

Research Article

Urban Development Implications on Water Quality in Bamenda City, Cameroon

Nfor Constance Kinyui¹, Mary Lum Fonteh Niba^{2,*}, Fombe Lawrence Fon³

¹Department of Geography and Planning, Faculty of Arts, The University of Bamenda, Bambili, Cameroon

²Department of Geography, Higher Teacher Training College, The University of Bamenda, Bambili, Cameroon

³Higher Institute of Transport and Logistics, The University of Bamenda, Bambili, Cameroon

Abstract

Urban development across the world significantly alters potable water quality. Urban wastes pose a pollution threat to water quality and supply. In Bamenda City, there is increasing alterations of water sources by pollution with inadequate capacity to manage the increasing demand for quality potable water. Large amounts of wastes are dumped in nearby drains and stream channels. This article aims to examine the implications of urban development on water quality, anchored on the premise that urban development significantly affects water quality in Bamenda City. A sample of 300 questionnaires were administered, complemented by field observations and secondary data sources. Water Laboratory Tests to determine biological parameters, Inorganic chemicals: Calcium, sodium, magnesium, sulfate, bicarbonate, nitrites, nitrates, phosphate and Heavy metals: lead, arsenic, cadmium, chromium, Mercury, copper, zinc, iron, aluminium based on WHO standards were done. Findings revealed Organoleptic properties for boreholes and well water were at acceptable limits and poses no danger. Physiochemical properties have pH values within the WHO acceptable limit (6.5-8.5), but higher in wet season (7.6) with concentrations of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NO_3^- , Cl^- , and NH_4^+ above the acceptable levels especially in wells, and streams. Probable number of bacteria per 100ml for the water ranged from 3-1100+, which is not at an acceptable standard due to urban pollution. Specific bacteria identified included *Enterobacteria spp*, *E. coli*, *Streptococcus spp*, *Salmonella spp*, *Shigella spp*, *Staphylococcus spp* and *Vibrio spp*. This shows a strong relationship between urban development and potable water supply. Water quality increases with improvement in urban development planning especially as urban potable water is a major resource for urban health care and sanitation. Planned urban development can ensure sustainable water quality supply in urbanising communities.

Keywords

Impact, Management, Urban Development, Water Quality, Water Sources

1. Introduction

Urban development across the world has significantly altered the quantity and quality of potable water resources. The disposal of solid wastes in dumps and sanitary landfills in

urban areas pose pollution threats to ground and surface water quality [1]. Leaching through the wastes contaminates potable water and reduces water quality [2]. Urban development ac-

*Corresponding author: mariefontehriba3@gmail.com (Mary Lum Fonteh Niba)

Received: 2 October 2025; Accepted: 22 October 2025; Published: 22 November 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

tivities generate large quantities of waste water that reduces potable water quality. Considering that waste treatment in developing countries is inadequate, waste disposal in urban areas constitute significant negative impacts across a range of aquatic ecosystems. Seasonal flooding in the phase of urban development especially in coastal towns and cities may intensify the effect as waste water mixes with storm water [3]. Urban areas with different environmental, social, and economic situations offers threats to urban water such as water scarcity, decreasing water quantity and pollution, water overuse and associated salt-water intrusion in addition to infrastructural, institutional, and social problems could be prevalent. As cities grow, the rate of increase in water consumption quickly outpaces population growth as seen between 1900 and 1995, where global water consumption grew more than two times the rate of population growth [4].

Urban development planning in developed countries affects the management of water quality. The impact is based on wastewater regulation which is complicated by overlapping lines of authority between health, agriculture, water supply, integrated urban water management and water sanitation practices [5]. Based on these dimensions' urban water management should ensure access to quality water and sanitation infrastructure and services. This is linked to the management of aspects that affect water quality including rainwater, wastewater, storm water drainage, runoff, waterborne diseases and epidemics, reducing the risk of water-related hazards including floods, droughts, and landslides [6, 7]. This is apparent in Asian cities which have faced serious challenges in water quality management practices. There have been gaps between urban water quality demand and supply of 6 billion m³ per year (16 million m³/day). Municipal solid waste increasingly contributes to water pollution, with growing purchasing power and broadening consumption options. These intensified the incremental volume of solid waste generation that reduces water quality [8]. Estimates indicate that municipal waste generation in China grew from 195 million tons in 2005 to 306 million tons in the year 2015 [9]. This affected water quality in 53% of monitored sections of the seven key river systems. The impact on water quality conditions was glaring with 63% of the monitored stretches of the Yellow River having poor water quality. Water pollution was responsible for 60% of the Huai River system, 75% of the Hai River, and 69% of the eastern section of the North-South Water diversion system. Every city in China has varying levels of low water quality; with no city having facilities that treat water that can be sufficiently consumed directly by the urban population [10].

The rapid wave of urbanization in African countries creates unprecedented challenges to the provision of water quality and sanitation. Lack of safe drinking water results in fecal-oral diseases such as diarrhea and outbreaks of malaria and cholera [4]. Pathogens in urban potable water is responsible for diarrheal occurrence. About 50% of drinking water lost is due to insufficient, outdated infrastructure and illegal

connections. Only 50% of households have access to piped drinking water in Sub-Saharan Africa [5]. Stakeholders' implication in urban water quality management in Cameroon is a collective efforts of the Ministry of Energy and Water Resources, Ministry of Public Health, Ministry of Housing and Urban Development in collaboration with non-state institutions [11]. In Bamenda City, there exists inadequate capacity to manage the increasing demand for quality potable water. Large amounts of wastes are dumped in nearby drains, river channels, catchment areas and watersheds. Regulated landfill sites do not exist and untreated solid waste is disposed of at open dump sites even on water sheds are used especially at upstream areas. This has resulted in water flows that convey greater amounts of pollutants which reduce water quality in the mid and downstream [10]. Given the pressure on the potable water resource, existing supplies are becoming more insufficient. Service providers lose large volumes of water to leaks in the distribution system. Water scarcity especially in the dry season have caused many homes to dig wells and boreholes for domestic use without proper testing leading to poor water quality that limits the volume of water available for specific uses. All these constitute research gaps as focus was on the management of water quantity, neglecting the impact of urban development on water quality [5, 7]. The rationale of this study was to determine the implication of urban development on the management of water quality. Specifically, the study focused on the effects of urban development-relations with organoleptic, physicochemical, and bacteriological properties from water sources which anchored on the premise that urban development significantly affects water quality in Bamenda City.

