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Determination of Groundwater Corrosion Indices in Yaounde - Cameroon: Seasonal Variations

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Abstract

This study determined the encrustativity, corrosivity, aggressivity indices of the groundwater and its variability with seasons in Yaounde. Six indices, Puckorius (PSI), Langelier (LSI), Ryznar (RSI), Larson–Skold (LI), Aggressivity (AI) and Corrosivity (CI) were programmed in Microsoft Excel and their spatial variations illustrated using Global Mapper18 and SurferV18. From the range of values for the model indices; LI is 80% non-corrosive, 15% corrosive and 5% highly corrosive in the wet season while 50% non-corrosive, 25% corrosive and 25% highly corrosive in the dry season. The PSI of the groundwater is encrusting in the wet season and corrosive in the dry season; LSI is corrosive in both seasons; RSI is intolerably corrosive in both seasons. Comparing these values of the six stability indices with seasons elucidated that groundwater of Yaounde is encrusting in one season and corrosive in another and there is variation in the percentage of corrosion, suitability and scaling indices. Carrying out groundwater tests only in one season might lead to errors in selecting material types, planning/construction of groundwater supply networks, selecting the best methods to prevent corrosion and storage of network replacement components, which may pose serious network management challenges. This potential to cause damage to groundwater supply infrastructure in Yaounde needs to be factored in present network planning, remediation and management to proffer solutions to such networks.

Keywords: *Groundwater; Corrosion-indices; Seasonal-variations; Yaounde-Cameroon*

1. Introduction

Yaoundé city, Mfoundi division in the Centre Region is the capital city of Cameroon is situated between longitudes 11.42˚E to 11.56˚E and latitudes 3.78˚ to 3.92˚N with elevations of 550 - 772 m. a.m.s.l (meters above mean sea level) covering an area of (12.41 Km × 17.12 Km) 212.46 Km^2 shown in Fig.1.

The main activities carried out in the study area seat of all ministerial head offices are mostly the business of government, industrial activities and small scale agriculture. Yaoundé has a typical Classic equatorial Guinean climate which is tropically wet and dry with a regular and abundant precipitation (1600 mm per day), an average annual air temperature of approximately 24˚C and an evaporation of about 800 mm per year [1]. This climate is characterized by four seasons: Four months of rainy season, from mid-August to mid-November and four months of dry season from mid-November to February with a short rainy season from March-June and a short dry season from July-August. Yaoundé's population is 3.066 million with a growth rate between 6% and 8% per annum [2]. This growth rate far exceeds the rate of development of infrastructure. As such, the government is left with a fire-brigade-reflex of pre-planned new-layouts and lots in response to housing; hoping other services will follow later. This results in chaotic urbanization which makes the development of water supply infrastructure problematic [3]. In Cameroon, pipe-borne water supply systems from the state utility are presently catering for the needs of less than 50% of cities and towns. In Yaoundé, less than 30% of households have direct access to drinking water from the state water supply utility company. The rest is supplied through networks by groundwater from borewells 40%, gravity catchment/Springs 10% and surface rivers / streams 20%. This is due to the fact that groundwater levels are shallow, dugwells/catchments are easier to construct, need less complex technical skills, are cheaper and as such more cosmopolitan [3]. Many researchers have carried out research on selected groundwater topics in the whole or parts of Yaoundé and environs. Notable amongst them are a comprehensive hydrogeological evaluation of the flow dynamics of the phreatic aquiferous formations in Yaounde[4]; mass balance of Nitrogen and Potassium in parts of Yaoundé [5]; assessment of groundwater quality for domestic and irrigation purposes in parts of Yaoundé [6]; use of geoelectric tools to explore the lithostratigraphy of the aquiferous formations in parts of Yaounde [7]; assessment of bacterial contamination in the Mfoundi Watershed and [8] modeling of groundwater flow in Yaounde IV district [1].

Piping, fixtures, valves, joints, storage reservoirs and pumps along the supply line are subject to encrustation, corrosion, aggressivity and suitability and this is a major threat to the proper functioning of various household and industrial supply networks and plants. Corrosion is the electrochemical deterioration of physical and chemical properties of materials due to interactions with its environment. Materials can be metals, polymers (plastics, rubbers), ceramics (concrete, brick) or composites mechanical mixtures of two or more materials with different properties [9] Corrosion is a physicochemical process which occurs between a substance and its surroundings and results in changing the properties of materials [10] The most important factors which can affect the corrosion rate include pH, temperature, hardness, alkalinity, residual chlorine, total dissolved solids (TDS), gases, dissolved salts, and microorganisms in water. From hygienic and economic points of view, these factors play an important role in corrosion and scaling in water supply utilities [11, 12]. In addition, the most important health problems related to corrosion are the presence of heavy metals like lead, copper, zinc, and arsenic in drinking water [13]. Pitting in pipes, reducing the lifetime of storage facilities and loss of water through leakages are consequences of the corrosion characteristics of water. Damage related to the corrosion process in countries such as Japan, America, Great Britain, Australia, and several other countries was several times higher than their gross domestic product [14].

