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Hydrogeochemical and Biological Evaluation of Packaged Groundwater Sold in Douala City, Cameroon

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Abstract

Douala is the economic capital of Cameroon situated between latitude 4.00 - 4.15 and longitude 9.65 - 9.95 with an estimated population of over two million and 65,000 households connected to the water supply network. The Douala/Kribi-Campo Basin is a divergent, marginal rift basin and one of the two Atlantic coastal basins of Cameroon, the other being the Rio del Rey Basin. This study evaluates the quality of packaged (Bottled/Sachet/Refilled) groundwater in Douala using hydrogeochemical tools: Gibbs diagrams, Piper diagrams, Durov diagrams, water quality indices and microbial (Coliform Count) analysis. Twenty packaged groundwater samples were sent for chemical and microbial analysis during two seasons. *In-situ* field measured physicochemical parameters ranged from, pH (5.70 - 8.40), Temperature (11.5˚C - 29.2˚C); EC (10 - 364 μS/cm) and TDS (6.7 - 243.88 mg/L). The total hardness ranged from 10.07 - 147.15 (mg of $CaCO_3$) soft. Gibb's diagram indicates the mechanism controlling water chemistry is rock-weathering and atmospheric precipitation. From Durov and Piper diagrams simple dissolution during recharge or mixing is the primary hydrogeochemical process in the evolution of the groundwater chemistry. The groundwater types are $CaHCO_3$ > $MgHCO_3$ with three hydrogeochemical facies in the order [Ca^{2+}-Mg^{2+}-Cl^-- SO_4^{2-}] > [Ca^{2+}-Mg^{2+}- HCO_3^-] > [Na^+-K^+- HCO_3^-]. The WQI is from 6.49 - 38.71 indicating all packaged groundwater in Douala is chemically suitable for consumption. The physicochemical parameters (pH, electrical conductivities, temperature and total dissolved solids) of packaged groundwater are below WHO guideline acceptable limits. From Microbial analysis (Cheesbrough classification), some packaged groundwater were unacceptable (with coliform) in both seasons. The poor quality of the packaged groundwater is considered dangerously unhygienic and thus of great concern. The poor quality

of the packaged groundwater is probably due to errors in the processing and packaging of the water. Packaged groundwater actors must have higher quality monitoring control.

Subject Areas

Environmental Sciences, Geology, Hydrology

Keywords

Packaged-Groundwater, Chemical-Quality, Biological-Quality, Cameroon

1. Introduction

Douala is the largest city in Cameroon and is situated between latitude 4.00 - 4.15 and longitude 9.65 - 9.95 as in Figure 1. It is the economic capital of Cameroon in the Littoral Region and hosts more than 80% of the industries in the country. It is divided into districts and has major markets in main quarters as shown in Figure 1. The climate of Douala indicates a hyper humid climate modified by the relief of Mt. Cameroon with a long rainy season from March to November and a short dry season from December to February marked, especially on the coast by significant precipitation. The average daily temperatures had been collected each month for 30 years by the Douala City Council (1984 to 2014) and the average monthly temperature varies from 24.8˚C in July and August to 27.7˚C in February with an annual average of 26.4˚C. January and February are identified as the hottest months of the year [1].

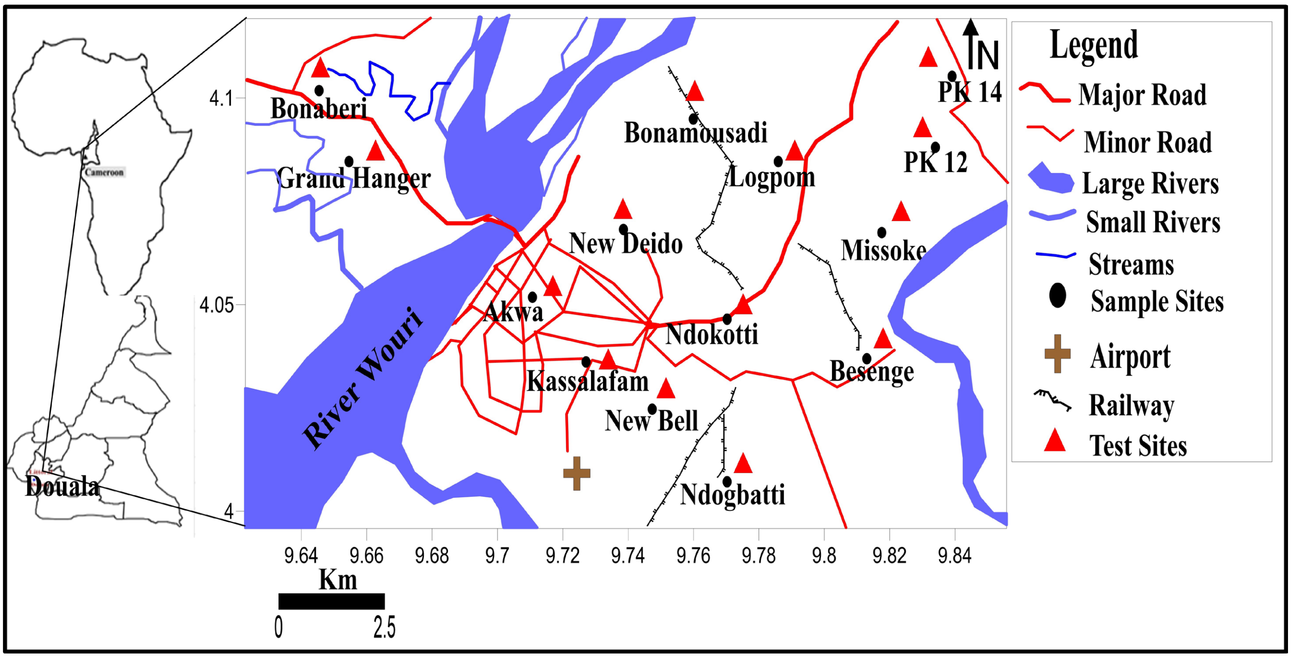


Figure 1. Sampled points of packaged groundwater in Douala (insert Cameroon and Africa).

Packaged water is manufactured or processed for sale sealed in food-grade bottles, sachets, or other containers and intended for human consumption [2]. Sale of packaged water has exploded all over the world in recent years, largely as a result of public perception that it is safe, tastes better, and has a better quality compared to raw tap water [3] [4] [5] [6]. Many water sources in developing countries are unhealthy because they contain harmful physical, chemical and biological agents [7].