2. Study Area and Methods

The study area is delimited to the City of Bamenda made up of three Municipalities (Bamenda I, II and III). This covers the urban landscape of Bamenda in Mezam Division of the North West Region of Cameroon located between Latitude 5o56 and 5o58 North of the Equator and Longitude 10o09 and 10o11 East of the Greenwich Meridian and situated at elevation 1258m above sea level [12]. It is segmented into two major areas: the upland area above the Bamenda escarpment along the Mendankwe-Nkwen axis and the lowland area below the Bamenda escarpment called 'Down town' found along the Mankon-Nkwen axis and the Nkwen-Mankon-Nsongwa-Alabukam Axis. The climate is tropical marked by a strong seasonality with a mean annual rainfall of about 2000mm and temperature ranging from 21oC-25oC [12]. At a growth rate of 2.5%, the urban population of Bamenda City was projected in 2024 to be 1279904 inhabitants. Using a survey and correlational research designs, a sample of 300 questionnaires were administered to the target population. This data was complemented by field observations and secondary data sources. Water Laboratory Tests were analysed at the Research Unit of Animal Physi-

ology and Microbiology and the Research Unit of Soil Analysis and Environmental Chemistry of the University of Dschang to determined micro-organisms and Inorganic chemicals: Calcium, sodium, magnesium, sulfate, bicarbonate, nitrites, nitrates, phosphate etc as well as Heavy metals: lead, arsenic, cadmium, chromium, Mercury, copper, zinc, iron, aluminium based on WHO standards. Private water sources were mostly tested because, many homes depend on wells, streams and boreholes since government agencies do not

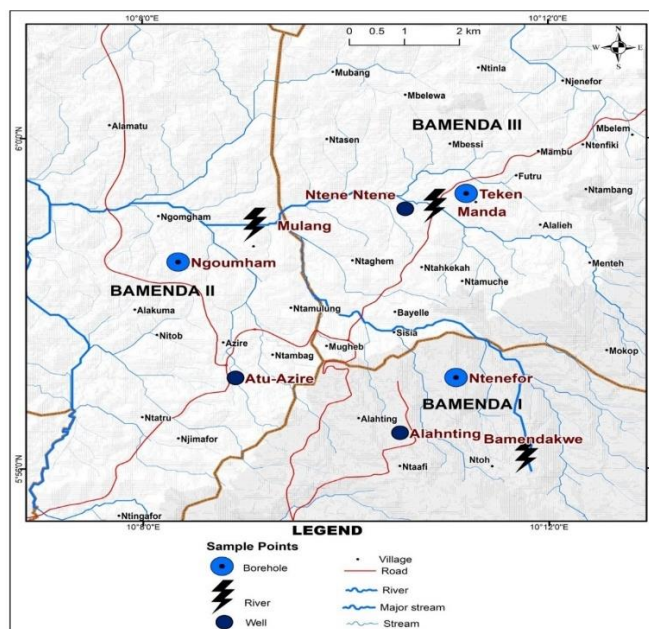
monitor or regulate water quality in private water sources such as wells, streams and boreholes which many homes depend on due to water scarcity.

A total of Nine (09) water samples were collected from three (03) sampling points in streams, boreholes and hand dug wells in Bamendankwe of Bamenda I, Ngomgham Bamenda II and Teken in Bamenda III Municipalities within the 2023 (wet season samples) and 2024 (dry season samples) (Table 1 and Figure 1).

Table 1. Water sampling points from streams, wells and boreholes in Bamenda City.

Bamenda I			Bamenda II		Bamenda III	
	Sample points	Coordinates	Sample points	Coordinates	Sample points	Coordinates
Streams	Bamendankwe	5.9355024 ⁰ N 10.1957161 ⁰ E	Mulang	5.9543391 ⁰ N 10.1808976 ⁰ E	Manda	5.9862632 ⁰ N 10.1813565 ⁰ E
Wells	Alahnting	5.937161 ⁰ N 10.1764537 ⁰ E	Atu-Aziri	5.9556443 ⁰ N 10.1456427 ⁰ E	Ntenetene	5.9857020 ⁰ N 10.1764547 ⁰ E
Boreholes	Ntenefor	5.937123 ⁰ N 10.1764653 ⁰ E	Ngomgham	5.9318284 ⁰ N 10.1755698 ⁰ E	Teken	5.973769 ⁰ N 10.1873102 ⁰ E

Source: Field work (2024)



Source: Field work 2024

Figure 1. Location of water sampling points for laboratory analysis.

For streams, two (02) water samples were collected at each sampling point in clean and labelled polyethylene containers of 500 mL capacity each. The containers and caps

were thoroughly rinsed with water to be sampled before collection. Collections were done very early in the morning before sunrise and the samples packaged in a cooler contain-

ing ice in order to maintain the temperature closed to 4°C to minimize physicochemical changes [13, 14]. The samples were finally transported to the Research Unit of Animal Physiology and Microbiology and the Research Unit of Soil Analysis and Environmental Chemistry of the University of Dschang for preservation and analyses.

Water samples for wells were collected in sterile bottles tied with a strong string to a piece of metal (about 400-500g) as the weight. The bottle cap was aseptically removed and the weighed bottle lowered into the well to a depth of about 1-2 meters. The bottle was brought up to the surface and covered with a screw cap when no air bubbles were seen inside. For the streams, water was allowed to flow into clean bottles continuously until they were full. The water was immediately transported in an ice container at 4°C to the laboratory for analysis. Water analysis was done following standard methods using the multiple tube fermentation technique. The multiple tubes fermentation technique or Most Probable Number (MPN) technique was used for the presumptive determination of total coliforms and the standard count plate technique was used for the determination of specific bacteria (Total faecal Coliform, Salmonella, Escherichia coli, Streptococcus spp, Staphylococcus spp, Shigella spp, Vibrio spp and Enterobacteria)

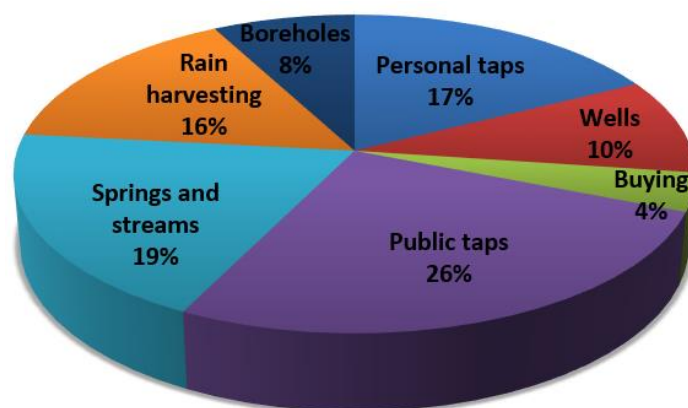
Organoleptic parameters were determined using the human senses. The appearance of the samples was determined by observing with the eyes. The characteristics of interest in-

cluded the perceptible colour of the water, state of floating of the particles and speed of flow. Odour was described by making use of the sense of smell either as being offensive or smelling. The pH was measured electrochemically using a pH meter. Water turbidity was measured using a turbid meter (DRT, 100B, MF scientific, Inc.) by allowing a beam of light to be projected towards the tube in which the samples were contained. Turbidity was measured in Nephelometric Turbidity Units (NTU). Electrical conductivity was measured using a conducti meter and recorded in $\mu\text{S}/\text{cm}$. Chloride content was measured using argentometric method (silver nitrate titration). Nitrate and ammonium were determined by Kjeldahl's distillation method. Phosphates were determined by UV-visible spectrophotometric analysis. Bicarbonates were determined by acid-base titration and sulphates by gravimetric analysis. Calcium and Magnesium ions were determined by complexometric titration. Iron, lead, zinc and aluminium were determined by colorimetry.