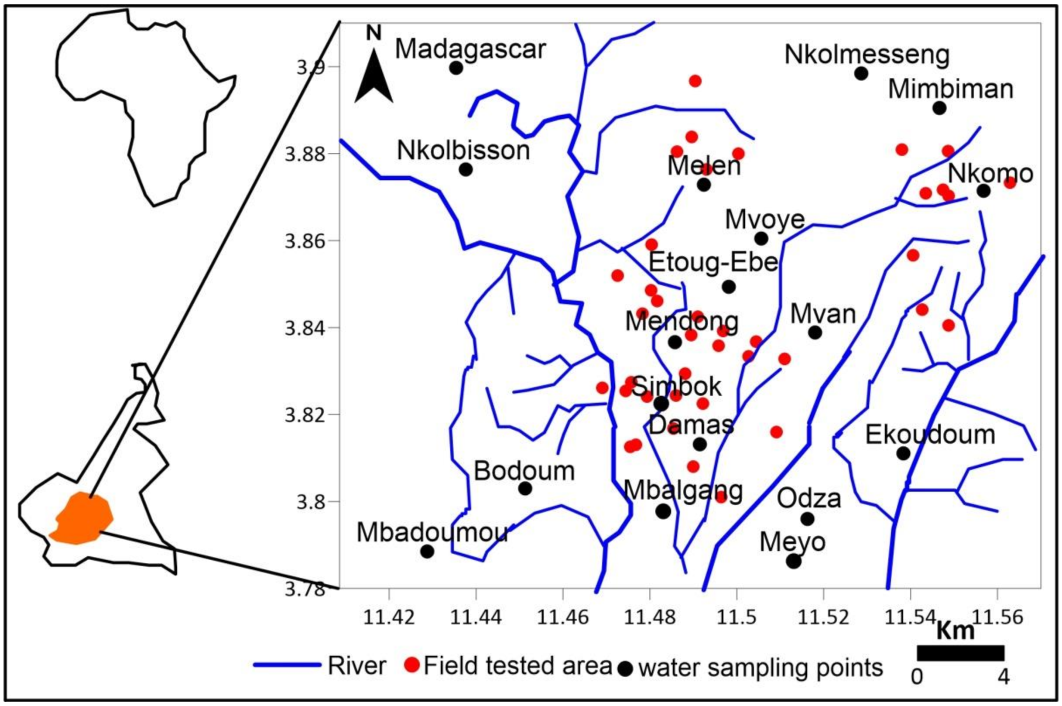

Fig. 1 Groundwater tests and sampling sites in Yaounde and environs

Scaling is a process in which divalent cations such as calcium and magnesium react with other water-soluble substances and form a thin layer in the inner walls of water pipe lines [15, 16]. The most common scaling layers are made of calcium carbonate. The scaling process can cause problems such as blocked tubes, reduction of the water discharge and the water pressure in the distribution network as well as increasing the operation and maintenance costs [17]. Four major problems related to groundwater industrial quality on supply networks are the possibility of encrustation (scaling), corrosion, aggressivity and suitability [18-22]. Internal corrosion of metal pipes is usually seen in water distribution systems of many communities [23-26]. Corrosion occurs when water reacts with or dissolves metal plumbing [27, 28]. Corrosion may cause the leaching of contaminants which increase the concentrations of metals in drinking water [29, 30]. As such, regular monitoring of groundwater industrial quality (encrustation, corrosion, aggressivity and suitability) impact on supply networks is a key factor during operation and management of such networks. The longevity of industrial equipment and the quality of finished products could be impacted by groundwater effects on the groundwater supply networks. The determination of the scaling and corrosion indices of groundwater in the distribution system seeks to preserve the basic characteristics of groundwater during its conveyance from the point of production to the households and industry.

In Yaounde the water supply network infrastructure was designed for surface water sources. Increasing population and water scarcity has forced most people and industries to resort to boreholes as the major source for their water. However, the groundwater effect on these supply networks is not always evaluated. This could be a serious problem since the effects of the groundwater on the supply network and infrastructure could be destructive if the corrosion indices are not determined for groundwater during the wet and dry seasons. This study of Yaounde to determine the encrustative, corrosive, aggressive and suitability indices for the precipitation of calcium carbonate by the groundwater and its variability with seasons which has not been dealt with by the other researchers is of prime importance.

1.1 Hydrology, Geology and Hydrogeology

Yaounde city is drained by the Mfoundi River and its many tributaries. The stream and river network is dense and dendritic (Fig. 1). The Yaoundé series are a group of rocks that outcrop extensively around the Yaoundé city. They belongs to a regional scale mapped unit thrusted southwards unto to the Congo craton that resulted from the collision of the northern Cameroon basin and the Congo craton to the south.

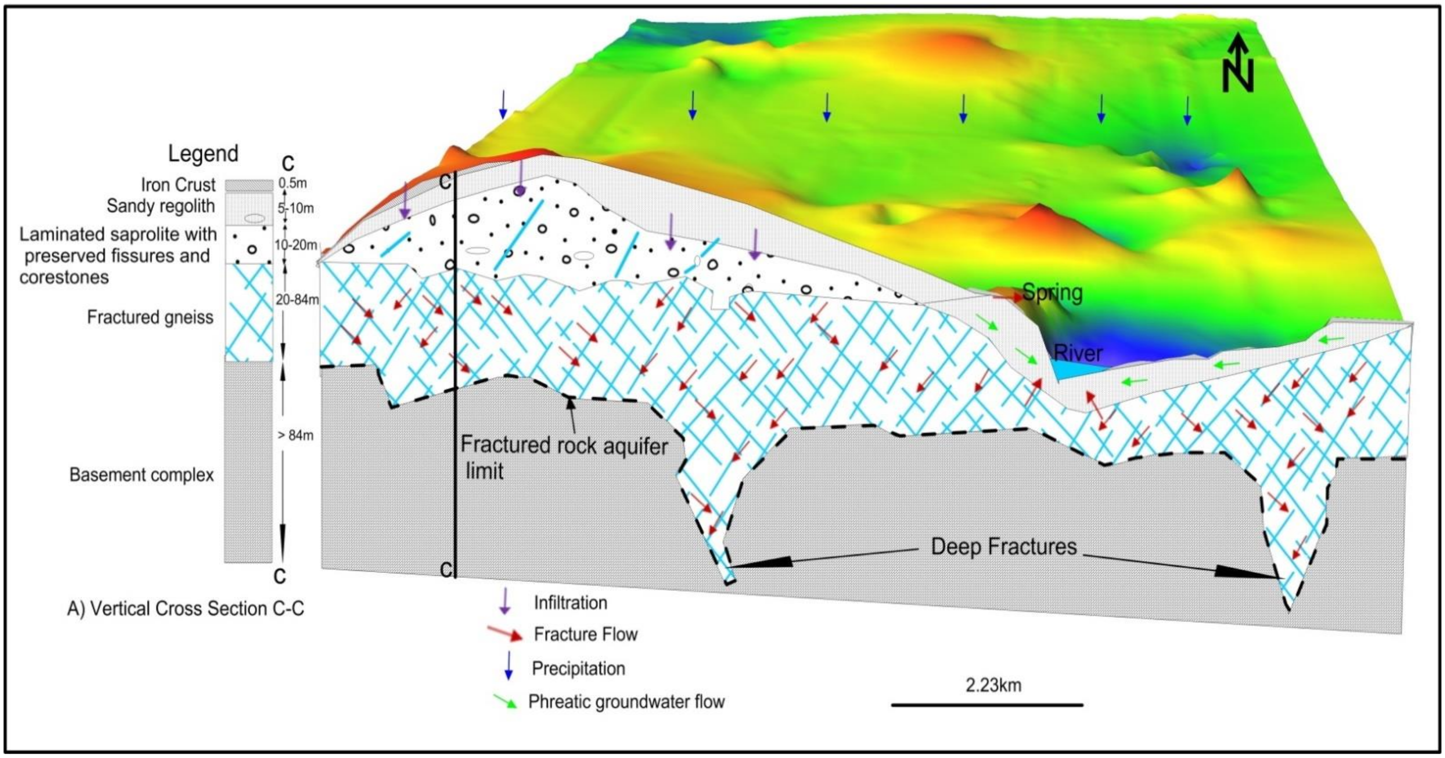

Fig. 2 Conceptual model Geology of weathered migmatite/gneiss-type aquifer in Yaoundé [3]