The World Health Organization estimates that over 1 billion people lack access to safe drinking water and about 4000 children die every day from water borne disease [8] and more than 500 million diarrhoea cases taking place each year in children below age five years in Asia, Africa and Latin America [9]. Most of the mortality and morbidity associated with water-related diseases in developing countries is due to infectious agents and the principal faecal-oral diseases are cholera, typhoid, shigellosis, amoebic dysentery, hepatitis-A and other types of diarrhoea. Water is the most shared natural resource in the world. Indeed, a man can remain several days without eating but cannot stay for more than three days without drinking water [10]. 80% of the illnesses present on the surface of the earth are water borne and drinking water is very often contaminated [11]. In Cameroon, the sector with the highest growth rate and demand is that of the packaged water. This product once considered luxurious by many has become accessible in the years after 2019 pandemic hand-washing-with-clean-water requirement. Cameroon's economic capital Douala has a distribution network of pipe-borne potable water by the utility service provider which in recent years has increased its production capacity. However, the population increase surpasses the water supply increase and consumption of packaged water has exploded. The past decade has seen a dramatic increase in the consumption of bottled and more especially plastic-bagged water in Cameroon. Even in countries where household tap water quality is considered excellent, demand for packaged water is high, making packaged water the fastest growing product of the nonalcoholic beverage market worldwide [3] [12]. Packaged water is mainly sourced from springs, streams, rivers, lakes, bore wells and treated by filtration deodorization ultraviolet rays then packaged and generally termed "natural" or "mineral" water implying the absence of any chemical additive. With the increase in consumption of packaged water, there is possibility of products not fit for human consumption because of pressure from demand and monetary interests [13].

The proliferation of such packaged water products in Douala raises the question as to whether they are hygienically produced, especially when the poor sanitary condition imposed by lack of infrastructure for control and monitoring in the city is taken into account. Although diseases outbreaks due to contaminated packaged water are uncommon, any possible contamination may lead to widespread epidemic because of the high demand and coverage [14]. Under improper or prolonged storage of packaged water, bacteria can grow to levels that may be harmful to human health [2] [5] [6]. Each type of packaged water is subject to special restrictions related to its production method, its composition or its packaging [15]. In the city of Douala, there are several brands of packaged water in plastics bottles or polyethylene sachets produced locally or imported. In the early years, water was sold either from covered buckets with a single cup for all consumers; in hand-filled hand-tied polythene bags or refilled-pre-used-washed-bottled (RPWB) water. Factory sealed plastic-bagged sachet (FPBS) water was introduced into the Douala market as an improvement on the types of vended water produced in Douala. The latter are still bought in large volumes because they are inexpensive. The standard of hygiene in the various stages in the production of the factory plastic-bagged-sachet (FPBS) water is similar to that of factory bottled (FB) water. Most FPBS factories use multi candle pressure filters (Berkefield, Doulton, UK), which employ an active carbon filter bed that removes sand, rusts, metal sediments, algal films and bacteria from the water [16]. The bags are closed using heat-sealing machines. In Cameroon, infections due to the consumption of drinking water have been signalled, and the problem of the sanitary quality of the sold drinking water in plastic sachets on the market has become the government's priority in recent years since cholera is endemic in Douala city [17]. The population of Douala is estimated to be more than 2.5 million inhabitants and only about 65,000 households are connected to the water supply network. Current CAMWATER water production stands at 110,000 m^3/day while current demand stands at 250,000 m^3/day [18]. Water distribution is erratic due to the aging pipe network with frequent breakages and inadequate supply volumes. The access to potable water constitutes an indispensable condition to health, an elementary right and a key component of protective sanitary policy. Knowledge of the hydrogeochemistry and biological quality of the groundwater from the phreatic aquiferous formations in the Douala basin and validation of the packaging process and end product consumed by the population is thus a necessity. The goal of this paper is to evaluate the chemical and biological quality of packaged water sourced from boreholes in different phreatic aquiferous formations in the Douala basin sold in Douala city, Cameroon.

1.1. Climate

The climate of Douala indicates a hyper humid climate modified by the relief of Mt. Cameroon with a long rainy season from March to November and a short dry season from December to February marked, especially on the coast by significant precipitation. The average daily temperatures had been collected each month for 30 years by the Douala City Council (1984 to 2014) and the average monthly temperature varies from 24.8˚C in July and August to 27.7˚C in February with an annual average of 26.4˚C. January and February are identified as the hottest months of the year [1].

1.2. Soils and Vegetation

The soils of Douala are generally sandy with a low water holding capacity. However, other types of ferralitic soils formed on the diversity of the present bedrock (basalt and gneiss) sometimes with clay content are observed. These soils are better suited to agriculture because of their chemical properties. The warm and humid climate of the city of Douala is conducive for the luxuriant development of dense forest, mangroves and some vegetable crops that regress the advancement of urban development.

1.3. Geologic Setting of Study Area

The Douala Basin also called the Douala/Kribi-Campo Basin [19] is a divergent, marginal rift basin and one of the two Atlantic coastal basins of Cameroon, the other being the Rio del Rey Basin. These form part of a series of sedimentary fills lining the West African coast. Regionally, the Douala Basin is located at the northern end of the South Atlantic rift [20] and [21] included this basin as the eastern extension and part of a series of West African coastal basins. The basin therefore, is generally linked to both the South and Equatorial Atlantic and forms part of the Gulf of Guinea which extends from Angola to Senegal, representing the scar left on the African continent by the separation of South America [22]. The Douala Basin is made up of two sub-basins, the Douala Sub-Basin to the north and Kribi-Campo Sub-Basin to the south [19]. Generally, the Douala Basin is composed of non-marine and marine sediments that range from Berremian-Aptian till Resent, making up the on- and offshore portions of the basin. The two sub-basins present quite remarkable difference in their lithostratigraphic sequences.

The Douala Basin developed during the Cretaceous break-up of Gondwana and the separation of Africa from South America. The initial rifting phase may have started during very Early Cretaceous time (Berriasian-Hauterivian) but the principal rifting episode in these areas occurred from late Berremian-Aptian time. The initial formation of oceanic crust as the continents separated is believed to have commenced during the late Aptian-late Albian interval. It would appear that the rifting was asymmetrical, as many of the syn-rift features that would normally be expected are not apparent at depth in this area, but they are abundant in the corresponding South American segment. Several additional tectonic events occurred during the passive "drift" phase of the continental margin evolution at 84 Ma (Santonian), 65 Ma (K/T boundary) and 37 Ma (late Eocene). These events, resulting in uplift, deformation and erosion at the basin margins, are generally attributed to changes in plate motion and intraplate stress fields due to convergent and collision events between Africa and Europe. The Santonian uplift and possibly the late Eocene events also appear to have resulted in significant mass wasting of the continental margin by gravity sliding, contributing towards reservoir formation. The final uplift event relates to the growth of the Cameroon Volcanic Line (CVL) and effectively lasts from 37 Ma through to present day on the northwest margin of the basin.

