Journal of Emerging Innovations in Engineering (JEIE)
Volume 2, Number 02, June 2026
ISSN: 3110-3375
Open Access: https://jurnal.sutajaya.org/jeie

Physico-chemical and bacteriological characterisation of water resources for food crop cultivation in the Santa Agrarian Basin, Cameroon

Muse Elvis Muno[1*]

[1]University of Bamenda, PO Box 39, Bambili, Cameroon

Article Info

Article history:
Received May 7th, 2026
Revised June 27th, 2026
Accepted June 29th, 2026

Keyword:
Water Quality; Groundwater; Surface Water; Irrigation; Physico-chemical Parameters

DOI:
https://doi.org/10.65664/jeie.v2i02.29
Page: 95 - 109

Correspondent Author:
**Muse Elvis Muno*
Email: elmuse45fast@gmail.com

ABSTRACT

Water quality is central to sustainable agricultural production and ensuring food security. This study assessed the physicochemical and bacteriological quality of water resources in the Santa Agrarian Basin, Cameroon, to determine their suitability for food crop irrigation. Twenty sampling points, comprising ten surface water and ten groundwater sources across five communities, were sampled during the dry (January–March 2024) and rainy (June–August 2024) seasons and analyzed for pH, dissolved oxygen, electrical conductivity, iron, manganese, ammonium, nitrate, phosphate, and fecal coliforms, with results compared against FAO irrigation water quality guidelines. The surface water pH ranged from 5.2 to 6.75, while electrical conductivity, iron, and manganese exceeded FAO thresholds in several communities, particularly Baba and Pinyin. Ammonium and nitrate concentrations rose sharply in the rainy season, exceeding the FAO limits by wide margins. The phosphate levels remained within acceptable limits. Bacteriological analysis detected fecal coliforms and Escherichia coli in 60% of the surface water samples, exceeding the FAO and Agriculture Organization safety thresholds for irrigation. These findings indicate localized but recurring water quality concerns linked to agricultural and sanitation practices. This study recommends integrated water resource management, farmer education, and low-cost treatment to safeguard irrigation water quality and food safety in the basin.

INTRODUCTION

Water plays a key role in global food security and serves as a fundamental input in agricultural production systems. As the global population approaches 10 billion by 2050, the demand for freshwater for irrigation is projected to rise significantly to meet the increasing food needs (FAO, 2020). However, approximately 40% of irrigation water worldwide is compromised by pollutants such as fertilizers, pathogens, and industrial effluents (WWAP, 2018; Mateo-Sagasta et al., 2017). Poor water quality not only reduces crop yields but also affects soil health and increases the risk of transmission of plant and human pathogens through food chains.

Despite being endowed with vast freshwater reserves, sub-Saharan Africa faces significant challenges due to uneven water distribution and limited access to clean water for agriculture,

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

particularly in rural areas (UNEP, 2021). Surface and groundwater sources in many parts of Africa are increasingly contaminated by agricultural runoff, human settlements, and livestock waste (Tiwari et al., 2019). Waterborne pathogens and excessive nutrients, such as nitrates and phosphates, are frequently detected in irrigation water, posing serious risks to crop safety, soil productivity, and long-term agricultural sustainability. Cameroon reflects these broader regional trends. In its highland regions, such as the Santa Agrarian Basin, agriculture is the primary livelihood for most households, which rely heavily on streams and shallow wells for irrigation purposes. However, the uncontrolled use of fertilizers, poor sanitation infrastructure, and land degradation threaten the quality of these water sources (Nguetnkam & Bitom, 2020). Similar concerns have been reported in the neighboring Bamenda area, where river and groundwater sources show comparable acidity and microbial contamination linked to human activity (Magha et al., 2021; Mufur et al., 2021). Despite this, few systematic studies have been conducted to assess the suitability of water resources for irrigation in the Santa Agrarian Basin.

This study therefore aimed to evaluate the physicochemical and bacteriological characteristics of surface and groundwater in the Santa Agrarian Basin to assess their fitness for crop cultivation. By generating a seasonally disaggregated dataset spanning surface and groundwater sources across five communities, this study contributes baseline evidence to inform irrigation water management, fertilizer regulation, and public health planning in the basin and offers a reference point for comparable highland catchments elsewhere in Cameroon.

METHOD

The Santa Agrarian Basin is located in the north-west region of Cameroon. It is situated between longitudes 9°58' and 10°18' east of the Greenwich Meridian and between latitudes 5°42' and 5°53' north of the equator. The basin is located approximately 20 km south of Bamenda and 60 km north of Bafoussam. It shares borders with Balikumbat and Galim to the east, Batibo and Wabane Sub-Divisions to the southwest, Bali to the west, Bamenda I to the north, Bamenda II to the northwest, and Babadjou and Mbouda to the south (Fig. 1). The basin experiences a Guinea-type climate with annual rainfall ranging from 2,000 to 3,000 mm and temperatures between 15°C and 25°C (Tedontsah at all, 2022).

Figure 1. Location of Santa Agrarian Basin in the North West Region, Cameroon

Source: Geo Database of Cameroon, 2017

Water samples were collected from five communities, comprising 20 sampling points (ten surface water and ten groundwater sources) across the Santa Agrarian Basin. Water samples were collected during the dry (January–March 2024) and rainy (June–August 2024) seasons to capture seasonal variations. Sampling points were strategically selected based on proximity to agricultural fields, the type of water source, and accessibility. At each station, two sets of samples were collected: one for physicochemical analysis and the other for bacteriological analysis. Sterile 1-litre polyethylene bottles were used for physico-chemical samples, and 500-mL sterile glass bottles were used for bacteriological samples. Bottles were pre-rinsed with distilled water and then with the water to be sampled to avoid contamination. After collection, the bottles were tightly capped, labelled with site codes and dates, and stored in an ice-pack cooler at <4°C to preserve sample integrity during transport to the laboratory. A 16-in-1 water test kit was used to measure key parameters, including pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO), and Escherichia coli (E. coli). Physical parameters, such as water temperature and turbidity, were measured in situ. Prior to fieldwork, the test kit was checked against the manufacturer's reference standards, and three replicate readings were taken at each sampling point per season, with the mean of the replicates used for subsequent analysis to minimize instrument drift and improve data reliability.

The data were compared with the FAO irrigation water quality guidelines (FAO, 2020), and spatial analysis was conducted using QGIS and ArcGIS to map water quality variations across the sampling sites.