3. Results and Discussions

3.1. Sources of Water in Bamenda City

There are diverse sources of water utilised by the population in the municipalities of Bamenda City (Figure 2).



Source: Fieldwork (2024)

Figure 2. Sources of water in Bamenda City.

A quarter of the population collect water from public taps (26 %). This is based on the incomes levels of the population which are low to install their personal home taps from CAMWATER (Cameroon Water Utilities Corporation), Council water supplies and community water schemes. This explains why 26% of the population in the municipalities still depend on community public taps. The public taps are provided by the state, council and NGOs (Non-Governmental Organisations) to the population in neighborhoods. There are

also cases where private individuals also provide stand pipes where the population can carry water for little or no pay. This explains why personal taps constitute 17% of the sources of water in Bamenda City. Another major source of water was from streams and springs (19%). This is common in peri-urban areas where the sources of natural water are still less polluted [14]. In the urban core, streams and springs are of poor quality and are less utilized for household consumption. These sources are used for industrial, agricultural and other

urban activities not linked to house consumption. Closely related to this natural water source is rain water harvesting (16%). This is very common in the rainy season in the city whereby the population device diverse ways in the harvesting and storing of rain water for household consumption [3].

3.2. Analysis of Water Quality in Bamenda City

The laboratory analysis to determine water supply management in terms of quality in Bamenda city included different parameters such as organoleptic, physiochemical and bacteriological properties of water. Water sample for labora-

tory test were taken from streams, wells and boreholes from different sampling points

3.2.1. Organoleptic Parameters of the Water Samples

Organoleptic parameters were examined for streams, boreholes and hand dug wells and results showed that the water sample from the boreholes and wells were clear, colourless, and odourless (Table 2).

Table 2. Organoleptic water properties for boreholes, stream and wells in Bamenda City.

Organo-leptic	Bamenda I			Bamenda II			Bamenda III			WHO Standard
	Bore-holes	Stream	wells	Bore-holes	Stream	Wells	Bore-holes	Stream	wells	
Appearance	Clear	Clear	Clear	Clear	Contains debris	Clear	Clear	Contains Debris	Clear	Clear
Colour	Colorless	Colorless	Colorless	Colorless	Brownish	Colorless	Colorless	Brownish	Colorless	Colorless
Odour	odorless	odorless	odorless	odorless	Perceived odor	Odorless	odorless	Perceived odor	Odorless	odorless

Source: Filed work (2024)

Ideally, safe drinking water should be clean and clear, as well as colourless and odourless. Colour, odour and taste in drinking water are generally indicators of contaminants [13]. Thus the organoleptic properties for boreholes and well water samples are within World Health Organization (WHO) acceptable limits and poses no danger if consumed in all the quarters across Bamenda City. Results of the organoleptic parameters of stream water sample was brownish with tiny debris and had a perceptible odour. This could be due to run-off of wastewater from the dumpsite into the river. The presence of debris in all stream sampled waters could be justified by the fact that the river is exposed to dust particles in

the dry season and exposed to floods in the rainy season. Thus, the water samples do not align with WHO standards for domestic water as far as organoleptic parameters are concerned and therefore require treatment before use. The Organoleptic analysis had variations in the different months of the year.

3.2.2. Physiochemical Properties of Sampled Water Points in Bamenda City

Spatial variations of different physiochemical properties in water samples from different municipalities for boreholes are shown on Table 3.

Table 3. Variations in different physiochemical properties in boreholes.

Water parameter	Bamenda I	Bamenda II	Bamenda III	WHO Acceptable Limits (2022)
Field Temperature (°C)	21.5	24.5	22.5	15 – 25
Turbidity (NTU)	0.4	0.59	5.0	≤ 5.0
Ph	6.60	6.50	6.50	6.5 - 8.5
Electrical conductivity, EC (µS/cm)	0.08	1.17	0.04	2.00

Water parameter	Bamenda I	Bamenda II	Bamenda III	WHO Acceptable Limits (2022)
Total Dissolved Solutes, TDS (mg/L)	40.0	50.0	20.0	600
Sodium ion, Na ⁺ (mg/L)	0.01	11.24	0.06	200
Potassium ion, K ⁺ (mg/L)	6.18	5.80	1.78	200
Calcium ion, Ca ²⁺ (mg/L)	18.40	24.60	9.60	75
Magnesium ion, Mg ²⁺ (mg/L)	2.55	10.80	2.31	30
Phosphate ion, PO ₄ ³⁻ (mg/L)	0.34	2.42	0.71	< 5
Ammonium nitrogen, NH ₄ ⁺ -N (mg/L)	0.10	30.80	0.30	30
Nitrate nitrogen, NO ₃ ⁻ -N (mg/L)	5.55	8.33	12.45	45
Hydrogen carbonate, HCO ₃ ⁻ (mg/L)	115.90	235.50	103.70	1000
Sulphate, SO ₄ ²⁻ (mg/L)	ND	15.35	ND	250
Chloride, Cl ⁻ (mg/L)	ND	75.45	ND	250
**Cadmium, Cd (mg/L)	ND	0.001	ND	0.003
Chromium, Cr (mg/L)	ND	0.04	ND	0.05
**Lead, Pb (mg/L)	ND	0.01	ND	0.01
**Mercury, Hg (mg/L)	ND	0.001	ND	0.01
**Arsenic, As (mg/L)	ND	ND	ND	0.01
Iron, Fe (mg/L)	0.03	0.29	0.15	0.30
Manganese, Mn (mg/L)	0.05	0.05	0.01	0.08
Nickel, Ni (mg/L)	ND	0.03	ND	0.07
Copper, Cu (mg/L)	0.60	0.71	0.78	2.00
Zinc, Zn (mg/L)	0.80	0.98	0.85	3.00

Source: Filed work (2024). ND= Not detectable

The pH values fell within the WHO acceptable limit (6.5-8.5), implying that there was no case of acidity or alkalinity in the water which could be accompanied by adverse consequences. The water temperature across board was also good as it fell within WHO acceptable limits. The mineralization of water is dominated by eight major ions namely: calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate and bicarbonate. All these ions are within WHO acceptable limits. The concentration of heavy metals fell below WHO acceptable limits in the water sample and this renders the water non-toxic. Most of the heavy metals were below detection limits by the instruments used implying that they may be completely absent in the water sample. Results of physicochemical analysis shows that the water properties fall within WHO acceptable limits for potable water and thus the

water is fit for consumption as far as physicochemical properties are concerned. Similar findings were resonated in the work of [15].

