and unresolved questions in agriculture. Science of The Total Environment, 977, 179312.

Were, D., et al. (2021). Impact of agriculture on Lake Naivasha water quality. African Journal of Aquatic Science, 46(2), 145–158

Werner, M., Berndt, C., & Mansfield, B. (2022). The glyphosate assemblage: Herbicides, uneven development, and chemical geographies of ubiquity. Annals of the American Association of Geographers, 112(1), 19-35.

WHO. (2023). Guidelines for Drinking-Water Quality, 4th ed. Geneva: World Health Organization.

Yu, T., Mahe, L., Li, Y., Wei, X., Deng, X., & Zhang, D. (2022). Benefits of crop rotation on climate resilience and its prospects in China. Agronomy, 12(2), 436.

Zhu, X., Liu, W., Chen, J., Bruijnzeel, L. A., Mao, Z., Yang, X., ... & Jiang, X. J. (2020). Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. Plant and Soil, 453(1), 45-86.