The basal formation in the Douala Sub-Basin is the Mundeck Formation [23]-[28] is Berremian-Aptian to Albian in age and unconformably overlies the Precambrian basement complex. It comprises basal conglomerates, conglomeritic sandstones, siltstones, claystones and shales that were deposited in a continental fluvio-lacustrine setting. The Logbajeck Formation, also known as the Mungo River Formation, is directly overlying the Mundeck Formation. It ranges in age from Cenomanian to early Campanian [28] and lithofacies include; sandstone, siltstone, limestone, marlstone and shale. Directly above the Logbajeck Formation lies the late Campanian-Maastrician Logbaba Formation made up of shale, sand and sandstone and in places, limestone, sandstone and shale alternate. The first Tertiary formation is the Paleocene-Eocene N'kapa Formation which is predominantly calcareous to slightly silty claystone that is locally inter-bedded with sandstone and glauconitic claystone. The Souelaba Formation overlies the N'kapa Formation and has been dated Oligocene-Miocene. It comprises claystone with inter-bedded sandstones and sands, locally calcareous, argillaceous and glauconitic. The next is the Matanda Formation whose age is dated Late Pliocene-Pleistocene. Its lithology is made up of gravels, sands with inter-bedded claystones and clays and sometimes calcareous. The basin is capped by the Pleistocene-Holocene Wouri Formation which directly overlies the Matanda Formation. It is exposed to sands, sandstones, claystones with local development of tuffs and lavas [29]. The main rock types in Douala City include; sandstones, limestone, shale, and alluvium [1] as in **Figure 2**.

2. Materials and Methods

2.1. Materials

The field materials and equipment used in the study are listed in **Table 1**. The equipment were calibrated and used according to manufacturer's specifications.

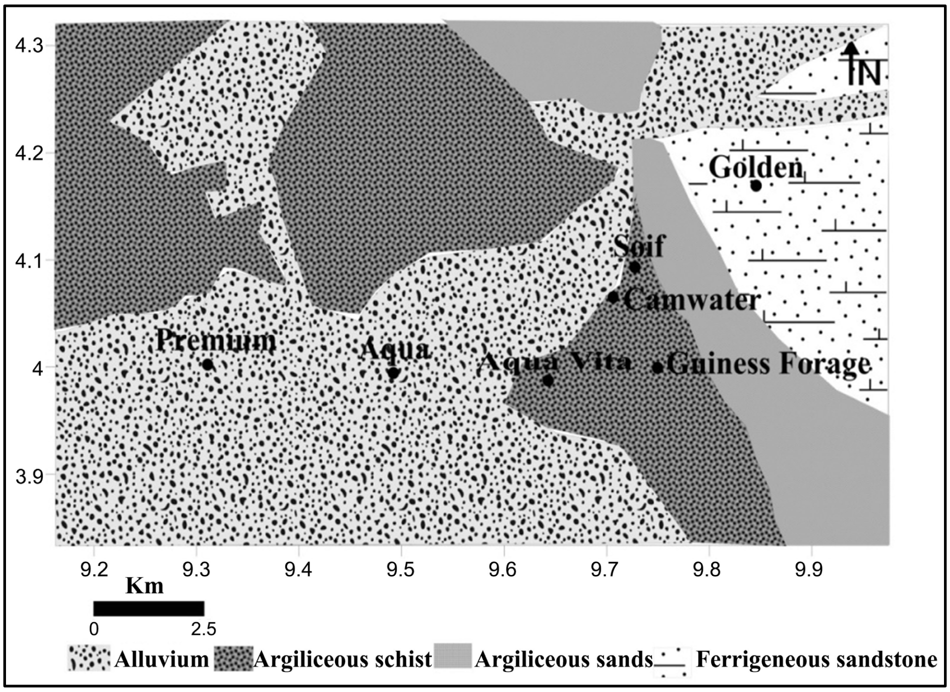


Figure 2. Geology of Douala and environs [30].

Table 1. Equipment, specification and their functions used during this study.

Equipment	Specification	Function
Bike	Commercial bikes (Bensikin)	Urban transportation to sites
GPS	Mobile GPS	To get coordinates of sampled and test sites
EC meter	HANNA HI 98304/HI98303	To measure Electrical Conductivity of water
pH Meter	HANNA HI 98127/HI98107	To measure the pH of water
Digital Thermometer	Extech 39240 (−50˚C to 200˚C)	To measure temperature of water and air
Sample bottles	Polystyrene 500 ml	To collect samples
Syringes	Polystyrene 50 ml	For sample preparation
Dilute nitric acid	1.51 g/cm^3, 1.41 g/cm^3 [68% w/w]	For the preservation of samples
Camera	Canon 3000 D	To take pictures
Field Note book	200 leaves	To take notes and record data

2.2. Methods

A reconnaissance survey was carried out to identify all main production sites and supply markets in Douala of packaged water. Seasonal tests/measurements were carried out in September (Wet seasons) in February (Dry season). The samples were collected from sales points in the markets and the sample situated at points where the companies sourced their groundwater for processing (boreholes). A total of 20 water samples were bought immediately after supply by the companies. Physicochemical parameters Temperature, pH, EC and TDS of packaged water were measured in-situ. In the field, physicochemical parameters Temperature, pH, EC and TDS of were measured at the production sites using a Temperature/pH/EC/TDS meter. For ethical reasons, the brand names of packaging entities were replaced with sample numbers.

The water samples were sent for analysis to ActLab Canada for;

1) Major cations in mg/L: Na^+, K^+ Ca^{2+}, Mg^{2+}, and NH^{4+};

2) Major anions in mg/L: HCO^{3-}, Cl^-, SO_4^{2-}, HPO_4^{2-} and NO_3^-.

Water Quality Index (WQI) is defined as a rating method that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption [31]. This was used to determine potability of water.

Gibbs Diagram [32] is a plot of $Na^+/(Na^+ + HCO_3^- + Ca^{2+})$ and $Cl^-/(Cl + HCO_3^-)$ as a function of TDS are widely employed to determine the sources of dissolved geochemical constituents These plots were used to reveal the relationships between water composition and the three main hydrogeochemical processes involved in ions acquisition; Atmospheric precipitation, rock weathering or evaporation crystallisation.

Pipers Diagram [33] is a graphical representation of the chemistry of water samples on three fields; the cation ternary field with Ca, Mg and Na + K apices, the anion ternary field with HCO_3, SO_4 and Cl^- apices. These two fields are projected onto a third diamond field [33]. The diamond field is a matrix transformation of the graph of the anions [sulphate + chloride]/Σ anions and cations [Na + K]/Σ cations. This plot was used as a hydrogeochemical tool to determine water-types and hydrogeochemical facies.

Durov diagram [34] is a composite plot consisting of two ternary diagrams where the milliequivalent percentages of cations are plotted perpendicularly against those of anions; the sides of the triangles form a central rectangular binary plot of total cation vs. total anion concentrations. These are divided into nine classes which give the hydrogeochemical processes during the evolution of the water in the aquiferous formations [35] [36].

Microbial test for the presence of coliforms in the packaged groundwater in Douala for twenty samples; ten samples per season were collected from the field in a cooler with ice and sent to the Life Science Laboratory of the University of Buea for analysis within 8 hours for both the wet and dry seasons. The Most Probable Number (MPN) of Coliform Bacteria (CB) in 100 ml was determined and the packaged groundwater classified according to Cheesbrough [37].