The pH values of water samples in the wet season were significantly higher than those in the dry season, with the highest value of 7.6 registered for various samples. Increase in pH could be due to the rains resulting in the dissolution of carbon dioxide to yield carbonic acid as shown by equation 1.

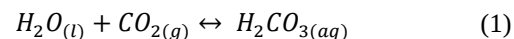


Table 4 presents the spatio-temporal variations in physicochemical properties of stream water samples across the City of Bamenda.

Table 4. Physicochemical parameters from stream water samples in Bamenda city.

Parameter	Rainy season			Dry season		
	Bamenda I	Bamenda II	Bamenda III	Bamenda I	Bamenda II	Bamenda III
Ph	7.6	7.6	7.1	6.9	6.9	7.6
Turbidity (NTU)	1.9	8.2	1.8	2.1	10.8	3.5
EC (mS/cm)	0.02	0.2	0.02	0.09	0.41	0.10
Ca ²⁺ (mg/L)	17.20	18.10	17.20	21.03	19.32	23.54
Mg ²⁺ (mg/L)	1.94	3.41	2.43	10.12	5.68	7.82
K ⁺ (mg/L)	2.77	2.56	2.30	1.78	2.78	2.11
Na ⁺ (mg/L)	0.08	1.00	0.08	1.02	1.83	1.92
HCO ₃ ⁻ (mg/L)	54.90	45.89	42.70	57.16	56.79	56.81
NO ₃ ⁻ (mg/L)	28.56	33.76	149.91	16.17	74.43	43.23
NH ₄ ⁺ (mg/L)	3.49	5.12	4.41	3.14	5.63	2.44
Cl ⁻ (mg/L)	8.40	96.72	11.95	7.15	116.22	14.82
Total iron (mg/L)	0.10	0.21	0.10	0.20	0.34	0.00
SO ₄ ²⁻ (mg/L)	590.40	725.42	656.00	361.12	433.23	246.89
PO ₄ ³⁻ (mg/L)	0.00	0.00	0.00	0.03	0.00	0.00

Source: Field work (2024); EC = Electrical conductivity

Acidic pH could equally be explained by the fact that leaching washes acidic cations H⁺ and Al³⁺ from the soil into the river source [13]. However, all the pH values fell within the range of 6.5–8.6.

The turbidity values ranged from 1.8 to 8.2 NTU in the wet season and from 2.1 to 10.8 NTU in the dry season. Turbidity values were within the limit prescribed by WHO (<5 NTU), except for the water samples of Bamenda II which had highest values in both seasons, with a maximum value of 10.8 NTU. High turbidity values in the Bamenda II samples could be attributed to the presence of organic matter and high suspended particles. This is because high turbidity results from construction and development activities, urban runoff, waste water discharge, agricultural practices etc. Such high values may indicate the presence of particles and dirt that contaminate potable water in the area. The slight increase in turbidity of samples in Bamenda II and III compared to Bamenda I, could be due to possible contamination from waste. The turbidity values were higher in the dry season than in the wet season.

The values of the electrical conductivity of the various stream water samples were higher in the dry season than in the wet season, which could be due to the higher concentration of ions in the dry season, as the volume of water drops. These results are similar to findings which explained that there are variations in the degree of concentration of ions in different seasons [16]. The level of dissolved salts in the samples was

low and hence does not present any risk of contamination.

The concentrations of Na⁺ and K⁺ in the three municipalities dropped from wet season to dry season. This could be as a result of the dilution factor associated with the rains. Also, the concentrations of sodium and potassium were higher in the samples downstream than upstream probably due to an inflow of the ions through the waste found at downstream. However, all the values obtained were far below the WHO and ANOR limits of 200 mg/L and 20 mg/L for Na⁺ and K⁺ respectively. Sodium which exists as Na⁺ ion is very low probably due to low NaCl as well as low sodium and aluminium silicates. Sodium in water generally results from the leaching of geological formations containing sodium chloride as well as rock salt decomposition like sodium and aluminium silicates. Low K⁺ ion concentration may be due to its low geochemical mobility.

Ca²⁺ and Mg²⁺ ions which are responsible for water hardness showed an increase in the concentrations of both ions in moving from the rainy to the dry season. Higher concentrations in the dry season may be due to the higher temperature, which increases concentration of salts by excessive evaporation. Depletion of hardness in rainy season may be due to the dilution by rainwater. The increase in hardness can be attributed to the decrease in water volume and increase in the rate of evaporation at high temperature, high loading organic substances, detergent, chloride, and other pollutants. The concentration of both ions was however lower than the WHO

guideline values of 75 and 50 mg/L for Ca^{2+} and Mg^{2+} respectively [17]. Hard water is good for drinking and cooking but not good for laundry, bathing and for use in the laboratory.

NH_4^+ found in the water sources was surely from biological breakdown of domestic and agricultural wastes and its presence was thus an indicator of bacterial, sewage, and animal wastes contaminations. However, its low concentrations, with significant differences in seasons below the permissible limit of 30 mg/L as prescribed by the WHO and ANOR, showed no associated health risk. The Cl^- was probably obtained from the dissolution of rocks. The lowest value of Cl^- (8.4 mg/L) was recorded in the water sample of Bamenda 1 and the highest (116.22 mg/L) recorded for in the dry season. The moderately high chloride concentrations in the downstream sample were possibly due to contamination from the waste leachates. Seasonal changes influenced the concentration of Cl^- in the

samples as the concentrations were higher in the dry season than in the wet season. This could be due to high dilution of the chloride because of high rainfall in the wet season. According to WHO and ANOR standards, concentration of chloride should not exceed 250 mg/L. The Cl^- concentration were thus within the permissible limit set by WHO. Low chloride ions in the sampled waters could be because of low NaCl, CaCl_2 , KCl, MgCl_2 in the geological formations of the study area, as it is generally derived from the decomposition of rock salts like sodium and aluminum silicates [18]. High Cl^- concentration in water damages metallic pipes and structure, as well as harms growing plants. Similar value of low Cl^- was reported in the drinking water of Turkey [10]. Analysis of heavy metals in water samples were also considered (Table 5).

Table 5. Total concentrations of heavy metals analyzed in streams.