As a result of this collision, rocks of the Yaoundé series were squeezed and pushed over the Ntem and Nyong complexes by thrusting. Following this collision, the rocks of the northern Cameroon basement and those of the Congo carton were then fused together by the Yaoundé series to form a suture zone leading to the Yaoundé series having a high dip to the south. The Yaoundé series comprises of low to high garnet-bearing metapellites and orthogneisses metamorphosed under a medium to high pressure metamorphism reaching the granulite facies (T = 750˚C - 800˚C and P = 100 - 1200 Mpa). Meta-intrusive rocks include mafic to intermediate rocks; pyroclasites and serpentinized chromite and nickel, ferrous ultramafic rocks associated with gabbro, diorites and mafic dykes. The Yaoundé gneisses were probably derived from the metasediments of shales and greywacke deposited in an extensional environment related to the Congo craton [31].

This basement consists of insoluble and impervious migmatites, gneisses and schists transpierced by faults and diaclases that give fissure permeability to the anisotropic and heterogeneous formations, which are highly weathered, producing predominantly well-drained Ferralitic soils [4]. These weathered soils with relics of fractures from the pristine rocks serve as aquifers for shallow groundwater, while fractures and faults in deeper unaltered rock constitute the deeper aquifer. The hydrodynamic functioning of the weathered horizon-fresh rock system acts as a two layer aquifer components he weathered horizon constitutes a shallow aquifers with thickness that varies from about 1 to 20 m, with a hydraulic conductivity from 10−4 to 10−6 m/s (Fig. 2).

Due to the undulating nature of the relief, the shallow aquifer gives rise to springs that ooze at the base of slopes forming spring lines and wetlands, which serve as discharge zones (springs and shallow wells) of water for domestic use and subsistence agriculture [3].

2. METHODOLOGY

A reconnaissance survey was carried out to identify wells, springs and streams in September 2020 as per [32]. Seasonal tests/measurements were carried out in October 2020 and March 2021 Wet season and Dry season respectively. 421 dug wells, were measured/tested insitu for: coordinates of wells, Surface elevation, Well water level, Dug wells depths, well diameter, pH, Total dissolved solids (TDS) and Temperature (^{o}C).

Seventy-five (75) groundwater samples; 40 wet season and 35 dry season were collected in a high density polyethylene (HPDE) 500 ml bottles sealed and sent to the laboratory as per sampling protocols; [33, 34] using the standard methods [35] to analyze for:

1. Major cations in mg/L: Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} NH_4^{+}.

2. Major anions in mg/L: HCO_3^{-}, Cl^{-} and SO_4^{2-}.

Mathematical formulae for models determining the various indices have been used for determining calcium carbonate saturation.
These are grouped into six model indices namely;
a) Langelier saturation index (LSI) model indicates water saturation level of calcium carbonate. This index defines the concept of saturation through pH as a main changeable factor. LSI measures the pH changes required to bring water to equilibrium [36]
b) Rayzner Sustainability index (RSI) reveals the correlation between the saturated state of calcium carbonate and formation of scale layers. In RSI, pH_s is determined by considering factual pH, calcium and bicarbonate ion concentrations, total dissolved solids, and temperature [37]. The RSI determines the severity of encrustation and corrosion on water supply networks. According to the Ryznar index, when the value of the index is less than 7, calcium carbonate is deposited on the pipe wall and when the value of the index is higher than 7, there is no deposition on the wall of the conduit piping.

c) The Larson–Skold index (LI) assesses the corrosiveness of water in the presence of steel pipes with low-carbon steel, PVC and cast-iron pipes [37].
d) Puckorius scaling index (PSI) gives the buffering capacity of water representing maximum possible scale formation at equilibrium state. PSI is experimental and represents the relationship between the state of saturated water and scaling. Values obtained in this equation are similar to those of the Rayzner index) [38, 39].
e) Aggressive index (AI) or Invasion scale index or aggressivity is concerned with the rate at which the water damages pipes, pumps, valves, Stop corks, storage tanks and other infrastrucure. It was developed according to a request of American consulting engineers to choose a type of asbestos - cement pipe and ensuring the durability structural resistance of pipes to corrosion at temperatures between 4 and 27 °C. Aggressive index (AI) is mostly used for asbestos and cement/concrete components used in the storage and supply network. It

assesses the impacts of some parameters such as pH, calcium concentrations, and alkalinity on groundwater corrosion and scale formation quality.

f) Corrosive Index (CI) measures the rate of corrosion in the network. The buffer capacity of water and the maximum amount of natural deposit by water are generally ignored in most calculations of the corrosiveness of water [37].

In other words, LSI and RSI indicate the difference between factual pH and saturated pH, caused by calcium carbonate in water. These formulations are given in table1.

Table 1: Formulae used for various model indices determination of groundwater industrial quality

SN	Model Index	Formulae	Industrial Groundwater Quality					
1	Langelier index (LSI) (1936)	$LSI = pH_A - pHs$	LSI<0 Corrosive		LSI=0 Neutral		LSI> 0 Encrusting	
2	Ryznar stability index: RSI (1944)	$RSI = 2pHs - pH_A$	4.0-5.0 Strongly Encrusting	5.0 - 6.0 Slightly Encrusting	6.0 – 7.0 Slightly Corrosive	7.0 – 7.5 Significantly Corrosive	7.5 – 9.0 Strongly Corrosive	I ≥ 9.0 Intolerably Corrosive
3	Larson-Skold index: LI (1958)	$LI= (Cl^- +SO_4^{2-}) / (HCO_3^- +CO_3^{2-})$	LI < 0.8 Non Corrosive		0.8 ≥ LI ≤ 1.2 Corrosive		LI > 1.2 Highly Corrosive	
4	Puckorius index (PSI) (1980)	$PSI = 2pH_{Eq} - pH_S$	PSI < 4.5 Encrusting		4.5 ≤ PSI ≤ 6.5 No Corrosion (Optimum)		PSI > 6.5 Corrosion	
5	Aggressivity index: AI(1995)	AI = pHA +C+D	AI < 0.8 or AI>12 Non-Aggressive		10 > AI < 12 Moderately- Aggressive		0.8 ≥ AI ≤ 10 Very Aggressive	
6	Corrosivity index: CI(1936)	$CI = (Cl\text{-}/35.5+2SO_4^{2-}/96) / [(CO_3^{2-} +HCO_3^-)/100]$		CI < 1 Suitable			CI ≥ 1 Unsuitable	