The results were mounted on Surfer V12 and AqQA 1.5, GIS platforms for data presentation, interpretation and analysis.

3. Results and Interpretation

3.1. Physicochemical Parameters

The In-situ physicochemical tests of water samples for pH, Temperature, EC and TDS vary with seasons **Table 2**, indicating seasonal influence on the phreatic aquifer.

3.1.1. pH

In the wet season, the pH values range from 5.7 - 8.4 with an average of 6.8 and 3.39 - 7.1 with an average of 5.7 in the dry season. These pH values indicate an acidic to alkaline nature of water in the study area as in **Figure 3**.

3.1.2. Temperature

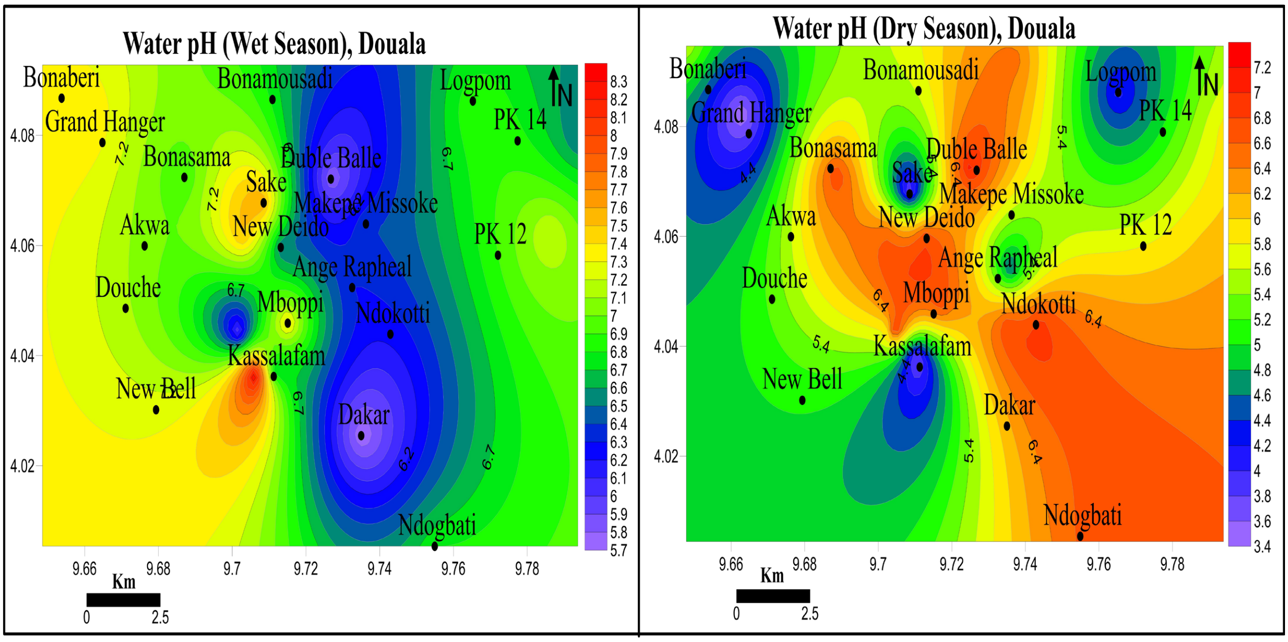
Temperatures ranged from 11.5˚C - 29.2˚C for the wet se4ason and 19.0˚C - 31.4˚C for the dry season as in **Figure 4**.

3.1.3. EC

The EC values ranged from 10 µS/cm to 364 µS/cm during the wet season and 2 µS/cm - 624 µS/cm in the dry season. These low EC values indicate fresh groundwater as in **Figure 5**.

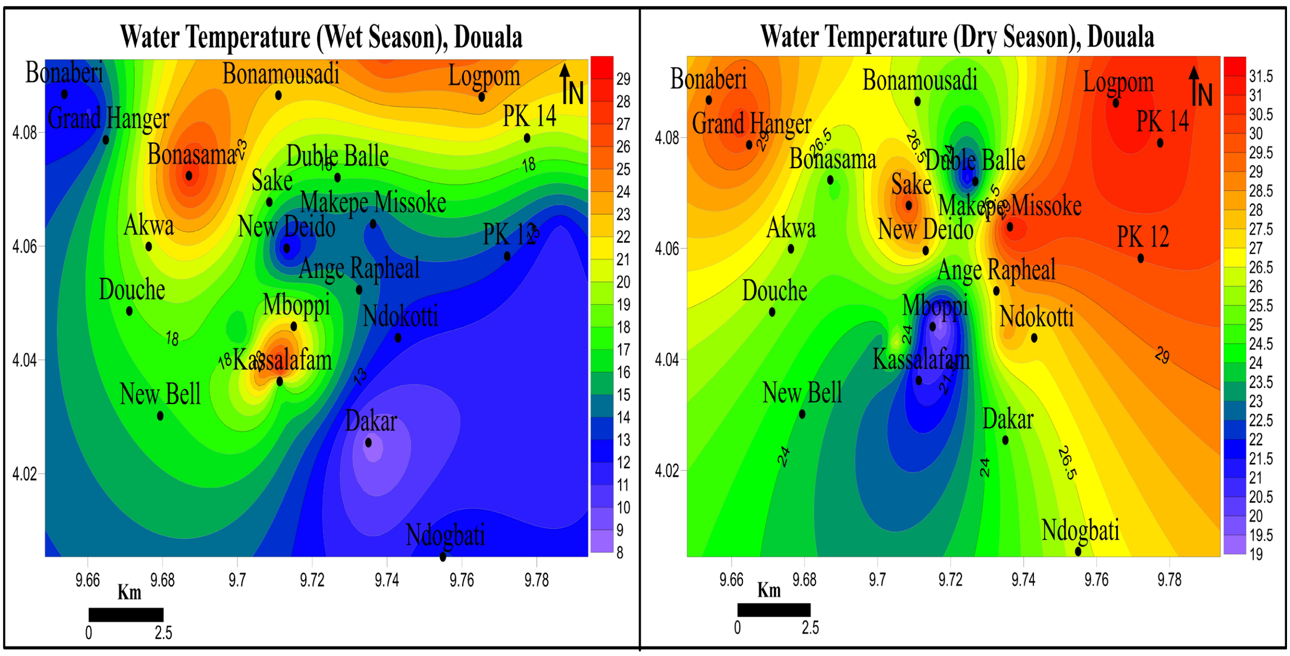
Table 2. Basic statistics of packaged groundwater physicochemical parameters during the wet season and dry seasons.

Parameters	Wet			Dry		
	Min	Max	Mean	Min	Max	Mean
pH	5.70	8.40	6.83	3.39	7.77	5.79
T (˚C)	11.5	29.2	18.01	19	31.4	26.93
EC (mS/cm)	10	364	126.45	2	624	167.80
TDS (mg/L)	6.7	243.88	84.72	1	323	84.65



(a) (b)

Figure 3. pH of packaged groundwater in Douala: (a) Wet Season and (b) Dry Season. Highest pH in wet season at Kassalafam while in the dry season, highest values were at Grand Hangar and Logpom. The pH values indicate an acidic to alkaline groundwater water.