Parameter/ (mg/L)	Rainy season			Dry season			MAC
	Ba I	Ba II	Ba III	Ba I	BaII	BaIII	MAX (WHO, 2022)
Pb^{2+}	0.01	0.01	0.02	0.02	0.02	0.04	0.01
Al^{3+}	1.52	1.87	0.98	1.85	2.15	1.32	0.20
Zn^{2+}	0.23	1.68	0.75	0.56	3.12	1.21	3.00
Fe	0.10	0.21	0.10	0.20	0.34	0.00	0.30

MAC: Maximum Allowable Concentrations Ba I=Bamenda I, Ba II =Bamenda II, Ba III= Bamenda III

Source: Field work (2024)

The values recorded for lead (Pb) ranged from 0.01 mg/L to 0.04 mg/L for both seasons, with a general increase in concentration in the dry season (possibly due to leaching. These values were above the WHO and AFNOR standard of 0.01 mg/L. The highest value was registered for the sample from Bamenda II and III due to possible contamination from the waste leaches. Exposure to such high concentrations in pregnant women, could cause miscarriage, while in men could damage the organs responsible for sperm production. The concentration of aluminium in the various samples ranged from 0.98 to 1.87 mg/L in the rainy season and from 1.32 to 2.15 mg/L in dry season with a general increase from the rainy to the dry season. All the values were above the WHO standard of 0.2 mg/L. Such levels of aluminium promote microbial growth in water systems which may lead to health complications.

The concentrations of Zinc (Zn) ranged between 0.23 and

1.68 mg/L in rainy season and between 0.56 and 3.12 mg/L in the dry season with an increase from rainy to the dry season. These results were below the 3.0 mg/L guideline value prescribed by WHO, except for the samples Bamenda II which in the dry season had a value of 3.12 mg/L. This possibly could be the reason for the higher values in the water samples of Bamenda II compared to those upstream Bamenda III. For Iron (Fe), the concentrations ranged from 0.1–0.21 mg/L in the rainy season and from 0 – 0.34 mg/L in the dry season without any significant changes with seasons All the results were below the 0.3 mg/L guideline value, except for the effluent sample which had a concentration of 0.34 mg/L in the dry season [19]. Concentrations of iron above 1.0 mg/L could cause ill health such as gastrointestinal irritation. Table 6 highlights the values of physiochemical properties in well water samples in Bamenda.

Table 6. Results of physiochemical properties in well in Bamenda City.

Physiochemical Properties	Bamenda I		Bamenda II		Bamenda III		WHO Standard
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	
Ph	6.0	7.3	6.0	7.0	6.0	7.5	6.5-8.5
EC (mS/cm)	70	70	56	60	61	90	2000
Turbidity (NTU)	0.67	0.30	0.05	0.10	0.89	1.80	0.1-5
N-NO ₃	0.001	2.525	0.002	3.640	0.014	4.480	50
Ca ²⁺ (mg/L)	0.27	8.31	0.20	8.26	0.11	8.58	200
Mg ²⁺ (mg/L)	8.29	8.48	ND	1.43	ND	1.33	150
K ⁺ (mg/L)	ND	1.00	ND	1.54	ND	1.09	20
Na ⁺ (mg/L)	12	106	12	117	18	254	20
HCO ₃ ⁻ (mg/L)	73.20	61.00	73.20	48.80	73.20	78.08	1000
NH ₄ ⁺ (mg/L)	0.040	5.320	0.026	7.280	0.006	9.520	1.5
Cl ⁻ (mg/L)	ND	ND	ND	ND	ND	ND	250
Fe (mg/L)	12.5	2.35	13.83	2.94	16.16	1.71	0.3
SO ₄ ²⁻ (mg/L)	0.043	0.164	0.072	0.180	0.072	0.197	250
PO ₄ ³⁻ (mg/L)	0.231	1.523	0.231	3.408	0.375	0.267	≥5
Zn (mg/L)	0.14	2.63	0.18	3.07	1.14	2.63	5.0
Pb (mg/L)	1.65	2.16	3.00	2.23	3.40	1.84	0.05
Cr (mg/L)	1.75	1.83	2.25	2.06	5.50	2.06	0.05

Source: Field work (2024); ND=Non Detectable

The pH of all the samples ranged from 6.0 to 7.5 with samples in Bamenda III having the highest pH value and sample in Bamenda II having the lowest. WHO pH limit range is 6.5 to 8.5. Thus, the pH of the samples fell within the limit in rainy season and out of it in dry season. A highly significant difference was recorded between the pH values in dry and rainy season. Within a tolerance level, the pH values do not therefore indicate any form of pollution. The electrical conductivity levels of all the samples ranged from 56 to 90 μ S/cm which was below the WHO limit of 2000 μ S/cm. These values were quite low and within limits indicating that there were very little dissolved solids. Therefore, there was no contamination from dissolved solids. The turbidity values of all the samples ranged from 0.05 to 1.8 NTU below the WHO limit of ≤ 5 and so, the values were within limits. This implies that the amount of suspended solids was quite small. Therefore, there was no pollution from suspended solids.

Also, no differences were recorded in the electrical conductivities and turbidity of the samples between the rainy and dry seasons. The concentration of N-NO₃ in the samples ranged from 0.001 to 4.48 mg/L which when compared with the WHO limit of 50 mg/L fell below the acceptable level so

the water was free of nitrate contamination. Again, the concentration of N-NH₄ ranged from 0.006 to 9.52 mg/L for the samples. The limit prescribed by WHO is 1.5 mg/L. Differences was recorded in the N-NO₃ and N-NH₄ content of the samples in dry and rainy seasons. All the N-NH₄ content in the dry season fell below the limit whereas the values for all the samples taken in the rainy season were above the limit, with that of Bamenda III being the highest (9.52 mg/L) and Bamenda I the lowest (5.3 mg/L) compared to Bamenda II and III. This implies that the three water sources were heavily contaminated with ammonium nitrogen in rainy season. High values of N-NH₄ recorded throughout the study period may have resulted from pollution with animal or human organic matter washed by the rains into water bodies and could indicate high mineralization of water, and an increase in organic matter loads, thus indicating poor water quality [15]. This can be resolved through biological nitrification or oxidation. The level of chlorine in the six samples collected was non-detectable. This is explained by the fact that chlorine is not used to disinfect the well water. The sulphate levels of all samples were very low (ranging from 0.043 to 0.17 mg/L) comparable to the WHO value of 250 mg/L. Differences were

recorded in the sulphate content of the water samples in rainy and dry seasons, showing a high fluctuation between the seasons. The phosphate levels of all samples ranged from 0.2314 to 3.4088 mg/L and fell within the WHO limit of ≤ 5 mg/L. There was therefore no phosphorus contamination. All the samples had a bicarbonate range of 48.8 to 78.08 mg/L which is below the WHO value of 1000 mg/L. Thus, no contamination resulted from bicarbonate. Also made the same conclusion on well water analysis with bicarbonate content as high as 1200 mg/L [11].