Statistical Analysis

For each parameter, descriptive statistics (minimum, maximum, and mean) were computed by season to characterize the spatial and temporal variability across the 20 sampling points (Table 1). Values were benchmarked against the corresponding FAO irrigation water quality guidelines for each parameter to assess compliance. Given the sample size per site-season combination, the present

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

analysis is primarily descriptive. Inferential comparisons (e.g., analysis of variance between seasons and sites) are recommended as a priority for future extensions of this dataset once a larger number of replicate samples per site becomes available.

RESULTS AND DISCUSSION

Results

Table 1 summarizes the descriptive statistics (minimum, maximum, and estimated mean) for each physico-chemical and bacteriological parameter by season, benchmarked against the corresponding FAO irrigation water quality guidelines.

Table 1: Seasonal descriptive statistics of physico-chemical and bacteriological parameters, Santa Agrarian Basin (2024)

Table 1 summarises the descriptive statistics (minimum, maximum, and estimated mean) for each physico-chemical and bacteriological parameter by season, benchmarked against the corresponding FAO irrigation water quality guideline.

Table 1: Seasonal descriptive statistics of physico-chemical and bacteriological parameters, Santa Agrarian Basin (2024)

Parameter	Dry season range	Dry season mean*	Rainy season range	Rainy season mean*	FAO guideline
pH	5.20–6.75	5.98	5.64–6.25	5.95	6.0–8.5
DO (mg/L)‡‡	100–150	125.0	100–150	125.0	No standard FAO threshold
EC (mS/cm)†	not reported	–	5.56–8.36	6.96	< 2.0
Fe (mg/L)	5.01–7.18	6.10	2.65–3.42	3.04	< 5.0
Mn (mg/L)	0.265–0.309	0.287	0.200–0.309	0.255	0.2–0.3
NH_4^+ (mg/L)	8.03–10.2	9.12	10.0–16.8	13.40	< 5.0
NO_3^- (mg/L)‡	0.0346–0.0478	0.041	100–150	125.0	< 50
PO_4^{3-} (mg/L)	0.01–0.05	0.03	0.036–0.05§	0.043	< 0.05
Total coliforms (CFU/100 mL)	—	150 (mean, both seasons)	—	—	< 10 (E. coli)
E. coli (CFU/100 mL)	—	25–40 (range, both seasons)	—	—	< 10

**Mean estimated as the midpoint of the reported range. †Electrical conductivity values were recorded in mS/cm; dry-season EC was not consistently captured across sites and should be re-verified against the raw dataset. ‡Dry- and rainy-season nitrate values differ by three orders of magnitude; this discrepancy should be re-checked against the original laboratory records, as it may reflect a unit or transcription error. §Rainy-season phosphate approached, but did not exceed, the FAO threshold. ‡‡Reported dissolved oxygen values (100–150 mg/L) are well above the physically expected saturation range for water (typically <15 mg/L) and should be re-checked, as they may reflect a different unit or measurement scale.*

Dissolved oxygen (DO) is a critical parameter for assessing water quality for crop cultivation, as it reflects the amount of oxygen available in water for biological and chemical processes. Adequate DO levels enhance nutrient uptake and promote root development, which are essential for optimal crop yields (Fig. 2). Both seasons showed DO values spanning approximately 100–150 mg/L across the entire basin (Table 1). In the rainy season, higher DO levels (123–128 mg/L) were observed in Pinyin, supporting root respiration, whereas lower levels (110–115 mg/L) were recorded in communities such as Wonloko and Kwang. During the dry season, the spatial pattern shifted, with some areas maintaining relatively high levels and others experiencing further declines. The consistent presence of high DO around Pinyin highlights its importance for crop vitality throughout the year, whereas lower DO areas, particularly during the dry season, pose challenges for farmers, as reduced oxygen availability can impair nutrient uptake and hinder plant growth. It should be noted that these DO readings are considerably higher than the range typically expected in natural waters (generally below 15 mg/L); this warrants verification against the instrument output and calibration records before the values are treated as final.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