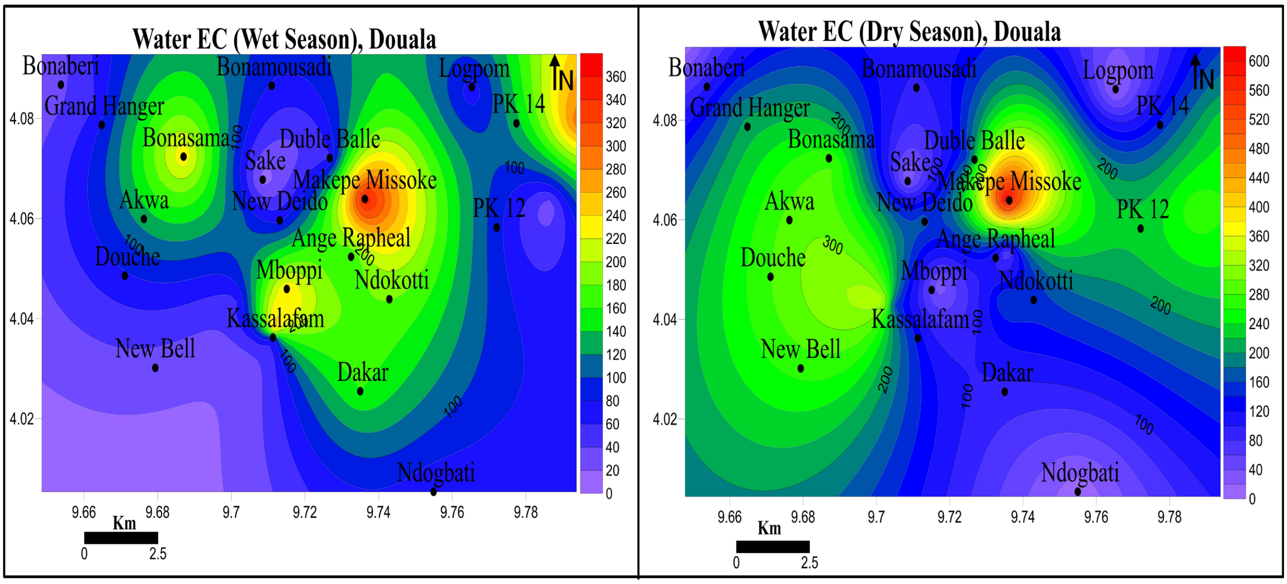


(a) (b)

Figure 4. Temperature Douala: (a) Wet Season and (b) Dry Season: Temperatures were higher in the dry season. This is typical of phreatic aquifers in hyper humid climatic regions like Douala.

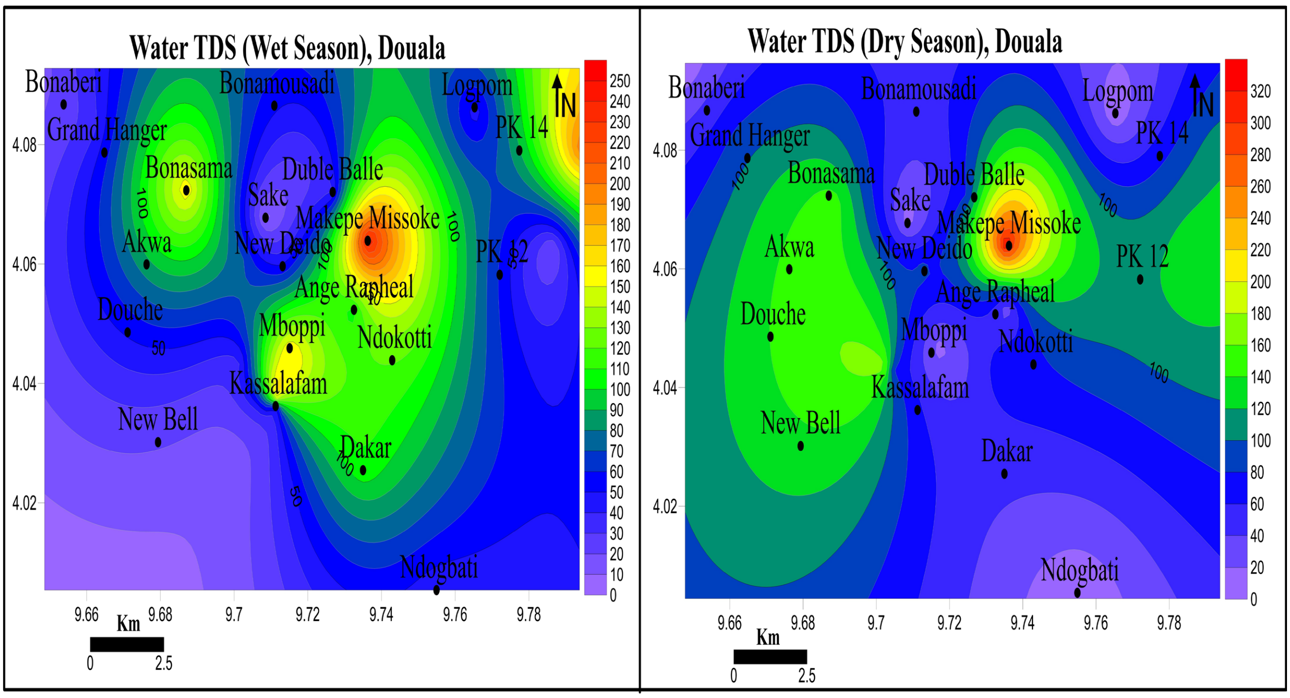
3.1.4. TDS

The total dissolved solids ranged from 6.7 mg/L - 243.9 mg/L in the wet season, while in the dry season, it ranged from 1 mg/L - 323 mg/L as in Figure 6.



(a) (b)

Figure 5. Electrical Conductivity (EC) Douala: (a) Wet Season and (b) Dry Season. Highest values of EC in both seasons were observed in Makepe Missoke. These are low values indicating fresh groundwater.



(a) (b)

Figure 6. Total Dissolved Solids (TDS) Douala: (a) Wet Season and (b) Dry Season. TDS was relatively higher in the dry season (Makepe Missoke). These low values indicate that the water is fresh and not mineralized.

3.2. Mechanism Controlling Chemistry of Packaged Groundwater in Douala

80% packaged groundwater samples plotted on the Gibb's diagram fell in the rock weathering dominance field while 20% plotted in the atmospheric precipitation dominance field. This indicates the major mechanism controlling water chemistry is chiefly the interaction between aquifer formation and groundwater as in Table 3 and Figure 7.

Table 3. Classification of mechanism controlling packaged groundwater chemistry in Douala.