Calcium and magnesium levels of all the samples ranged from 0.11 to 8.58 mg/L and 1.33 to 8.48 mg/L, respectively. These values were below the WHO limit of 200 mg/L for calcium and 150 mg/L for magnesium. Thus, no contamination by calcium and magnesium was observed and consequently, the water is soft. Differences were recorded in the calcium content of the water samples in dry and rainy season. Sodium and potassium levels ranged from 12 to 254 mg/L and 1 to 1.54 mg/L, respectively compared to the WHO limit of 20 mg/L for both sodium and potassium. There, potassium levels fell within limit while sodium levels far exceeded the limit on average. Therefore, there is sodium contamination for all the samples with sample in Bamenda III being the highest and sample in Bamenda I being the least. The value of the sample for Bamenda III was 185 mg/L on average which is very close to 200 mg/L and was considered high though, this is only much risky to hypertensive patients.

The levels of chromium in the water samples ranged from 1.75 to 5.5 mg/L. This fell above the WHO limit of 0.05 mg/L. The highest value was found for the Bamenda III sample and the lowest for the Bamenda I sample. This means that the water was polluted with chromium as indicated by the results for dry and rainy season. Chromium is found to be carcino-

genic therefore its presence in water exposes residents consuming the water to be vulnerable to health risk such as uncontrolled cell growth. This may have resulted from the use of fungicides, pigments and paints. The levels of lead in all the samples ranged from 1.65 to 3.4 mg/L compared to the WHO limit of 0.05 mg/L which may have resulted from lead acid batteries usage, the use of electronic equipment or plumbing activities. Lead is damaging to the nervous system. This equally leads to delays in physical and mental development in children. The levels of iron for the samples ranged from 1.71 to 16.16 mg/L comparable with 0.3 mg/L value for WHO limit. This was highest for the water sample in Bamenda III and the lowest for Bamenda I water sample. On the average, the values were higher than those prescribed by WHO. This implies that there was heavy metal contamination of the water sources with iron for the seasons which could cause health and environmental damage. However, this is not very risky given that there are so many uses of iron in the human system. The zinc levels for all samples ranged between 0.14 and 3.26 mg/L compared to 5 mg/L for WHO limit, respectively. On the average therefore, the values were within the limit; thus, there was no pollution by zinc. Differences were recorded in the iron and zinc content of the samples in two seasons, showing a high fluctuation between the seasons [13]. The zinc value was high in the wet season than dry season because heavy rain can cause zinc to runoff from roofs, building, and other structures.

3.2.3. Bacteriological Analysis from Water Samples in Bamenda City

Results of Bacteriological analysis for specific microbes isolated (colony forming unit/me) in boreholes show variations in the different spatial units (Table 7).

Table 7. Specific Microbes isolated (total fecal coliforms)/colony forming unit/ ml from boreholes.

Specific Microbes	Enterobacteria spp	E. coli	Streptococcus spp	Salmonella spp	Shigalla spp	Staphylococcus spp	Vibrio spp
Bamenda I	00	00	00	00	00	00	00
Bamenda II	00	00	00	00	00	00	00
Bamenda III	07	03	07	00	00	00	00
WHO limits	00	00	00	00	00	00	00

Source: Field work (2023)

Results obtained by the Most Probable Number (MPN) technique showed that Faecal coliforms were not present in borehole water sample except a borehole in Bamenda III. Coliform bacteria are microorganisms found in water, soil and faeces of humans and animals and most of them are harmless and do not usually cause diseases. However, their presence indicates that faecal wastes may be contaminating the water

and means that pathogenic organisms could be present. In view of the coliform count content in 100 mL of water, the water was classified. Standard count plate technique which is used for detailed analysis of water samples revealed colonization by faecal coliforms such as Enterobacteria, E. coli, Streptococcus spp. Quality standards for water intended for human consumption prescribed by WHO require 0 CFU/mL

of water for all indicator bacteria of faecal pollution as reported in the findings of [22]. The analysis of the sampled water revealed faecal pollution. This means they faced an infiltration of pathogenic microorganisms from human and animal wastes. The bacteria contents in the water source (s) decreased in the order Enterobacteria spp > Staphylococcus spp > Streptococcus spp > E. coli as described by [11]. Biologically speaking, the water from a borehole in Bamenda III is not very suitable for consumption due to microbes that were isolated during the laboratory analysis. Therefore, the following recommendations should be followed to ensure that the water is safe for consumption.

Treatment methods (chlorination) should be applied to the water supply and equipment following the water volume determined. The quantity of sodium hypochlorite or calcium hypochlorite used for treatment per session will depend on the estimated water volume in each borehole. Calcium hypochlorite (solid grains that you buy from the market) is preferable because it has a longer residual time in water and will thus keep the water safe for a longer period. The recom-

mended quantity of bleach to be poured into the well is 3-5 g/m³, approximately a tea spoon. This should be done after every three months. When bleach is applied, the water should only be consumed after 1 to 2 hours. A protected tank for water storage should be constructed and this tank should be clean after every one month to prevent bacteria growth. The water should also be filtered to remove any suspended particles and bacteria that escaped the disinfection process before consumption. Construction of houses and toilet systems should be at least 30 m from the water source to prevent leaching of waste into the water source. Physio-chemical and bacteriological analyses should be carried out periodically to determine pathogenic microbes from either external contamination or seasonal changes. According to WHO guidelines, standard analyses are best carried out before the start of the rainy/dry season and at least at the end of the rainy/dry season.

There were variations in the Bacterial properties that were present in the water from wells in the different seasons across the study area (Table 8).

Table 8. Variations in specific microbes in wells in Bamenda City.

Specific Microbes	Bamenda I		Bamenda II		Bamenda III		WHO Standards
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	
Enterobacteria	30	20	1000	20	20	200	0
E-Coli	20	10	600	20	20	150	0
Streptococcus	50	50	500	50	50	200	0
Salmonella	0	0	30	0	0	10	0
Shigella	0	0	20	5	0	10	0
Stephylococcus	14	12	08	18	20	20	0

Source: Field work (2024)

All the samples contained total faecal coliforms, namely enterobacteria, E. coli, Streptococcus, Salmonella, shigella and stephylococcus with the first three predominating and the last two almost absent. This presence of high numbers of faecal coliforms and faecal streptococci is an indication of water pollution, because faecal coliforms and faecal streptococci are used as an indication of faecal contamination and reflect the risk of pathogens presence in the water. Sample for Bamenda II recorded the highest number of all the bacteria forms, seconded by sample for Bamenda III. The heavy presence of the faecal forms of bacteria is as a result of the presence of either animal or human faeces or both or the presence of organic matter in the water indicating faecal pollution [20]. Ideally, and following the WHO recommen-

dations, there should be no bacteria available per 100 ml of the water sample.