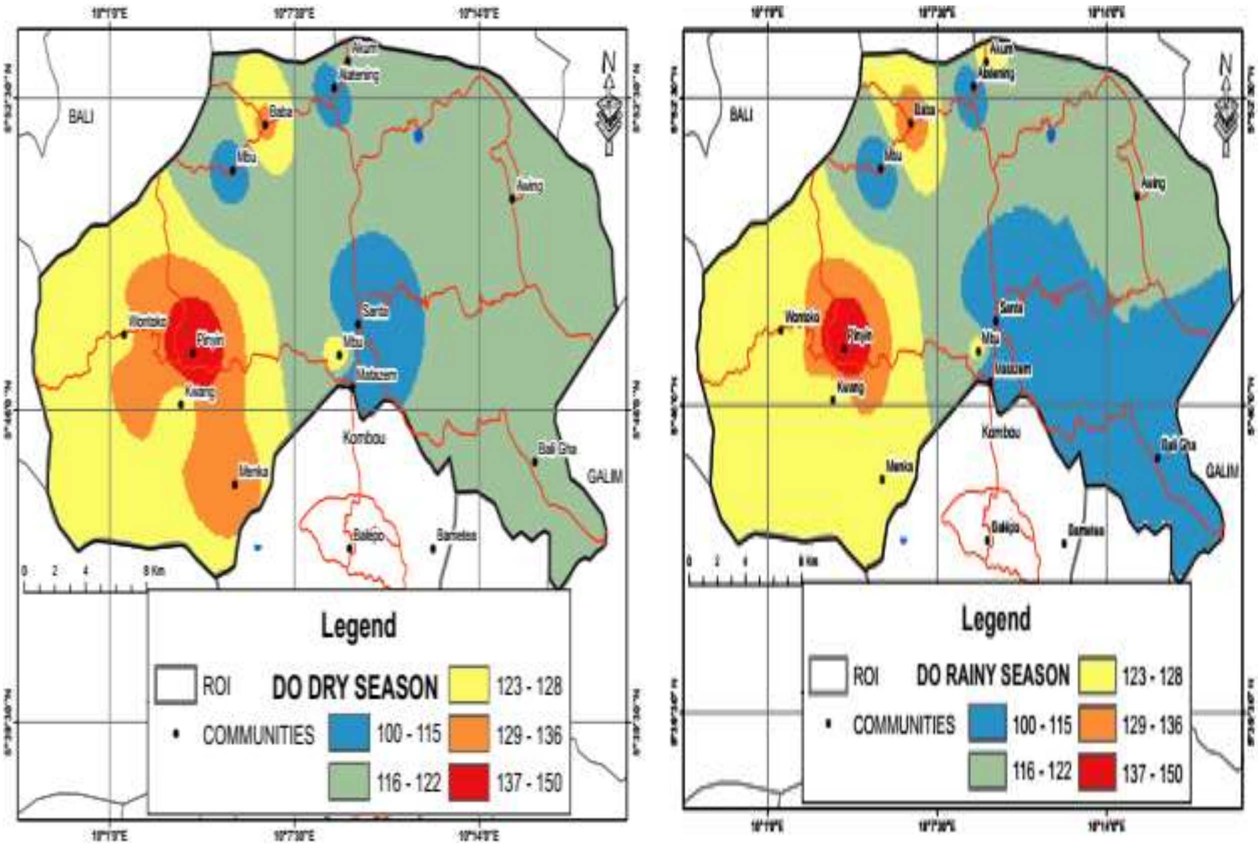

Figure 2A: Dissolved oxygen in dry season

Figure 2B: Dissolved oxygen in rainy season

Figure 2. Dissolved oxygen concentration in water samples

Source: Fieldwork, 2024

Electrical conductivity (EC) also exhibited notable spatial variations. During the rainy season, the values in Baba village ranged from 7.44 to 8.36 mS/cm, exceeding the FAO recommended limit of 2.0 mS/cm for irrigation water. In contrast, lower EC values were recorded in Pinyin, Awing, Wontinko, and Kwang, ranging from 5.56–7.43 mS/cm. The surrounding communities of Akum and Atinge also recorded moderately high EC values. FAO guidelines indicate that excessive salinity, as reflected by a high EC, can degrade water suitability for irrigation by increasing the risk of soil salinization.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

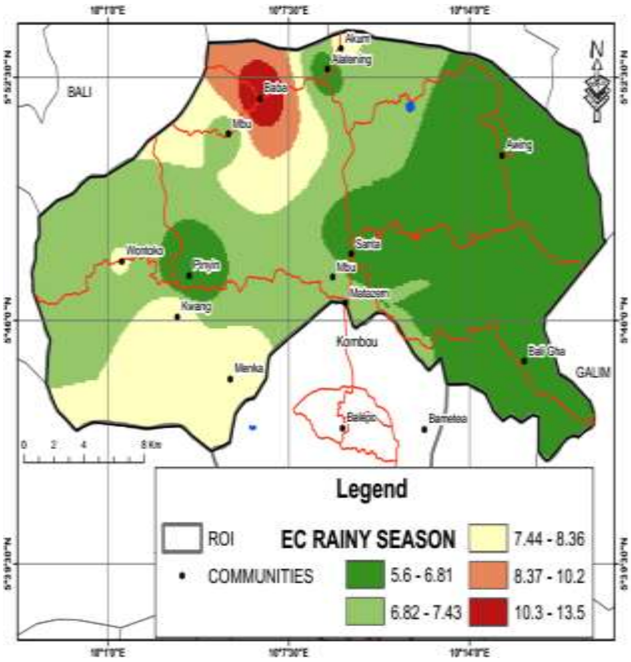

Figure 3A: Electrical conductivity in rainy season water samples

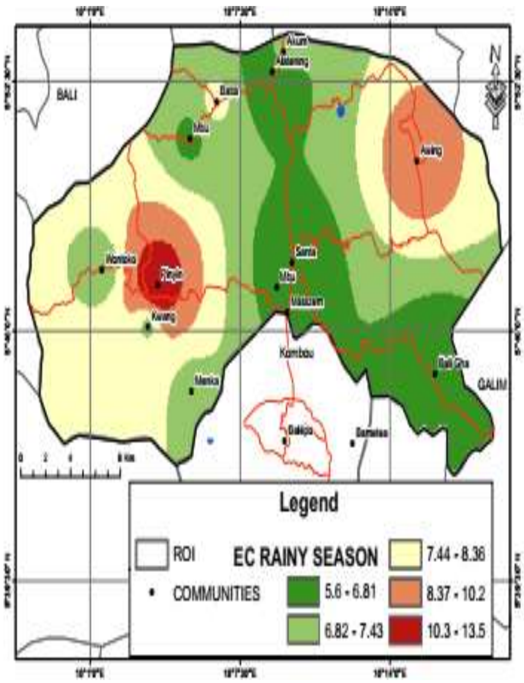

Figure 3B: Electrical conductivity in dry season water samples

Figure 3. Electrical conductivity in water samples

Source: Fieldwork, 2024

Iron is another essential element that significantly influences the water quality for agricultural purposes. Although iron is a naturally occurring mineral found in soil and water, its concentration in irrigation water must be carefully monitored. According to Figure 4, the iron concentrations in the dry season were high across several areas of the Santa Agrarian Basin. The community of Baba showed the highest levels, ranging from 6.72–7.18 mg/L. These values exceeded the FAO-recommended limit of 5 mg/L for irrigation water. Surrounding communities, such as Pinyin and Kwang, also exhibited high levels (5.01–6.71 mg/L), indicating that iron contamination is a widespread issue during the dry season. In the rainy season, iron levels decreased substantially throughout the region, with the highest recorded values dropping to 3.09–3.42 mg/L, primarily around Mbu and Wontinko, reflecting an improvement in water quality attributable to rainfall-induced dilution. However, moderate levels persisted in areas such as Pinyin and Kwang (2.65–2.86 mg/L), indicating that while conditions improve seasonally, some communities continue to face elevated iron concentrations in drinking water.