Cations	Wet Season	
	No of Samples	Percentage
Atmospheric-precipitation dominance	1	10
Rock-weathering dominance	9	90
Evaporation-crystallization dominance	0	0
Anions		
Atmospheric-precipitation dominance	1	10
Rock-weathering dominance	9	90
Evaporation-crystallization dominance	0	0
Cations + Anions		
Atmospheric-precipitation dominance	18	90
Rock-weathering dominance	2	10
Evaporation-crystallization dominance	0	0

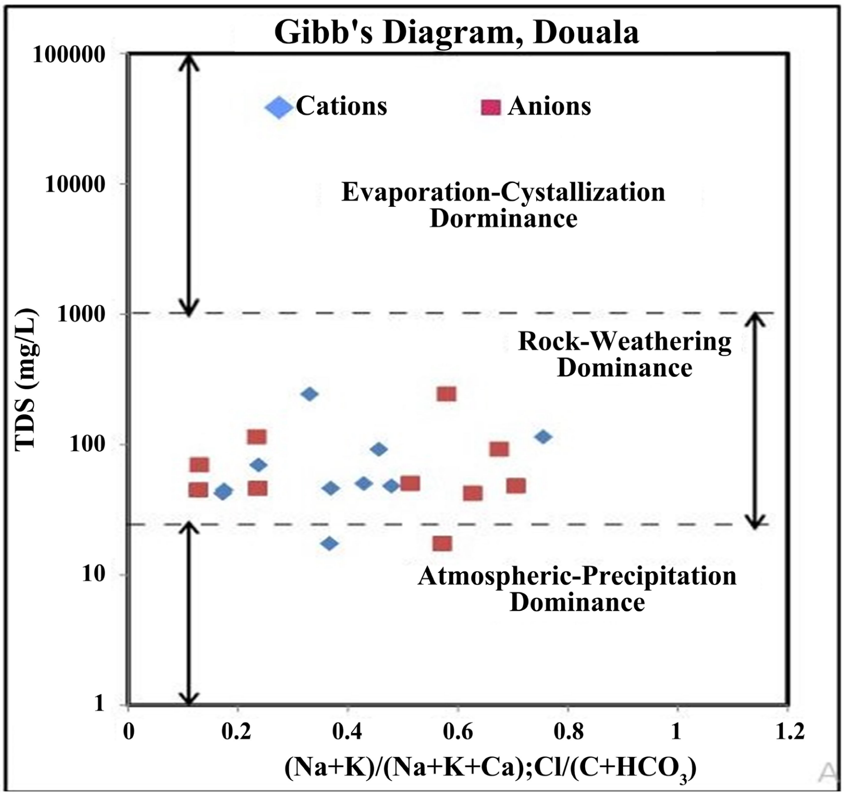


Figure 7. Mechanisms controlling the evolution of packaged groundwater chemistry in Douala. The main mechanisms are rock-weathering and atmospheric precipitation.

3.3. Water Type and Hydrogeochemical Facies

From the Piper trilinear diagram, majority of the samples (60%) belong to Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} (field I) demonstrating the dominance of alkaline earths over alkali (viz., Ca + Mg > Na + K) and strong acidic anions over weak acidic anions (*i.e.*, Cl + SO_4 > HCO_3). Some samples (30%) plotted under field (IV) belong to Ca^{2+}-Mg^{2+}-HCO_3^- signifying the dominance of alkaline earths over alkali and weak acidic anions over strong acidic anions. One sample plotted in field III belong to Na^+-K^+-HCO_3^-. Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-}, Ca^{2+}-Mg^{2+}-HCO_3, Na^+-K^+-HCO_3^-. The main groundwater types are $CaHCO_3$ > $MgHCO_3$ > NaCl and Main hydrogeochemical facies present are in the order [$CaMgHCO_3$] > [$CaMgSO_4$] > [$NaKHCO_3$] as in Table 4 and Figure 8.

Table 4. Classification of packaged groundwater based on Piper diagram [33] to depict water types.

Water Types	Samples	Percentage
Normal earth alkaline water with prevailing HCO_3^-, SO_4^{2-} **or** Cl^-	6	60
Normal earth alkaline water with prevailing HCO_3^-	3	30
Alkaline water with prevailing HCO_3^-	1	10

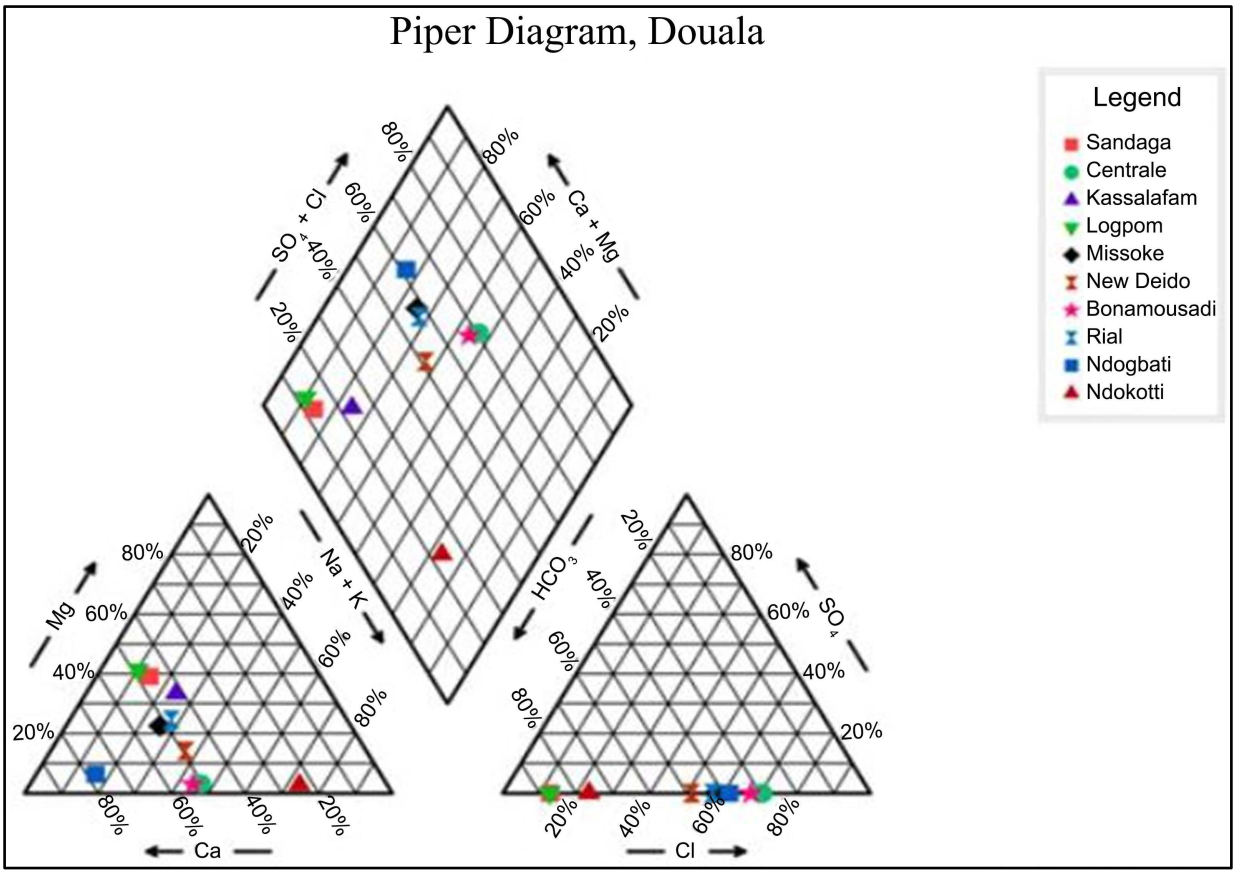


Figure 8. Piper's diagram of water types and hydrogeochemical facies of packaged groundwater in Douala.