There are many factors which influence groundwater and surface water quality which include the type of pollution source (s), the nature of the soil and anthropogenic influences. Ideally, drinking water should not contain any microorganism known to be pathogenic, capable of causing diseases or any bacteria indicative of faecal pollution [19]. Water pollution caused by faecal contamination is a serious problem due to the potential risk of contracting diseases from pathogens [21]. The results on microbes for streams are shown on Table 9 that illustrates the microbe count for streams in the Bamenda City Municipality.

Table 9. Results of specific microbes in streams for the Bamenda city.

Specific microbes	Bamenda I		Bamenda II		Bamenda III		WHO Standard
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	
Enterobacteria	160	240	320	410	180	280	00
Streptococcus	05	03	15	10	10	05	00
Salmonella	10	30	45	50	45	55	00
E. coli	50	140	180	170	160	160	00
Shigella	00	08	10	20	03	19	00
Staphylococcus	14	27	00	02	05	05	00

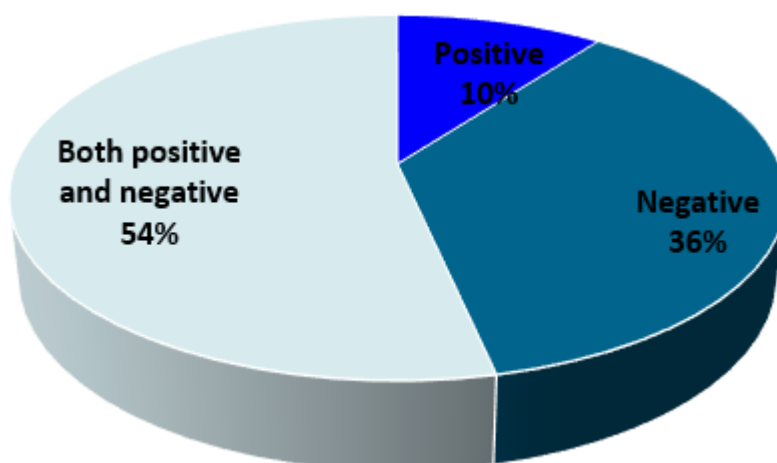
Source: Field work 2024

Faecal contamination is of global concern owing to the negative health risks associated with it. The samples of stream water for Bamenda I, II, III were analysed for specific microbes which included Enterobacteria spp, E. coli, Streptococcus spp, Salmonella spp, Shigella spp, Staphylococcus spp and Vibrio spp highest in Bamenda II, suggesting contamination by human or animal faeces, and equally possible contamination from waste dump sites, all related to poor hygiene and sanitation. Higher colony counts of pathogenic bacteria in the sample downstream suggested contamination by human or

animal faeces and equally possible contamination from the effluent, all related to poor hygiene and sanitation [22]. Any water sample that harbours any pathogenic bacteria is not suitable for consumption [13].

3.3. Effects of Urban Land Use on Water Supply

Urban development and accessibility to potable water supply are closely intertwined depicting positive and negative implications in Bamenda City (Figure 3).



Source: Field work (2024)

Figure 3. Population perception on the impact of urban development on water quality.

The impacts are both positive and negative (53.4%) explained by the fact that urban development leads to increased water demand which supersedes the corresponding supplies leading to insufficient water. This reduces water quality due to increasing water management challenges accounting for 36.3% of the negative impacts as echoed by [9]. The 10.3% positive

implications are evident in the fact that proper urban development leads to innovations in water supply. Urban development is manifested on periodical physical changes in the different land uses all over the city of Bamenda. These changes are significantly impacting the management of water quality supply in diverse dimensions (Table 10).

Table 10. Effects of urban land use changes on water quality in Bamenda City.

Impacts	Bamenda I		Bamenda II		Bamenda III	
	Freq	%	Freq	%	Freq	%
Water pollution	4	18.2	39	24.2	14	11.5
Water related illnesses	3	13.6	32	21.1	16	13.1
Reduced ground water recharge	5	22.7	21	13.3	27	22.1
Catchment degradation	6	27.3	13	8.8	30	24.6
Stream volume reduction	3	13.6	15	10	13	10.7
Eutrophication	1	4.5	36	22.6	22	18.03
Total	22	100.0	156	100.0	122	100.0

Source: Field work (2024)

Land use changes introduce mutations in vegetation cover and reduces the permeability and porosity of the soils. All this affect surface water infiltration and ground water recharge [5]. Catchment degradation in the city of Bamenda is based on deforestation which increases soil erosion and catchment sedimentation, reduces groundwater recharge, and increases storm water runoff. Agricultural intensification in the urban and peri-urban areas is resulting to increased nutrient and sedimentation, contaminating water sources in catchment areas especially in the uplands of Bamenda I and III. This is founded in a study that pointed out that land use changes reduce ecosystem services [23]. This has further contributed to a reduction in the volume of water flow (13.6%) in Bamenda I urban area. This is seen in the irregularity and reduced groundwater recharge in this area as taps and wells dry up in most of the localities especially in the dry season. In Bamenda II, land use changes implications are seen in water pollution that reduces the quality of potable water to the population (24.2%). Bamenda II Sub-Division have the combined effects of sewer (sewage tanks) overflows leading to increased pressure on combined sewer systems, and the release of untreated wastewater into potable water systems. Water source pollution also results from groundwater contamination as urban land uses change and urbanization have increased the risk of groundwater contamination from sources such as leaking sewers as seen in Mulang and Old Town in Bamenda II Sub-Division [9]. The random and unplanned construction of houses have also increased flood risk, carrying assorted waste products into water bodies in the city. This has resulted to water related illnesses as pointed out by 21.1% of the population in Bamenda II urban area. This is reflected in findings highlighting negative implications for Green City development of water balance [7].

4. Conclusion and Recommendations

Urban development process has greatly altered the quality of water from their sources. Water quality analysis from water samples were collected from streams, wells and boreholes commonly used by the population of Bamenda city. Considering the properties found in water from different sources, most of them align with the water quality standards set by the [13]. Most of the stream water sources are overloaded with properties that reduces the water quality due to pollution. Organoleptic and physiochemical parameters showed that most of the samples were of good and acceptable pH limits ranging from moderately acidic to weakly basic and had high mineral contents (nitrates and sulphate). All water samples for streams contained sulphate and nitrate ions amidst other ions higher than the WHO guideline limits and the water sources ranged from soft to moderately hard water with lead and aluminium above the WHO guideline value in all the samples. Samples revealed that the stream water was of the calcium and magnesium bicarbonate type, indicating shallow fresh ground waters. Small to high seasonal influences were observed in the variations of most of the parameters including pH and the concentrations of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NO_3^- , Cl^- , and NH_4^+ . Biological properties indicate that the water supply systems are at risk due to water contaminations from micro-organisms, high concentration of sulphate, high value for ammonium, high value of bicarbonate, low mineral contents as a result of poor waste management practices. This implies that there is a strong relationship between urban development and potable water supply. This shows that, as the rate of urban development increases the quality of water decreases especially for surface water sources. This is suggestive of the fact that stakeholder involvements in the management of planned urban development can ensure sustainable water quality supply in urbanising communities. This is due to rapid population

growth with increasing demand for urban potable water is major resource for urban health care and sanitation across the world.