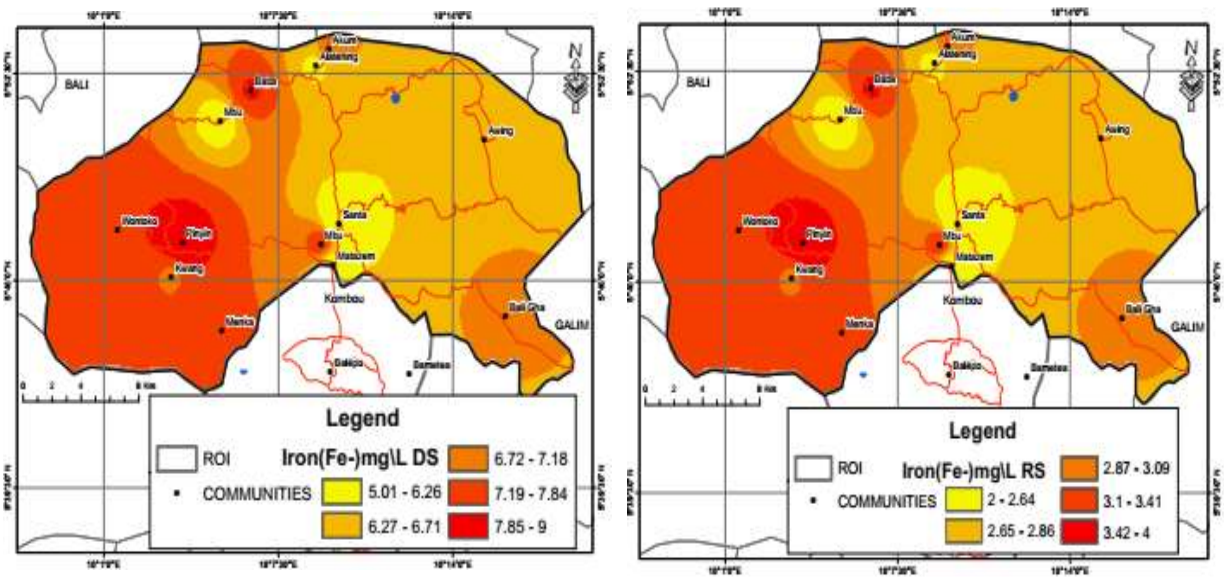

Figure 4A: Iron in dry season water samples

Figure 4B: Iron in rainy season water samples

Figure 4. Iron concentration in water samples

Source: Fieldwork, 2024

Manganese also exhibited significant spatial concentration patterns in the Santa Agrarian Basin. As a naturally occurring element in soil and groundwater, manganese plays a vital role in plant metabolism at low concentrations (Fig. 5); however, high levels can be problematic. In the dry season, Mn levels ranged from 0.265 to 0.309 mg/L, with the highest concentrations occurring around Baba and Pinyin. While these values are within the upper threshold of the FAO range for irrigation (0.2–0.3 mg/L), they still signal potential long-term concerns if levels continue to rise or persist across seasons. During the rainy season, manganese concentrations decreased across most of the basin (0.200–0.264 mg/L), with Mbu and Wontinko showing the lowest levels, indicating a seasonal improvement due to rainfall dilution. However, moderate-to-high levels persisted in Pinyin (0.287–0.309 mg/L). While Mn is an essential micronutrient for plants, excess amounts can lead to toxicity, particularly in poorly drained or acidic soils.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

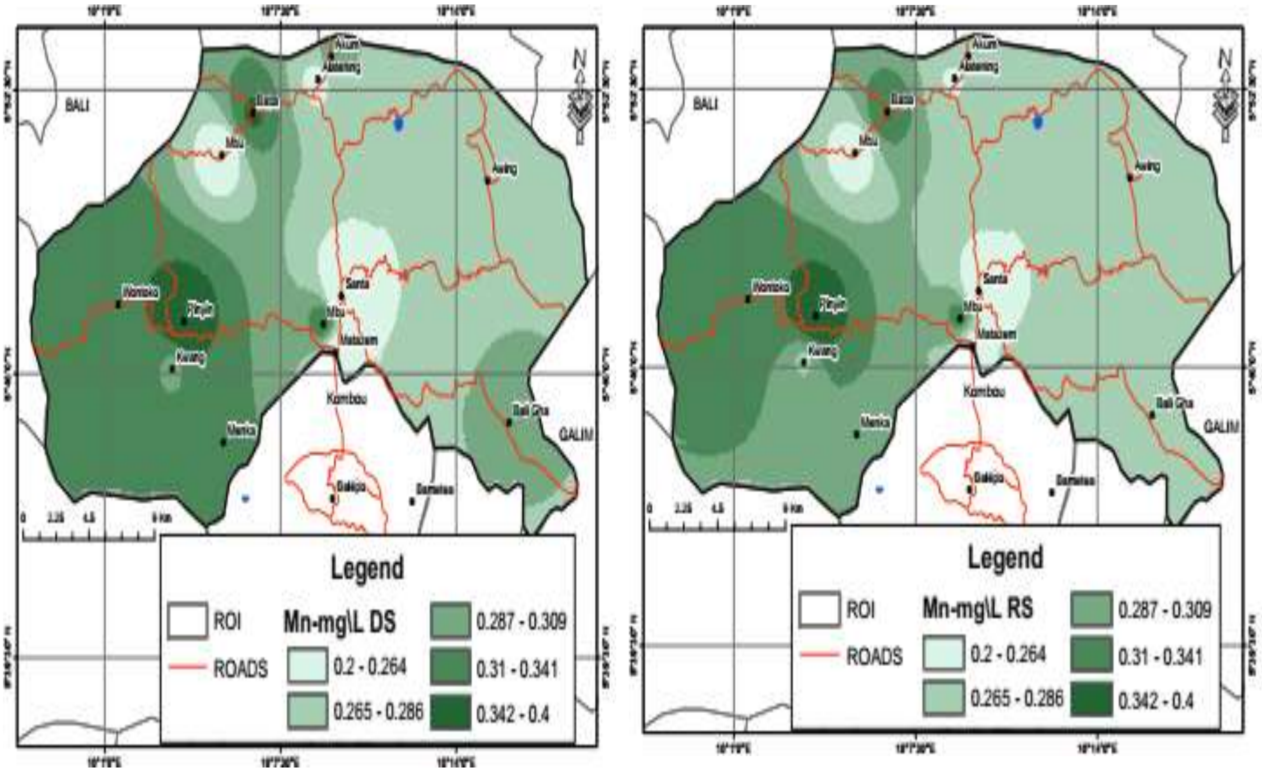

Figure 5A: Manganese concentrations in dry season water samples

Figure 5A: Manganese concentrations in rainy season water samples

Figure 5. Manganese concentrations in water samples
Source: Fieldwork, 2024

Ammonium is also a critical determinant of water quality for agricultural use, particularly in irrigation systems. As a form of nitrogen, ammonium serves as a valuable nutrient for crop growth, contributing to plant protein synthesis and overall productivity. However, the presence of these substances in irrigation water must be carefully regulated. Excessive ammonium concentrations can lead to imbalances in soil nutrient composition, potentially causing toxicity in sensitive crops and altering soil pH. Moreover, high ammonium levels indicate organic pollution or the presence of agricultural runoff, which can further degrade water quality and harm the soil microbial communities (Fig. 6). The FAO recommends that ammonium concentrations in irrigation water remain below 5 mg/L to prevent adverse effects on plant health and soil structure.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