pH_A = Actual pH value of the sample; pH_{Eq}= Equilibrium Ph; A= (log [TDS] -1)/10; B= −13.12×log (T) +34.55

pHs = pH at saturation in $CaCO_3$; $pH_S = (9.3+A+B) - (C+D)$; $pH_{Eq} = 1.465×log (T.alk) +4.54$; C= log [Ca2+] - 0.4; T= Kelvin temperature of water sample

(T.alk) = Total alkalinity; D= log [T.alk]

3. RESULTS AND DISCUSSION

From physicochemical parameters in the rainy season, pH ranged from, 7.1- 8.5; Temperature, 20.31 – 27.22^{0}C and TDS, 10- 520 mg/L while in the dry season, pH ranged from 7.01 – 8.92; Temperature, 18.90 – 22.02^{0}C and TDS, 10- 510 mg/L. Puckorius Scaling Index (PSI) is 100% encrusting in the wet season and 100% corrosive in the dry season; Langelier Saturation Index (LSI) is 100% corrosive in both wet and dry seasons; Ryznar Stability Index (RSI) is100% intolerably corrosive in both wet and dry seasons; Larson-Skold Index (LI) is 5% highly corrosive, 15% corrosive and 80% non-corrosive in the wet season while it is 11% highly corrosive and 89% non-corrosive in the dry season; Aggressive Index (AI) is 100% very aggressive in both seasons and Corrosivity Index (CI) is 70% suitable and 30% unsuitable in the wet season, while 86% suitable and 14% unsuitable in the dry season (Table 2).

Table 2: Summary of model indices for the effect of groundwater on water supply networks in Yaounde

SN	Index	Wet Season				Dry Season			
		Mean	Range	No	(% sample)	Mean	Range	No	(% sample)
1	Puckorius Scaling Index (PSI)	2.82	1.58 - 4.85	40	Encrusting (100%)	127.98	126.74 - 129.54	35	Corrosive (100%)
2	Langelier Saturation Index (LSI)	- 4.66	- 6.16 - -2.23	40	Corrosive (100%)	- 69.61	- 71.40 - -67.27	35	Corrosive (100%)
3	Ryznar Stability Index (RSI)	17.02	12.85 – 19.91	40	Intolerably Corrosive (100 %)	146.85	142.94 – 149.81	35	Intolerably Corrosive (100 %)
4	Larson-Skold Index (LI)			33	No corrosive (80%)			31	No corrosion (89%)
		0.11	-3.47 - 2.33	4	Corrosive (15%)	0.30	0.04 - 3.84	4	Highly Corrosive (11%)
				3	Highly Corrosive (5%)				

5	Aggressive Index (AI)	6.89	5.44 - 9.31	40	Very aggressive (100%)	6.65	4.83 – 8.98	35	Very aggressive (100%)
6	Corrosivity Index (CI)	0.28	0.06 - 1.41	35 5	Suitable (70%) Unsuitable (30%)	0.22	0.06 - 1.35	30 5	Suitable (86%) Unsuitable (14%)

Thus these indices are very variable with seasons shown in spatial variation diagrams in figures 3, 4, 5, 6, 7 and 8.

PSI, LSI, RSI, LI, AI and CI are designed to be predictive tools for calcium carbonate scale and only that they are not suitable for estimating calcium phosphate, calcium sulfate, silica or magnesium silicate scale. These indices can only be used accurately for untreated water (groundwater) or with treatments (phosphonates and acrylates) that “solubilize” calcium carbonate.