Abbreviations

MPN	Most Probable Number
NTU	Nephelometric Turbidity Units
CAMWATER	Cameroon Water Utilities Corporation
NGOs	Non-Governmental Organization
ND	Not Detectable
WHO	World Health Organisation
EC	Electrical Conductivity
ANOR	Standards and Quality Agency
MAC	Maximum Allowable Concentrations
pH	Potential of Hydrogen

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Fernandez-Anez, G. Ve-lazquez R. and Perez-Prada F. (2023). Governance and Implementation of Smart City Projects in The Mediterranean Region, European Investment Bank.
- [2] Jim énez, A., Saikia, P., Gin é R., Avello, P., Leten, J., Lymer, B. L., Schneider, K., & Ward, R. (2020). Unpacking water governance: A framework for practitioners. *Water* (Switzerland). <https://doi.org/10.3390/w12030827>
- [3] Bahri, A., Sally, H., McCartney, M., Namara, R., Awulachew, S., Van Koppen, B. (2011). Integrated Urban Watershed Management: Towards sustainable solutions in Africa. (Contributions from the Rosenberg International Forum on Water Policy).
- [4] Estrada R. (2022). Water Quality: Case Study on the Alto Atoyac basin in Puebla, Mexico. *Journals of Sustainable Development* Volume 14.
- [5] Mafuta, C., Formo, R. K., Nellemann, C., Li, F. (eds) (2011). Green Hills, Blue Cities: An Ecosystems Approach to Water Resources Management for African Cities. A Rapid Response Assessment. United Nations Environmental Programme, GRID-Arendal.
- [6] Alabi A. A., Popoola O. I., Olurin O. T., Ogungbe A. S., Ogunkoya, O. A. and Okediji SO. (2020) Assessment of groundwater potential and quality using geophysical and physicochemical methods in the basement terrain of South-western. *Nigeria Environ Earth Sci* 79: 364. <https://doi.org/10.1007/s12665-020-09107>
- [7] Van R. D. (2011). Integrated Urban Watershed Management: Towards sustainable solutions in Africa” In Garrido, A.; Ingram, H. (Eds.). *Water for food in a changing world*. London, UK: Routledge. pp. 50-70. (Contributions from the Rosenberg International Forum on Water Policy)
- [8] Dutta, V. (2012). Land Use Dynamics and Peri-urban Growth Characteristics: Reflections on Master Plan and Urban Suitability from a Sprawling North Indian City. *Environment and Urbanization Asia* September 2012, 3(2), 277-301. <https://doi.org/10.1177/0975425312473226>
- [9] World Bank. (2022). World development report 2020: Infrastructure for Development. New York: Oxford University Press. <https://doi.org/10.1596/978-0-1952-0992-1>
- [10] Li, P., Wang, D., and Li, W. (2022). Water resources development and management in large river basin: An Introduction. *Environ Earth Sci* 8, 179 (2022).
- [11] Temgoua, E. (2011). Chemical and Bacteriological Analysis of Drinking Water from Alternative Sources in the Dschang Municipality, Cameroon. *Journal of environmental protection*. Vol. 2, No. 05, p620-628.
- [12] National Institute of Statistics (2023). Regional Agency for the North West 2018 Edition. 313p.
- [13] World Health Organization (2022). Guidelines for drinking-water quality (fourth edition incorporating the first Addendum), WHO Library Cataloguing-in-Publication Data. 20 Avenue Appia, 1211 Geneva 27, Switzerland, pp631.
- [14] Asian Development Bank (2025). Valuing water and enhancing livability in Asia and the Pacific. *Water and Urban Development Forum 2025*. Manila, Philippines. 17p.
- [15] Mufur, A. M., Awah, M. T., Nono, G. D. K., Tamfuh, P. A., Wotchoko, P., & Beyala, K. K. V. (2021). Physico-chemical and bacteriological characterisation of surface water in Bamenda (North West Cameroon). *Applied Water Science*, 11(12): 1-13.
- [16] Mofor, N. A., Mbene, K., Njoyim, E. B. T., Nchofua, F. B. and Nkemajen, E. A. (2023). Domestic Water Quality Assessment in Nteingue Community, West Region of Cameroon. *American Journal of Water Resources*, 11(3): 88-97. <https://doi.org/10.12691/ajwr-11-3-1>
- [17] Nchofua, F. B., Mofor, A. N., Njoyim, E. B. and Mvondo-Ze, A. D. (2020). Assessment of ground water quality in Baba I vil-lage, North-West Cameroon. *Journal of Geoscience and Environment Protection*, 8, 87-104.
- [18] Trang D. T., Molbak K., Phung D. C., and Dalsgaard A. (2007). Helminth infections among people using wastewater and human excreta in peri-urban agriculture and aquaculture in Hanoi, Vietnam. *Tropical Medicine and International Health*, 12(2) 82–90.
- [19] World Health Organization (2006). Guidelines for Drinking Water Quality: Incorporating First Addendum. 3rd Edition, WHO Press, Geneva.
- [20] Nguedio-Yongsi, H. G. (2011) Microbiological Evaluation of Drinking Water in a Sub-Saharan Urban Community (Yaound é). *American journal of Biochemistry and Molecular Biology*, 1, 68-81.

- [21] Nkobe, M. K., Ndong, B., Djousse, K. B. M. and Nyasse, S. (2024) Evaluation of Four Anthropogenic Activity Impacts on Heavy Metal Quality of the Kumba River in the South West Region of Cameroon. *Journal of Water Resource and Protection*, 16, 361-380. <https://doi.org/10.4236/jwarp.2024.165020>
- [22] Kuitcha D, Ndjama J, Tita AM, Lienou G, Kamgang KBV, Ateba BH, Ekodeck GE (2010). Bacterial contamination of water points of the upper Mfoundi watershed, Yaounde. *Cameroon Afr J Microbiol Res* 4(7): 568–574.
- [23] Zorrilla-Miras, P., Palomo, I., Gómez-Baggethun, E., Martín-López, B., Lomas, P. L., & Montes, C. (2014). Effects of land-use change on wetland ecosystem services: A case study in the Doñana marshes (SW Spain). *Landscape and Urban Planning*, 122, 160-174. <https://doi.org/10.1016/j.landurbplan.2013.09.013>