3.4. Chemical Evolution of Groundwater

From the Durov diagram (**Figure 9**) 40% of the samples plot in field 5 attributed to fresh recently recharged groundwater with simple dissolution or mixing and no dominant major anion or cation, while 30% show mixing or uncommon dissolution influences as in **Table 5** and **Figure 9**.

3.5. Water Quality

3.5.1. Domestic Water Quality

Ionic content of water in the study area was used to evaluate groundwater suitability for domestic use: The recommended values are of the [37] guidelines.

3.5.2. Water Quality Index (WQI)

WQI values of packaged water in Douala City ranged from 6.49 - 38.71 as in **Table 6**. Packaged groundwater in Douala is good to excellent for use **Figure 9** and **Table 6**. Water Quality Index WQI is considered the most effective tool to convey the water quality information in its simplest form to the public [31].

3.5.3. Total Hardness

The total hardness of packaged groundwater samples ranged from 10.07 - 147.15 mg of $CaCO_3$ as in **Figure 10** with an average of 50.49 mg/l of $CaCO_3$ which indicates the packaged groundwater is soft.

Table 5. Groundwater types from Durov diagram indicating hydrogeochemical processes involved during flow through the aquifer [36].

Water Types	Wet Season	
	No	%
No dominant anion or cation indicates water exhibiting simple dissolution or mixing.	4	40
SO_4 dominant or anion discriminate and Na dominant; is water type not frequently encountered and indicates probable mixing or uncommon dissolution influences.	3	30
This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed.	1	10
SO_4 dominates, or anion discriminant and Ca dominant, Ca and SO_4 dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be indicated.	1	10
Cl and Na dominant indicate end-point down gradient waters through dissolution.	1	10

Table 6. Classification of packaged groundwater in Douala based on WQI.

Class	Values	Quality	Number	%
1	0 - 25	Excellent	7	70
2	26 - 50	Good	3	30

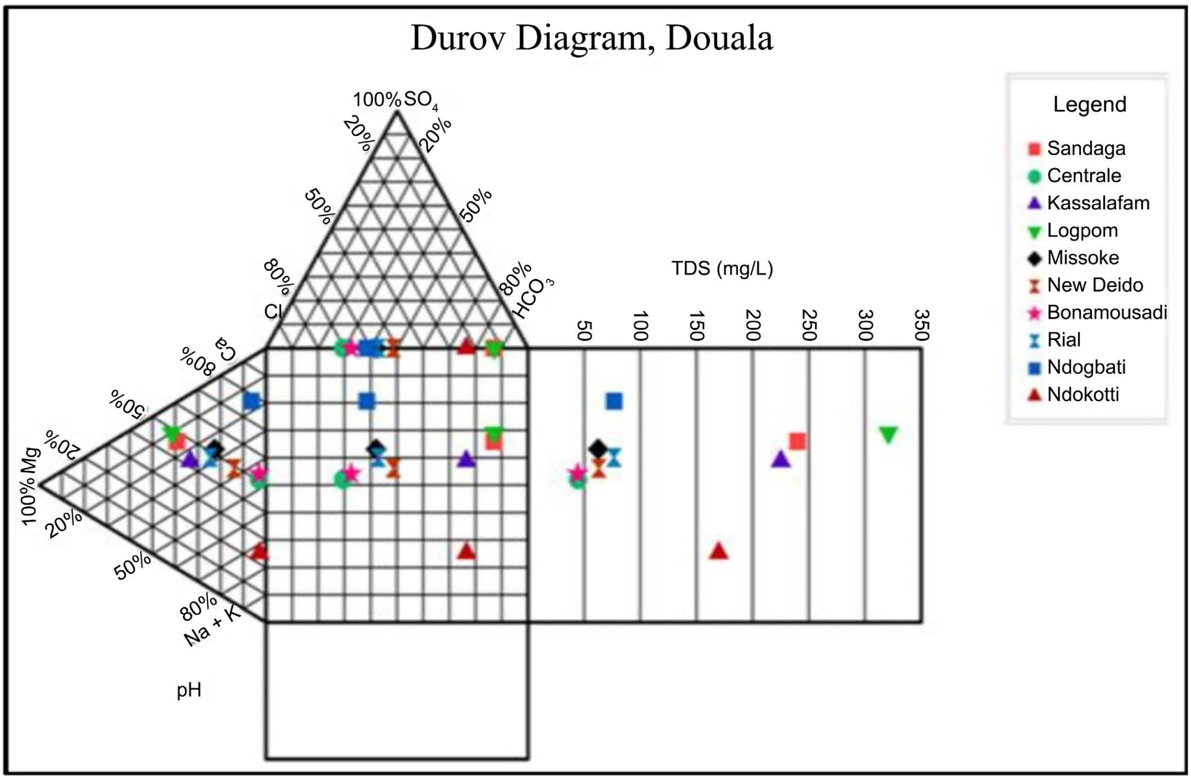


Figure 9. Durov diagram of packaged groundwater in Douala.