Table 3: Yaounde groundwater chemistry during the wet season

SN	Place	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	pH	ºC	TDS
1	Nsam	0.37	3.67	13	7.21	25.6	1.6	14	8.1	20	50
2	Nsam	0.71	3.76	26	9.58	9.76	3.2	36	8.2	23	60
3	Nsam	0.58	2.03	17.4	7.14	11	4.1	42	7.1	22	50
4	Nsam	0.14	0.74	8.68	5.59	19.5	0.9	14	7.6	22	60
5	Nsam	0.41	2.73	17.4	8.9	6.1	2.1	1	7.7	23	40
6	Tamtam	1.17	11.7	43.4	14.2	29.3	5.2	96	8.2	21	50
7	Tamtam	0.05	1.48	8.68	4.43	6.1	0.8	4	8.3	25	70
8	Tamtam	0.94	9.67	39.1	18.9	48.8	4.7	64	7.8	25	50
9	Tamtam	2.12	28.9	86.8	15.4	29.9	10	64	7.5	23	30
10	Tamtam	1.27	14.1	47.8	17.4	115	5.9	75	7.9	21	40
11	Simbock	0.16	0.7	4.24	3.6	22.4	0.6	5	7.8	24	70
12	Simbock	0.3	1.12	8.68	6.05	20.7	1.2	4	8.4	23	210
13	Simbock	2.1	30	70.5	12.3	354	14	81	8.4	23	130
14	Simbock	0.2	2.18	10	8.02	28.4	1.7	25	8.5	23	90
15	Simbock	0.34	3.82	18.9	13.6	40	2.4	17	7.7	23	270
16	Nkolmesseng	1.33	11.2	47.8	10.2	20.7	6	64	7.7	25	320
17	Nkolmesseng	0.9	8.23	34.7	10.9	24.4	4.3	32	7.4	25	270
18	Nkolmesseng	0.44	2.03	21.7	10.2	24.4	2.5	22	7.7	24	370
19	Nkolmesseng	2.16	19.2	56.4	10.7	157	8	56	7.9	22	380
20	Nkolmesseng	0.76	3.82	21.7	10.4	11	3	29	7.6	25	290
21	Etoug-ebe	0.37	3.12	8.68	8.61	2.44	1.3	24	7.6	23	410
22	Etoug-ebe	0.28	2.03	8.68	7.43	13.4	1.2	8	7.5	27	520
23	Etoug-ebe	0.44	3.28	17.4	13.3	9.76	2.1	14	7.9	23	180
24	Etoug-ebe	0.32	3.67	13	11.7	8.54	1.6	12	7.7	27	310
25	Etoug-ebe	0.28	3.47	17.4	11.2	18.3	1.9	9	7.2	24	60
26	Damas	0.14	0.9	4.34	3.72	20.7	0.6	5	7.2	24	60
27	Damas	0.28	1.09	8.68	7.43	19.5	1.2	4	7.9	24	60
28	Damas	3.31	41.7	113	12.3	369	14	81	7.1	25	60
29	Damas	0.18	2.18	13	8.02	26.8	1.4	25	7.9	23	50
30	Damas	0.41	3.82	21.7	14.8	31.7	2.4	17	7.8	24	40
31	Madagascar	1.93	13.2	56.4	19.7	18.3	7.6	18	8.1	25	10
32	Madagascar	0.76	3.28	26	10.3	23.2	3.3	42	8.2	24	150
33	Madagascar	2.07	19.9	65.1	10.3	84.2	8.5	16	8.1	23	30
34	Madagascar	0.41	3.82	13	1.01	19.5	1.7	8	7.6	25	110
35	Madagascar	0.32	0.55	13	9.83	13.4	1.6	5	7.7	23	30
36	Mimbomann	0.32	1.83	17.4	11.7	17.1	1.9	11	7.2	20	50
37	Mimbomann	0.18	1.48	4.34	4.29	28.1	0.6	3	7.3	20	340
38	Mimbomann	1.08	12.6	43.4	32.9	12.2	5.2	29	7.5	22	50
39	Mimbomann	0.41	0.74	4.34	7.24	13.4	1	11	7.9	23	60
40	Mimbomann	0.81	6.4	26	21.9	26.8	3.9	36	7.6	23	120
	Min	**0.05**	**0.55**	**4.24**	**1.01**	**2.44**	**0.6**	**1**	**7.1**	**20**	**10**
	Max	**3.31**	**41.7**	**113**	**32.9**	**369**	**14**	**96**	**8.5**	**27**	**520**
	Mean	**0.77**	**7.25**	**27.4**	**10.8**	**44.5**	**3.6**	**28**	**7.8**	**23**	**140**
	STD	**0.74**	**9.22**	**24.6**	**5.75**	**79.1**	**3.5**	**26**	**0.4**	**2**	**133**

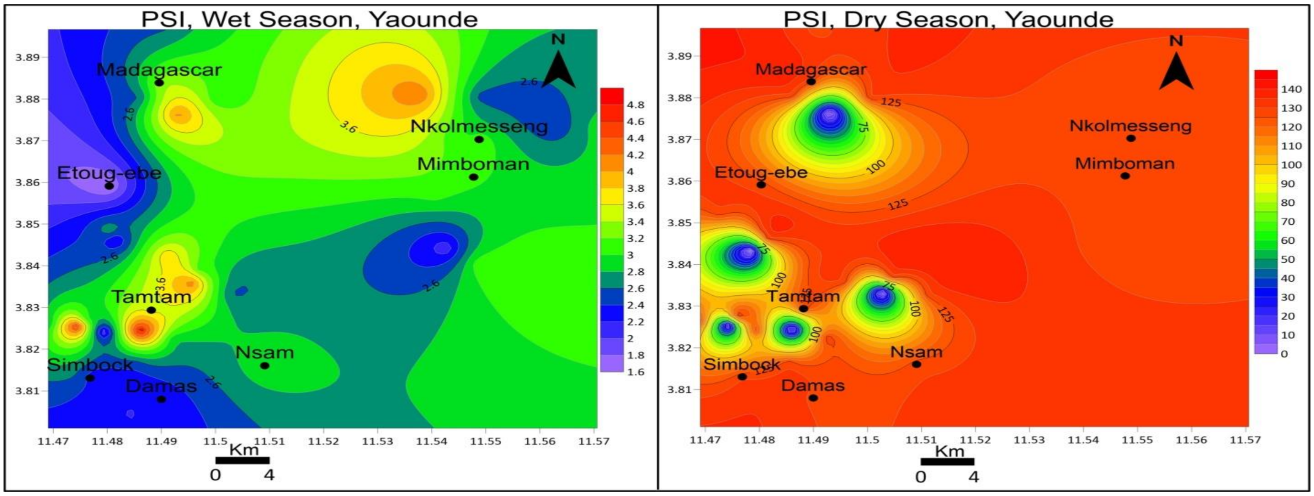

Fig. 3 Puckorius Scaling Index (PSI) is 100 % encrusting in the wet season and 100 % corrosive in the dry season