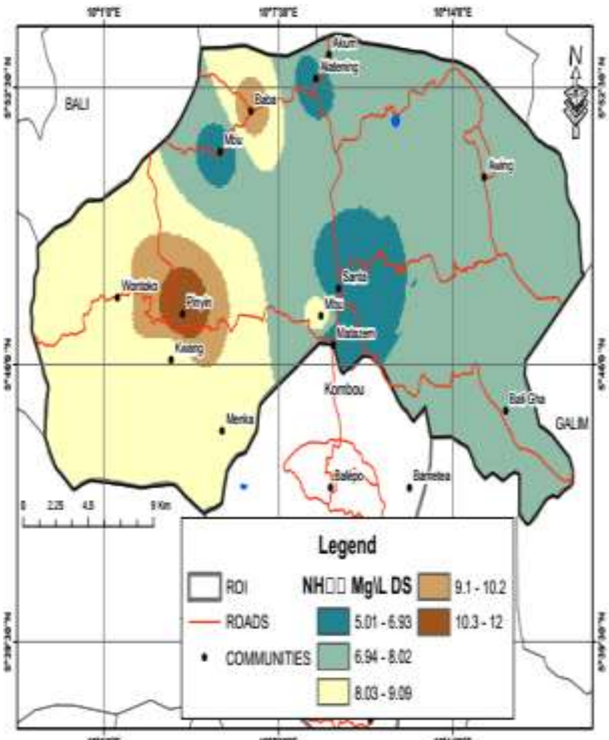

Figure 6A: Ammonium concentrations in dray season water samples

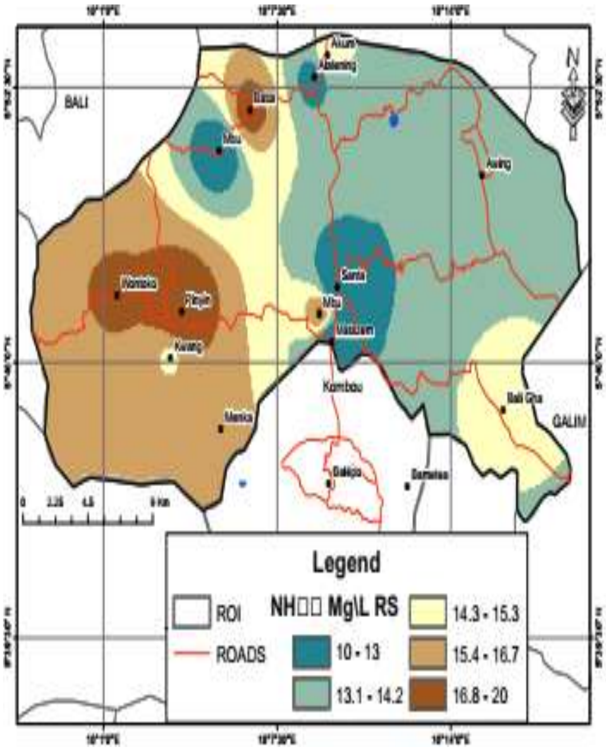

Figure 6B: Ammonium concentrations in rainy season water samples

Figure 6. Ammonium concentration in water samples

Source: Fieldwork, 2024

According to Figure 6, ammonium concentrations in the dry season ranged from 8.03 to 10.2 mg/L, with higher levels around Pinyin and Wontinko. Elevated ammonium levels indicate nutrient pollution, often resulting from agricultural runoff, sewage discharge, or organic matter decomposition. During the rainy season, ammonium levels increased further, ranging from 10.0 to 16.8 mg/L, particularly around Pinyin and Kwang. This increase is attributed to increased runoff during rainfall, which washes more nutrients into water sources. The observed concentrations in both seasons in the Santa Agrarian Basin exceeded the FAO safe threshold of 5 mg/L, highlighting a potential risk to agricultural productivity.

Nitrate is another important parameter for determining the suitability of water for agricultural use (Fig. 7). As the primary form of nitrogen available to plants, nitrate is essential for healthy crop growth and plays a key role in leaf development and yield. However, when present in excessive amounts in irrigation water, nitrates can pose environmental and agronomic challenges, including nutrient imbalances, excessive vegetative growth at the expense of fruit or grain development, and an increased risk of nitrate leaching into groundwater. This not only reduces fertilizer efficiency but can also contribute to water pollution and health risks if it is consumed. According to FAO guidelines, the nitrate levels in irrigation water should not exceed 50 mg/L to avoid harmful effects on crops and the environment.