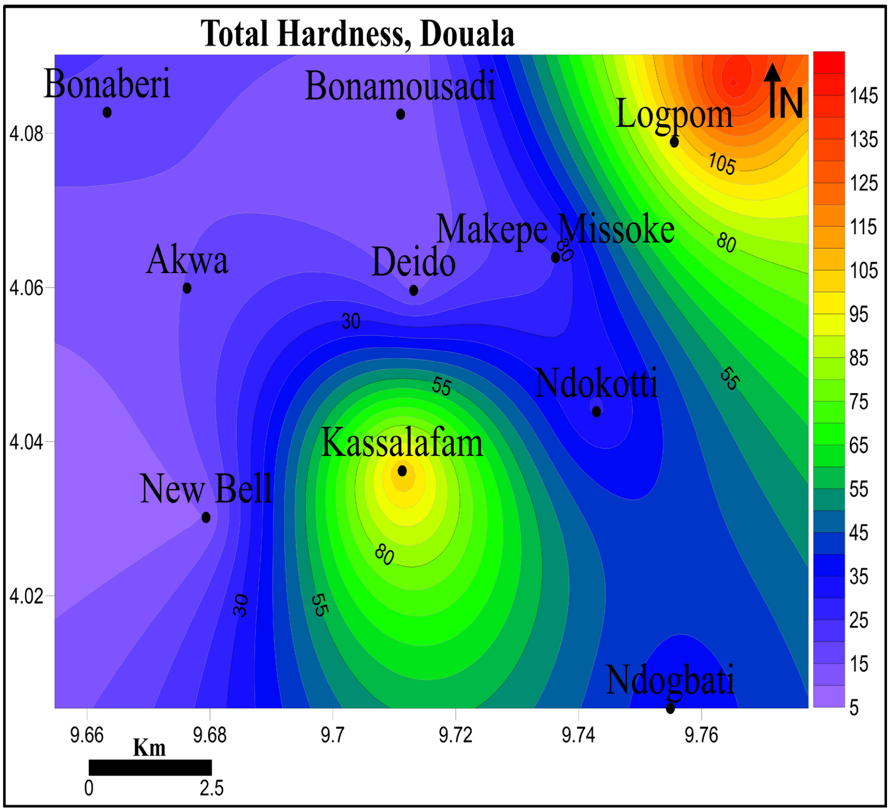


Figure 10. Total hardness for packaged groundwater in Douala. Relatively high values occurred in Logpom.

3.6. Microbial Test Results

The MPN (Most Probable Number) of coliforms per 100 ml of water samples was determined from tables (Table 7) [37]. The results were mounted on Surfer V12, a GIS platform, to obtain the special variations of MPN of coliforms per 100 ml of water in Douala.

From laboratory results, the MPN of coliform per 100 ml of packaged groundwater it was found that, in the wet season; 50% of Sachet, 100% of Bottled and 50% of Refilled packaged groundwater were unacceptable while in the dry season; 100% of Sachet, 75% of Bottled and 60% of Refilled packaged groundwater were acceptable for drinking water set by Cheesbrough [37] as in Table 8. The presence of coliforms made some packaged groundwater unacceptable. There was greater coliform contamination of faecal origin in the packaged groundwater in the wet season than the dry seasons and packaged groundwater that contains coliform is not suitable for use [38]. The poor quality of some of the packaged water is considered dangerously unhygienic and thus of great concern.

Table 7. Results of most probable number (MPN) of Coliform Bacteria (CB) per 100 ml of packaged groundwater and classification [37].

SN	Source Location	Package Type	Wet Season		Dry Season	
			MPN	CB	MPN	Remark
1	Bonaberi	Sachet water	2	U	0	A
2	Grand Hanger	Sachet Water	18	U	0	A
3	Bonasama	Sachet Water	30	U	0	A
4	New Deido	Sachet Water	0	A	0	A
5	Sandaga	Sachet Water	0	A	0	A
6	New Bell	Sachet Water	0	A	0	A
7	Mboppi	Bottled Water	4	U	0	A
8	Douche	Bottled Water	0	U	0	A
9	Makepe Missoke	Bottled Water	8	U	16	U
10	Duble Balle	Bottled Water	10	U	0	A
11	Bonamousadi	Refilled Water	0	A	26	U
12	Kasalafam	Refilled Water	0	A	0	A
13	Ndokotti	Refilled Water	0	A	0	A
14	PK 14	Refilled Water	1	U	0	A
15	PK 12	Refilled Water	11	U	0	A
16	Dakar	Refilled Water	0	A	23	U
17	Ndogbatti	Refilled Water	24	U	0	A
18	Ange Raphael	Refilled Water	1	U	1	U
19	Logpom	Refilled Water	37	U	32	U
20	Sake	Refilled Water	0	A	0	A

A (Acceptable); U (Unacceptable).

Table 8. Faecal (MPN) contamination in packaged groundwater in Douala.

SN	Package type	Wet Season		Dry season	
		acceptable	unacceptable	acceptable	Unacceptable
1	Sachet (06)	03(50%)	03(50%)	06 (100%)	00 (0 %)
2	Bottled (04)	00 (0%)	04 (100%)	03 (75%)	01 (25%)
3	Refilled (10)	05 (50%)	05 (50%)	06 (60%)	04 (40%)

4. Discussion

Though there is a seasonal variation of pH, temperature, EC, and TDS, all physicochemical parameters are within the WHO limit in the groundwater in Douala. High temperatures throughout the year can account for the high temperature values obtained in the wet and dry season. The pH was acidic to neutral. This can be attributed to the dissolution and draining of decomposed vegetable materials and other biodegradable wastes from the surroundings by runoffs. Low values of EC and TDS signify the absence of dissolved solutes in the water, classifying the packaged groundwater in the Douala as fresh (TDS < 1000 mg/L). HCO_3^- and Cl^- were the major anions. The higher occurrence of HCO_3^- which is the main alkaline factor in almost all water are indicative of the diverse salinization sources including precipitation, halite dissolution, other enriched clayey sediments, agricultural and domestic sources [39]. Durov and Piper diagrams illustrated that simple mineral dissolution during recharge or mixing is the main hydrogeochemical process involved, with major dominant cation and anion being Na^+ and HCO_3^- respectively. There are two main water types; $CaHCO_3$ > $MgHCO_3$ and 3 hydrogeochemical facies present [Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-}] > [Ca^{2+}-Mg^{2+}-HCO_3^-] > [Na^+-K^+-HCO_3^-]. Gibb's diagram showed that the mechanism controlling water chemistry in Douala is rock-weathering interaction and atmospheric-precipitation dominance. This is similar to results gotten by [40] in Kumba and [29] in Yaounde. The WQI indicates that all packaged groundwater are chemically suitable for consumption and other utilitarian purposes as they belong to the excellent water quality class. The values of total hardness were low indicating that the water is safe for consumption and beneficial towards health. The coliform counts for some packaged water were unacceptable for both seasons. The poor quality of the packaged groundwater is considered dangerously unhygienic and thus of great concern since coliform indicates the presence of potential pathogens.

5. Conclusions

The physicochemical parameters (pH, electrical conductivities, temperature and total dissolved solids) of packaged groundwater are below WHO guideline acceptable limits. The total packaged groundwater hardness is soft. The main packaged groundwater types are in the order $CaHCO_3$ > $MgHCO_3$ and Main hydrogeochemical facies present are in the order [$CaMgHCO_3$] > [$CaMgSO_4$] >

[$NaKHCO_3$]. The hydrogeochemical processes controlling the groundwater is simple dissolution and ion exchange.

The biological quality of some packaged groundwater was unfit for human consumption.

The poor quality of the packaged groundwater is considered dangerously unhygienic and thus of great concern.

The poor quality of the packaged groundwater is probably due to errors in the processing and packaging of the water. Packaged groundwater companies must have higher quality monitoring control.

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Availability of Data and Material

All data submitted were generated from this study

Conflicts of Interest

The authors have no conflicts of interest to declare.

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