Table 4: Yaounde groundwater chemistry during the dry season

SN	Place	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	pH	ºC	TDS
1	Nsam	0.46	4.6	16.82	1.65	7.32	2.87	9.5	8	20.3	50
2	Nsam	0.62	3.94	14.01	5.66	4.88	1.69	5.12	8	19.8	30
3	Nsam	0.39	1.72	8.4	8.49	14.64	1.41	3.25	7	20	60
4	Nsam	0.18	0.38	2.81	0.26	7.32	1.23	1.88	7	19.9	50
5	Nsam	0.37	3.16	11.21	2.3	9.76	0.87	1.88	7	20.9	40
6	Tamtam	1.32	12.44	41.36	7.97	40.26	1.91	5.63	8	20	60
7	Tamtam	0.08	0.66	1.38	0.66	23.18	2.51	4.53	7.9	20.9	80
8	Tamtam	2.01	24.77	74.45	5.14	86.62	13.36	17.58	8.1	20	40
9	Tamtam	0.91	8.62	24.81	2.44	31.72	4.06	1.79	8.3	19.2	40
10	Tamtam	1.5	14.82	44.13	1.98	68.32	8.94	0.42	8.9	18.9	30
11	Simbock	0.09	0.56	3.18	4.2	40.65	1.69	1.89	7.8	21	80
12	Simbock	0.28	0.86	6.76	1.45	27.07	1.09	1.37	7.8	19.2	210
13	Simbock	3.42	17.84	40.65	5.99	287.45	6.89	89.2	8.4	21	130
14	Simbock	0.32	2.54	9.56	6.32	12.98	1.55	27.9	7.8	20	90
15	Simbock	0.46	3.51	13.49	1.38	32.75	1.76	13.02	7.6	20.2	320
16	Nkolmesseng	1.4	13.1	39.3	2.77	13.42	1.32	0.32	7.5	19.9	330
17	Nkolmesseng	1.01	10.06	30.76	0.53	10.98	1	2.95	7.6	21	220
18	Nkolmesseng	0.39	2.11	11.21	5.93	14.64	0.73	1.99	7.9	20.9	310
19	Nkolmesseng	0.3	1.64	8.4	0.26	9.76	0.73	1.68	7.4	19	320
20	Nkolmesseng	0.76	4.41	19.6	4.28	62.22	1.87	1.37	7.3	21.2	210
21	Etoug-ebe	0.08	0.66	2.76	0.92	34.16	4.15	9.68	7.7	20.2	420
22	Etoug-ebe	0.22	0.98	2.76	0	12.2	0.36	0.97	7.7	19.8	510
23	Etoug-ebe	0.3	2.77	11.03	5.4	151.28	25.94	6.95	7.5	21.2	190
24	Etoug-ebe	0.39	2.5	8.27	2.77	6.1	1.5	5.37	7	19.2	340
25	Etoug-ebe	0.45	4.6	13.79	0.99	103.7	6.7	8.74	7.3	20.2	40
26	Damas	0.05	0.98	3.18	4.35	35.38	1.69	0.95	7.7	21.8	70
27	Damas	0.07	0.86	3.18	1.71	26.84	1.09	1.37	7.6	21.9	60
28	Damas	3.42	17.84	32.06	5.99	265.38	7.34	0.74	7.5	20	40
29	Damas	0.23	2.54	9.56	6.32	15.86	1.32	3.26	8.1	20.9	30
30	Damas	0.46	3.16	12.74	1.38	29.28	1.78	2.53	8	21	10
31	Madagascar	1.57	16.61	23.8	2.11	40.26	1.91	5.63	8	21	130
32	Madagascar	0.62	3.51	14.78	0.59	23.18	2.51	5.53	7.6	22	40
33	Madagascar	2.55	32.02	44.68	14.16	56.12	1.82	0.63	7.5	21.5	130
34	Mimbomann	0.37	4.8	17.24	2.11	40.26	0.96	0.32	7.5	21.6	40
35	Mimbomann	0.48	6.86	22.16	1.05	17.04	8.71	0.84	7.6	20	70
	Min	**0.05**	**0.38**	**1.38**	**0**	**4.88**	**0.36**	**0.32**	**7**	**18.9**	**10**
	Max	**3.42**	**32.02**	**74.45**	**14.16**	**287.45**	**25.94**	**89.2**	**8.9**	**22**	**510**

Mean	0.7866	6.641	18.408	3.415	47.514	3.579	7.051	7.7	20.4	138
STD	0.8781	7.598	16.235	3.031	64.902	4.87	15.36	0.4	0.84	131

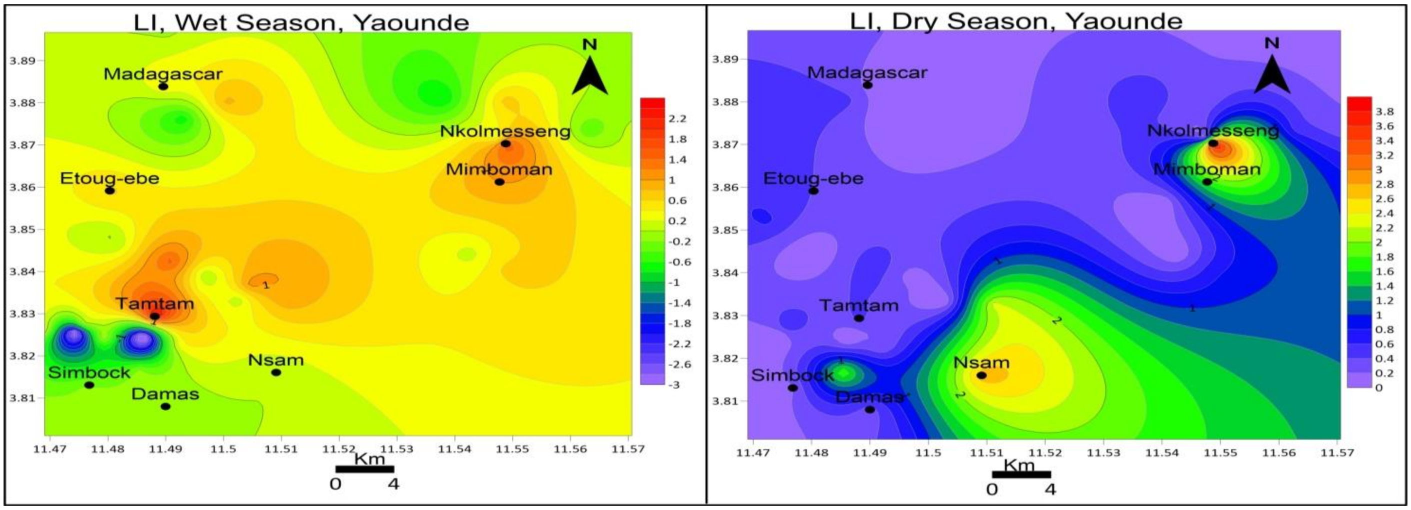

Fig. 5 Larson-Skold Index (LI) is 80% non-corrosive, 15% corrosive and 5% highly corrosive in the wet season while 50% non-corrosive, 25% corrosive and 25% highly corrosive in the dry season