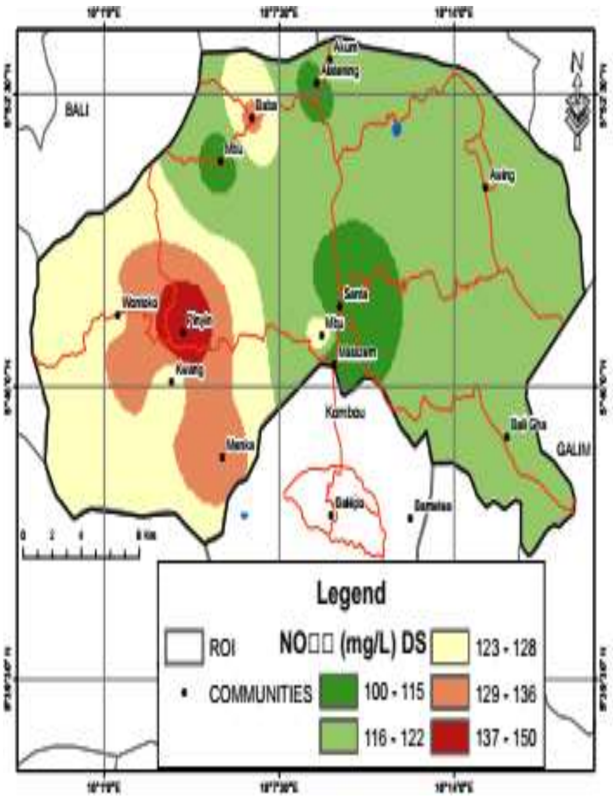

Figure 6A: Nitrates concentrations in dray season water samples

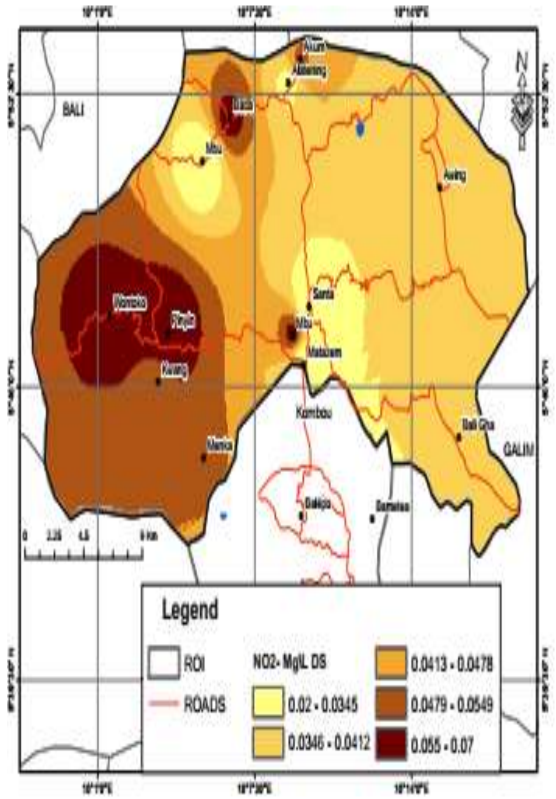

Figure 6A: Nitrates concentrations in rainy season water samples

Figure 7. Nitrate concentration in water samples
Source: Fieldwork, 2024

According to Figure 7, in the dry season, the nitrate concentrations ranged from 0.0346 to 0.0478 mg/L, with higher levels observed around Wontinko and Kwang. Although these levels are comparatively low, they indicate the potential for nutrient loading, which can eventually affect soil quality and crop health. During the rainy season, nitrate levels increased markedly, ranging from 100 to 150 mg/L, particularly around Pinyin and Wontinko, which is attributable to increased runoff carrying fertilizers and organic material into water bodies. This substantial seasonal difference exceeds three orders of magnitude and should be re-verified against the original laboratory data, as it may reflect a transcription or unit error rather than a true seasonal effect. The rainy season values, taken at face value, exceeded the FAO guideline of 50 mg/L, indicating a significant risk to agricultural productivity that warrants confirmation with reanalyzed samples.

pH is a fundamental factor in determining the quality of water for crop cultivation, as it directly influences nutrient availability, soil chemistry and plant health. The pH of irrigation water affects the solubility of essential nutrients; when water is too acidic (low pH) or too alkaline (high pH), certain nutrients become less available to plants or may reach toxic levels. Most crops grow best when irrigation water has a pH between 6.0 and 7.5, allowing for optimal nutrient uptake and microbial activity in the soil. Water with a pH below 6.0 can increase the solubility of toxic elements such as aluminum and manganese, leading to root damage and reduced crop performance, whereas water with a pH above 8.0 may cause deficiencies in iron, zinc, and phosphorus. In the Santa Agrarian Basin, where variability in pH was observed, close monitoring is warranted (Fig. 8).

Figure 8: pH concentrations in water samples
Source: Fieldwork, 2024

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i02.29

As shown in Figure 8, the pH values in the dry season ranged from 5.2 to 6.75, indicating slightly to moderately acidic water conditions. The most acidic zones (pH 5.2–5.63) were located in Awing and Manka, moderately acidic areas (pH 5.64–5.85) included Kwang, and slightly acidic to near-neutral pH levels (6.02–6.25) were recorded in Akum and parts of Mbu.

Phosphate plays a significant role in water quality and has important implications for crop cultivation in the region. As a key component of phosphorus, phosphate is essential for plant processes, such as root development, energy transfer, and flowering. Small amounts of phosphate in irrigation water can enhance crop growth by supplementing soil nutrients; however, excessive phosphate concentrations can lead to nutrient imbalances and environmental concerns. High phosphate levels in irrigation water often result from agricultural runoff, fertilizer leaching, or wastewater discharge, and can contribute to phosphorus buildup in soils (Fig. 9), which may reduce nutrient uptake efficiency and, in extreme cases, promote algal blooms and eutrophication in nearby water bodies. According to FAO guidelines, phosphate concentrations in irrigation water should generally remain below 0.05 mg/L to prevent adverse effects on soil and water quality.

Figure 9: Phosphate concentrations in water samples
Source: Fieldwork, 2024

The analysis of phosphate (PO_4^{3-}) concentrations in water samples from the Santa Agrarian Basin revealed notable seasonal variations. During the dry season, phosphate levels ranged from 0.01 to 0.05 mg/L, with the lowest concentrations (0.01–0.023 mg/L) dominating the central and eastern parts of the basin, including Santa, Awing, and Bali-Gashu, whereas higher concentrations (0.036–0.05 mg/L) were localized in the western community of Wontoku. In the rainy season, a broader distribution of elevated phosphate levels was recorded, particularly in the western part of the basin. Areas such as Wontoku and Mbu experienced phosphate concentrations approaching, but not exceeding, the upper FAO limit of 0.05 mg/L. Compared with the FAO standards for irrigation water, all observed phosphate values fell within the acceptable range.

Bacteriological analysis of irrigation water in the Santa Agrarian Basin revealed moderate levels of microbial presence. Total coliform counts averaged 150 CFU/100 mL, while E. coli levels ranged between 25 and 40 CFU/100 mL, exceeding the FAO recommended threshold of <10 CFU/100 mL for safe irrigation, particularly for crops consumed raw. Despite these elevated figures, no Salmonella or Clostridium perfringens were detected in any of the samples analyzed, suggesting the absence of more severe pathogenic bacteria. However, the detectable levels of E. coli raise public health concerns, especially in relation to the irrigation of leafy vegetables and other raw produce. During focus group discussions with local farmers, some participants reported occasional skin irritation and mild rashes after prolonged exposure to irrigation water, although such cases were not widespread.

Discussion

Physicochemical and bacteriological assessments of water resources in the Santa Agrarian Basin revealed several critical factors influencing their suitability for irrigation and sustainable food crop production. One of the key findings was the acidic pH range (5.2–6.75) recorded during the dry season, with the lowest values concentrated in areas such as Awing. This trend is consistent with observations in other highland regions of Cameroon, where intensive leaching and volcanic soil profiles promote soil and water acidification (Nguetnkam & Bitom, 2020; Tamfuh et al. 2018). The relatively stable rainy season pH (5.64–6.25) in Santa indicates a buffering capacity provided by local soil mineralogy, contrasting with the findings of Tiwari et al. (2019) in parts of sub-Saharan Africa, where pH fluctuates more drastically owing to inconsistent rainfall patterns. Nevertheless, pH values across both seasons remained below the FAO's recommended irrigation range of 6.0–8.5 (FAO, 2020), potentially constraining nutrient uptake and microbial activity, especially for pH-sensitive crops such as groundnuts and leafy greens.