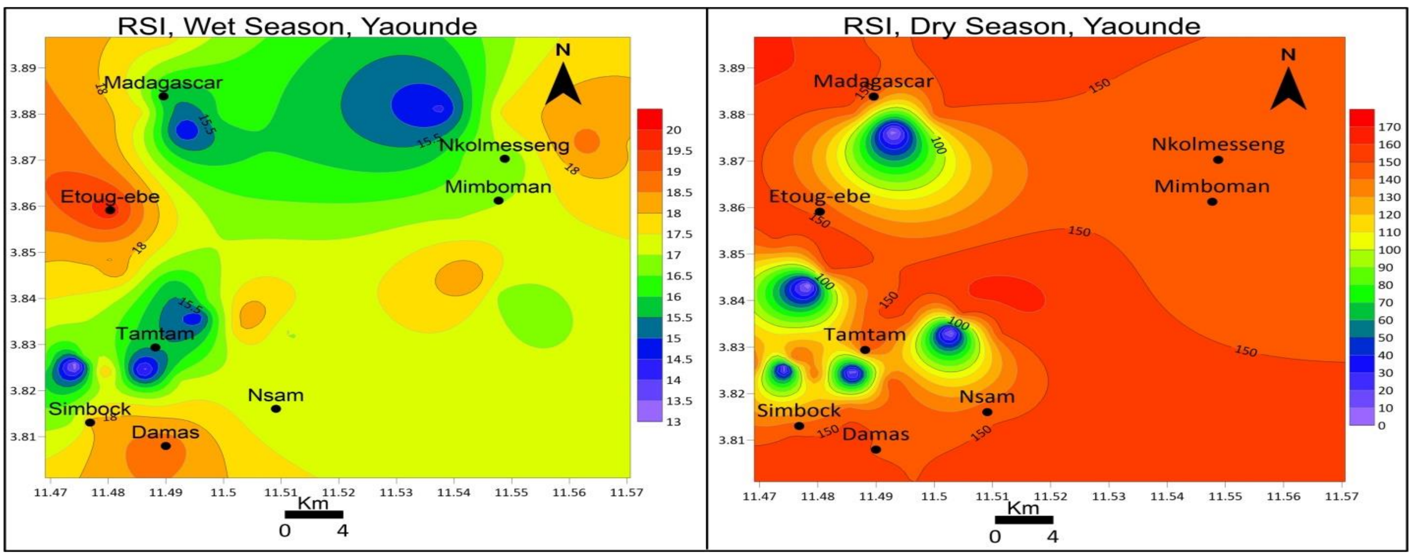

Fig. 4 Ryznar Stability Index (RSI) is 100 % intolerably corrosive in both wet and dry seasons

They are not useful for predicting calcium carbonate scale creation in water already treated with “crystal modifiers” since such treatments (polymaleates, sulfonated styrene/maleic anhydride, or terpolymers) cause foulants to precipitate, but do not result in a true scale.

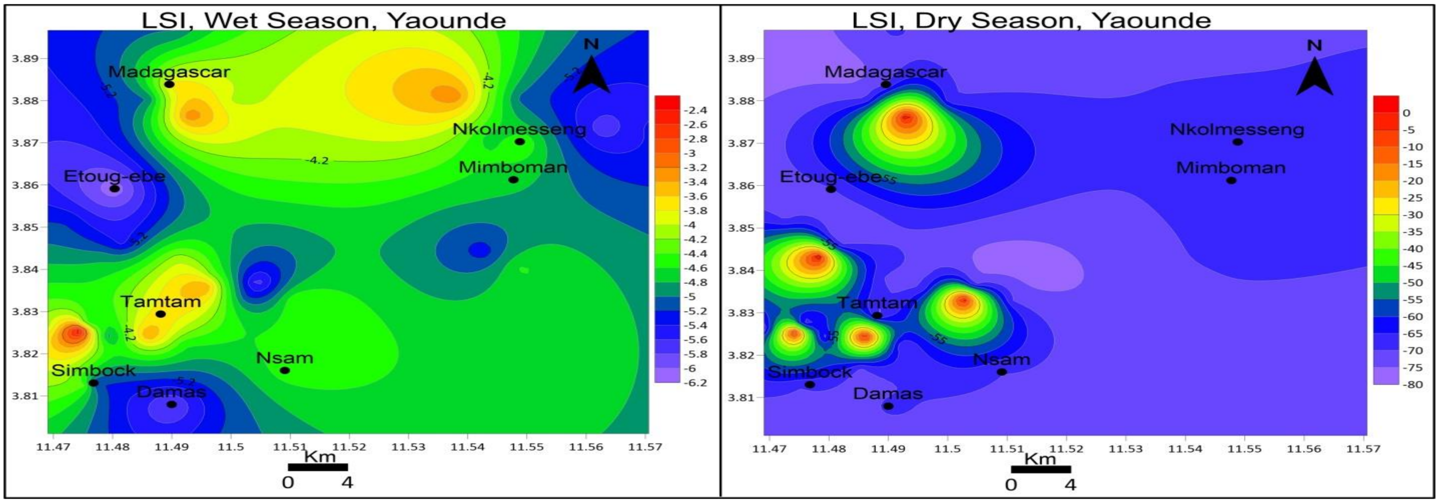

Fig. 6 Langelier Saturation Index (LSI) is 100% is corrosive in both wet and dry seasons

In Yaounde and elsewhere in Cameroon groundwater is supplied after simple filtration through various networks since it is assumed to be clean. Thus the evaluation using these model indices is relevant and applicable. The LSI index may be positive, negative, or neutral. Rather than using the published value of LSI = 0 as a break point, many experienced observers show a preference for values greater than 1.5 or 1.7 (even as high as 2.5) as warning of scale formation and those less than negative 1.5 as indications of aggressive water [40]. Hence, it is now very crucial to monitor the groundwater indices on the supply network in the study area.

Owing to the importance of groundwater, measurements have to be conducted not only to scrutinize water quality and quantity in supply networks, but also to optimize water consumption [41].

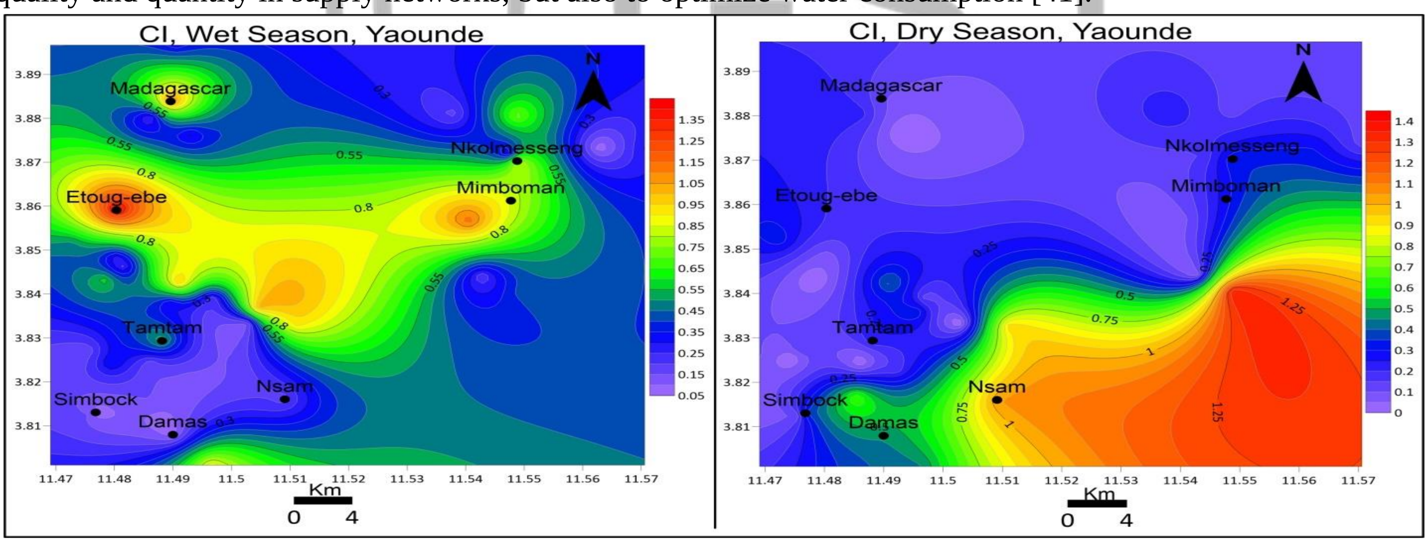

Fig. 7 Corrosivity Index (CI) is 70% suitable and 30% unsuitable in the wet season, while 85% suitable and 15% unsuitable in the dry season.

Groundwater corrosion indices verifications must be considered in planning programs for water asset management and other management activities since failures will lead to significant costs.

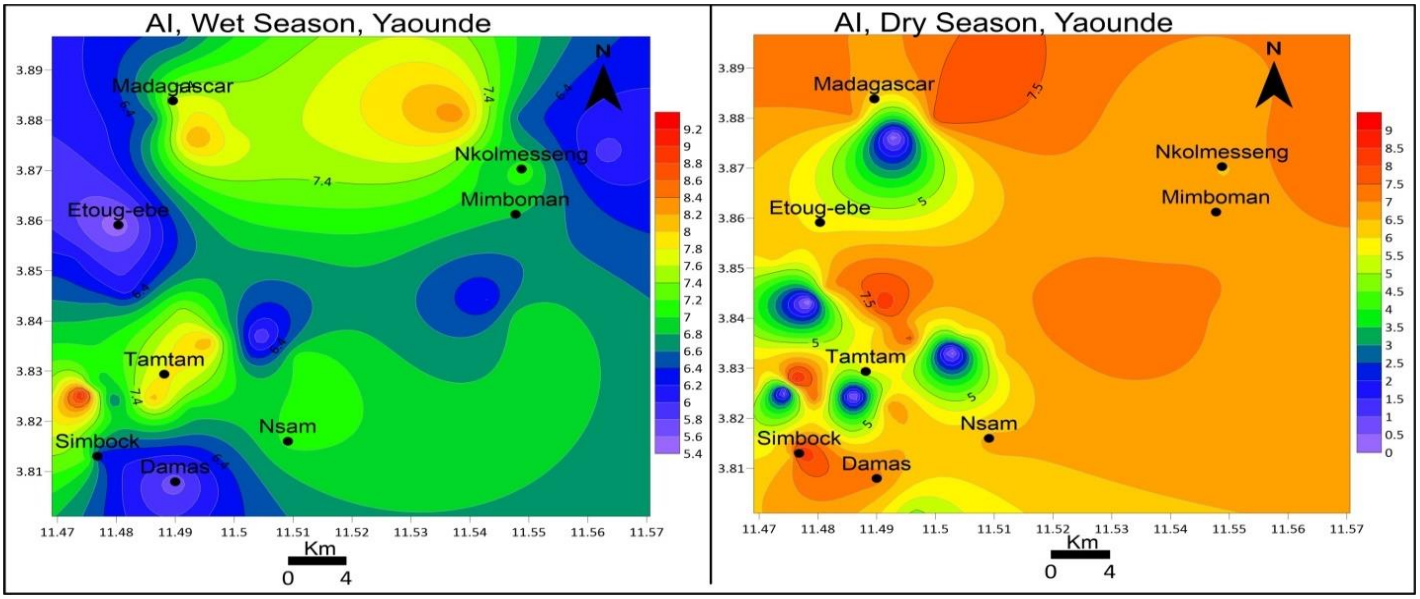

Fig. 8 Aggressive Index (AI) is 100% very aggressive in both wet and dry seasons

This is how certain problems like encrustations are exacerbated and can cause a reduction in groundwater quantity in the long term [42]. Another problem is rooted in the groundwater chemical quality which can cause scale formation and corrosion in treatment equipment and infrastructures [43]. Corrosion is a physical-chemical reaction which is the consequence of exposure to the environment and can cause a plethora of changes in materials.

Potable groundwater and other types of usable groundwater in industry and agribusiness should be non-corrosive in order to be considered appropriate by valid universal standards. Thus, these indices must be monitored regularly. What makes scale formation indices notoriously highlighted is that it causes deficiency in boilers and industrial equipment owing to this phenomenon. Furthermore, it can shorten the life of water supply networks or even deteriorate their function [44]. The dire consequences of scale formation and corrosion include pipes blockages, reduction in groundwater flow, unexpected flaws in pipes, and decay in the inner walls of pipes leading to leakages in pipes and failures in network infrastructures. In such cases, large amounts of water can be lost. Studying measured concentrations and statistical indices can clarify reasons for failures in supply networks. From the indices groundwater in Yaounde could have corrosion and scale formation due to sulfate and chloride anions as was the case in the rural dispensing network of Tabas in Iran [45].

5. CONCLUSION

- The groundwater corrosion indices in Yaounde have been evaluated.

- The groundwater is aggressive and intolerably corrosive in both wet and dry seasons, encrusting in the wet season and more suitable for the precipitation of calcium carbonate on networks infrastructure in the dry season.

- Groundwater in Yaounde exhibits variability with seasons of the model indices, with a great potential to cause damage to groundwater supply networks and infrastructure.

- Since there are potentials for the groundwater to cause damage to supply networks and infrastructure in Yaounde, there is a need to determine the actual damage to pipes and fittings in the high rise buildings and also to proffer solutions to challenges in groundwater supply network planning, remediation and management.

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Author's contributions

Akoachere R. A: Conceptualization, supervision, resources, methodology, writing, the original draft, editing, and validation.

Yaya, O.O: Software, editing Validation

Eyong T. A: software, visualization, data curation, validation.

Egbe S. E: software, visualization, data curation, validation.

Nji, B. N: validation and Editing

Tambe D. B: visualization and validation.

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