Dissolved oxygen (DO) levels during the rainy season were highest in Pinyin, creating favorable conditions for root respiration and beneficial aerobic soil microorganisms. These findings align with those of Mateo-Sagasta et al. (2017), who emphasized the role of DO in supporting soil biological processes essential for nutrient cycling. In contrast, lower DO levels in zones such as Kwang, and further reductions during the dry season, mirror observations by UNEP (2021) and Mfonka et al. (2026), who noted that water bodies in the Western Highlands of Cameroon often suffer from reduced oxygen levels during dry spells because of organic matter buildup and limited flow. These reductions can impair microbial decomposition and slow nutrient release, thereby affecting crop yields, especially in areas with poor drainage or shallow root systems.

The electrical conductivity (EC) results highlighted emerging salinity concerns. Baba village recorded rainy season values between 7.44 and 8.36 mS/cm, exceeding the FAO threshold of 2.0 mS/cm for safe irrigation (FAO, 2020). This supports the findings of Tedontsah (2022) and Takoutsing et al. (2016), who linked high EC levels in parts of Cameroon's highlands to natural mineralization and fertilizer runoff. Conversely, lower EC values in Pinyin, Kwang, and Awing remained within more acceptable limits, indicating localized hydrochemical differences. The dry-season EC data were not consistently recorded across all sites in the present study, which limits direct seasonal comparison; this gap should be addressed in the raw dataset before final submission, as WWAP (2018) suggests that uniform increases would be expected due to evaporative concentration during the dry season. Such variability likely reflects the differing land-use practices, crop intensities, and aquifer recharge patterns across the basin.

Concerning iron (Fe) concentrations, values reached 6.72–7.18 mg/L in Baba during the dry season, which is above the FAO irrigation limit of 5 mg/L. High iron levels in this region are likely driven by the weathering of iron-rich basaltic rocks, as confirmed by Nguetnkam and Bitom (2020) and Kwekam et al. (2010), who studied iron accumulation in Cameroonian volcanic terrains, and are consistent with the broader hydrogeochemical patterns reported for other Cameroonian highland catchments by Menti et al. (2023). The rainy season showed reduced iron values (3.09–3.42 mg/L) due to dilution, consistent with the observations of Tiwari et al. (2019). However, persistent moderate concentrations in Pinyin and Kwang (2.65–2.86 mg/L) indicate chronic geogenic contamination, posing a long-term risk to irrigation infrastructure and crop health, particularly in soils with low organic matter content levels.

Manganese (Mn) concentrations ranged from 0.265 to 0.309 mg/L in the dry season and were slightly lower during the rainy season (0.200–0.264 mg/L). These values hover near the FAO/WHO safe threshold (0.2–0.3 mg/L) and are consistent with those reported by Tamfuh et al. (2018) and Mateo-Sagasta et al. (2017), who both reported seasonal fluctuations of manganese in agricultural watersheds. The sustained high levels of Pinyin likely result from lithogenic sources and mobilization under acidic conditions, contrasting with the UNEP (2021) assumption that trace metals are diluted uniformly during rainy seasons. If left unmanaged, manganese can accumulate in the soil and interfere with photosynthesis and enzymatic activity (Takoutsing et al., 2019), especially in the sandy soils common in certain parts of the basin.

Ammonium (NH_4^+) concentrations were also high, ranging from 8.03–10.2 mg/L in the dry season to 10.0–16.8 mg/L during the rainy season, far above the FAO limit of 5 mg/L. These results are consistent with those of Fomenky et al. (2019) and Tiwari et al. (2019), who associated ammonium surges in sub-Saharan watersheds with fertilizer overuse, livestock runoff, and poor nutrient management, and align with the elevated nutrient loads reported for irrigation groundwater in comparable West African farming systems by Hammani et al. (2022). This contrasts with WWAP (2018), which reported more stable ammonium levels, suggesting that human activity plays a greater role than previously assumed. Excess ammonium can cause nutrient lockout, reduce phosphorus availability, and lead to soil acidification, emphasizing the need for controlled fertilizer application and buffer zones in runoff-prone areas.

The study also recorded a sharp rise in nitrate (NO_3^-) levels, from 0.0346–0.0478 mg/L in the dry season to 100–150 mg/L in the rainy season. Taken at face value, the rainy season concentrations greatly exceed the FAO threshold of 50 mg/L and would confirm the findings of Nguetnkam and Bitom (2020) and Yengoh et al. (2010), who identified fertilizer-driven nitrate leaching in Cameroon's highland farming systems, and are broadly consistent with the elevated nitrate levels reported by Mufur et al. (2021) for the nearby Mezam River system. However, the three orders of magnitude difference between the two seasons is unusually large and should be re-verified against the original laboratory records before the values are treated as conclusive, since it may reflect a unit or transcription inconsistency rather than a genuine seasonal effect. If confirmed, high nitrate levels would not only threaten groundwater quality but also increase the risk of eutrophication, especially in stagnant irrigation reservoirs. Integrated nutrient management, including cover cropping and soil testing, is recommended to reduce runoff and improve fertilizer efficiency in either case.

Phosphate (PO_4^{3-}) concentrations ranged from 0.01 to 0.05 mg/L, peaking at Wontoku during the rainy season. Although these values remained within the FAO's recommended limits, their proximity to the upper threshold warrants continued monitoring. Similar phosphate accumulation trends were observed by Tedontsah (2022) and Tamfuh et al. (2018) in Western Cameroon, where intensive cultivation and erosion-prone slopes contributed to phosphorus loading in water bodies. Continued accumulation could contribute to algal blooms and sediment binding of phosphorus, reducing its long-term bioavailability to crops.

Finally, the bacteriological analysis showed that 60% of the surface water samples contained fecal coliforms and E. coli, surpassing the FAO safety standards for irrigation, especially for produce consumed raw. Although no Salmonella or Clostridium perfringens were found, the presence of E. coli echoes the public health risks raised by UNEP (2021) and Fomenky et al. (2019) in rural farming areas, where poor sanitation, open defecation, and livestock access to streams remain common. Comparable microbial contamination has also been documented in the Mezam River system near Bamenda (Mufur et al., 2021). Reports from local farmers of occasional skin rashes after irrigation reinforce the call for low-cost water treatment systems, farmer education, and improved sanitation practices to ensure the safe use of irrigation water, especially in vegetable-producing areas.

CONCLUSION

This study assessed the physico-chemical and bacteriological characteristics of irrigation water sources in the Santa Agrarian Basin to determine their suitability for agricultural use. Overall, water quality across the basin remained within acceptable limits for crop production for several key parameters, including pH, iron, and phosphate in the rainy season, when benchmarked against FAO irrigation guidelines. However, electrical conductivity, iron, and manganese exceeded FAO thresholds in specific communities (notably Baba and Pinyin) particularly during the dry season, while ammonium and nitrate concentrations exceeded recommended limits in both seasons, most markedly during the rainy season, indicating localised contamination linked to fertiliser runoff, poor waste disposal practices, and limited buffer zones along stream channels. The bacteriological assessment further revealed fecal coliform and E. coli contamination in 60% of surface water samples, reflecting organic pollution from domestic and animal waste and rendering such water unsuitable for direct use on crops consumed raw without prior treatment. Taken together, these findings point to a basin where irrigation water quality is spatially variable rather than uniformly safe or unsafe, underscoring the need for site-specific water treatment, stricter fertiliser and waste management practices, and continued seasonal monitoring, with re-verification of the dissolved oxygen, electrical conductivity, and nitrate datasets in particular, to safeguard both crop productivity and food safety in the Santa Agrarian Basin.

REFERENCES

FAO. (2020). The state of food and agriculture 2020: Overcoming water challenges in agriculture. Food and Agriculture Organization of the United Nations. https://www.fao.org/publications/sofa/2020/en/

Fomenky, N. N., Tening, A. S., Asongwe, G. A., Mbene, K., & Nka-Folep, F. F. (2019). Seasonal variations of some physico-chemical properties of water sources that feed Rivers Wouri and

Meme of Cameroon. *African Journal of Environmental Science and Technology, 13*(10), 425–438. https://doi.org/10.5897/AJEST2019.2737

Hammani, B., Abubakar, I., Danlami, A., Gimba, A. M., Abdulkadir, M., & Muhammad, Z. (2022). Assessment of physicochemical properties of groundwater for irrigation purposes from Difa, Dadinkowa and Gwani communities of Yamaltu-Deba Local Government Area of Gombe State, Nigeria. Journal of Applied Sciences and Environmental Management, 26(10), 1693–1699. https://doi.org/10.4314/jasem.v26i10.4

Kwekam, M., Liégeois, J.-P., & Njonfang, E. (2010). Geochemical and isotopic evidence for the origin of iron-rich basaltic rocks in Cameroon. Journal of African Earth Sciences, 58(4), 567–578. https://doi.org/10.1016/j.jafrearsci.2010.04.002

Magha, A., Awah, M. T., Kouankap Nono, G. D., Tamfuh, P. A., Wotchoko, P., Adoh, M., & Kabeyene, V. B. K. (2021). Assessment of groundwater quality for domestic and irrigation purposes in Northern Bamenda (Cameroon). Journal of Water Resource and Protection, 13(1), 1–19. https://doi.org/10.4236/jwarp.2021.131001

Mateo-Sagasta, J., Zadeh, S. M., & Turral, H. (2017). Water pollution from agriculture: A global review. FAO Water Reports, 106. Food and Agriculture Organization of the United Nations.

Menti, A. N., Wotany, E. R., Christopher, A., Wirmvem, M. J., & Ngai, N. J. (2023). Hydrogeochemical characterization of ground and surface water in the eastern part of the Adamawa-Yade domain, Bertoua-Cameroon. Discover Water, 3, Article 10. https://doi.org/10.1007/s43832-023-00034-0

Mfonka, Z., Nap Njiemessa, F. N., Nsangou, D., Kouassy Kaledje, P. S., Kpoumie, A., Emvoutou, H. C., Nlend, B. I., Nkoue Ndondo, R. G., Ngo Boum Nkot, S., Mvondo Owono, F., Etame, J., Ndjigui, P. D., & Ndam Ngoupayou, J. R. (2026). Water supply and spring discharges assessment in the Foumban locality, Western Highlands of Cameroon. *Hydrology*, *14*(2), 22–36. https://doi.org/10.11648/j.hyd.20261402.11

Mufur, A. M., Awah, M. T., Kouankap Nono, G. D., Tamfuh, P. A., Wotchoko, P., & Kamgang Kabeyene, V. B. (2021). Physico-chemical and bacteriological characterisation of surface water in Bamenda (North West Cameroon). Applied Water Science, 11, Article 189. https://doi.org/10.1007/s13201-021-01512-3

Tedontsah, V. P. L., Mbog, M. B., Ngon Ngon, G. F., Edzoa, R. C., Tassongwa, B., Bitom, D., & Etame, J. (2022). Physicochemical properties and fertility assessment of soils in Foumban (West Cameroon). *Applied and Environmental Soil Science, 2022*. https://doi.org/10.1155/2022/7889430

Nguetnkam, J. P., & Bitom, D. L. (2020). Hydrogeochemical characterization of groundwater in the highlands of Cameroon. Journal of African Earth Sciences, 162, 103710. https://doi.org/10.1016/j.jafrearsci.2019.103710

Takoutsing, B., Weber, J., Aynekulu, E., Rodríguez Martín, J. A., Shepherd, K., Sila, A., Tchoundjeu, Z., & Diby, L. (2016). Assessment of soil health indicators for sustainable production of maize in smallholder farming systems in the highlands of Cameroon. Geoderma, 276, 64–73. DOI: https://doi.org/10.1016/j.geoderma.2016.04.027

Tamfuh, P. A., Temgoua, E., Wotchoko, P., Boukong, A., & Bitom, D. (2018). Soil properties and land capability evaluation in a mountainous ecosystem of North-West Cameroon. *Journal of Geoscience and Environment Protection*, *6*(7), 15–33. https://doi.org/10.4236/gep.2018.67002

Tiwari, A., Singh, A. K., & Mahato, M. K. (2019). Assessment of groundwater quality and its suitability for irrigation in parts of sub-Saharan Africa. Environmental Monitoring and Assessment, 191(8), 489. https://doi.org/10.1007/s10661-019-7660-2

UNEP. (2021). Africa water vision 2025: Equitable and sustainable use of water for socioeconomic development. United Nations Environment Programme. https://www.unep.org/resources/report/africa-water-vision-2025

WWAP (World Water Assessment Programme). (2018). The United Nations world water development report 2018: Nature-based solutions for water. United Nations Educational, Scientific and Cultural Organization. https://www.unesco.org/reports/wwdr/2018/en

Yengoh, G. T., Ardö, J., & Boon, E. (2010). Fertilizer use and nitrate leaching in highland farming systems of Cameroon. Agriculture, Ecosystems & Environment, 139(1-2), 150–159. https://doi.org/10.1016/j.agee.2010.08.002