Hydrogeological and Hydrogeochemical Investigation of Shallow Groundwater in Gembu, Mambilla Plateau, Nigeria

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Abstract

Hydrogeological and hydrogeochemical techniques were used to investigate shallow groundwater in Gembu, Mambilla Plateau, Nigeria. A total of ninety (99) nine hand dug wells were studied, where their geographic location and ground elevation, well depth, water-level were determined. Thirty three (33) representative samples collected from hand dug wells in the study area were analysed for their physico-chemical characteristics. Standard field and laboratory procedures were taken in the collection and analysis of the water samples. The area is underlain by granitic rocks of two major varieties, biotite granite and alkali feldspar granite, composed mainly of biotite, orthoclase feldspar, quartz, hornblende and opaque minerals. Hydrogeological mapping carried out shows that the elevation of the wells above sea level ranges from 1529 m to 1592 m, while well depths (WD) range from 1.2 m to 55.4 m with most of the wells falling between depths of 3.2 m – 7.7 m. Depth to water (DW) ranges from 0.4 to 52.2 m, with the water column (WC) falling between 0.3 m and 3.2 m. Water level elevation (WLE) which defines the hydraulic head in the area ranges from 1528.3 m to 1585.8 m. Groundwater flows generally towards the eastern portion of the central part of the area, with localized minor low portions , representing local flow directions in western part of the area. The results further show that the physical and chemical parameters of the groundwater are all within the permissible limits of World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ), with the exception of magnesium (Mg^{++}) and iron (Fe^{++}). Only two of the 33 wells had concentration of bicarbonate and phosphate above the permissible limits, hence the water is not considered safe for drinking. The dominant hydrogeochemical facies was found to be sodium-potassium-sulphate-chloride (Na-K+ SO_4^{2-} + Cl^-) type. The dominant process contributing ions to the groundwater in Gembu is rock: water interaction, with minor contribution of domestic effluents and vegetable farming within the metropolis.

Keywords: Hydrogeochemsitry, Water: Rock interaction, Water quality, Gembu, Mabilla Plateau.

1. Introduction

Water is one of the most abundant gifts of life whose numerous uses are fundamental for existence. It could also be a huge threat to health if sufficient measures are not put in place to ensure its suitability for both domestic and industrial purpose. More than half of the world's population depends on groundwater for drinking water purpose; amazingly the resource is widely used and very important to the health and economy of the world. Groundwater occurs in about 98% of the world's fresh water and it is fairly distributed throughout the world. It has good microbiological and organic quality and requiring minimal or no treatment (Foster, 1998) where it occurs in its natural state. The quality of groundwater in any area is a consequence of a combination of geology and human activities, the former been responsible for lithogenic and the later for anthropogenic contamination. Many diseases in rural communities are caused by consumption of contaminated water. This is usually as a result of leaching of rocks, indiscriminate disposal of solid waste, sewage and agricultural chemicals. Ensuring the quality of groundwater is a hydrogeological task that incorporates a detailed study of the rock type and human activities in an area

As population rise the need of water for domestic and various economical purposes rise alongside, since government cannot meet up with expectation of providing adequate water supply, the individual has to device a means of easy access to provide for themselves with little or no consideration to the quality of the water. The people of Gembu, north-east Nigeria basically depend on groundwater as their major source of water through hand dug wells. Quite a reasonable number of wells have been dug by individuals in the area to meet up with the huge demand for water. Many previous workers have studied the subject of groundwater in different parts of Nigeria (Tijani, 1994; Ishaku et al., 2009; Eduvie and Olaniyan, 2013; Kankpe et al., 2014; Afuye *et al*., 2015; Idris-Nda et al., 2013; Sidi et al., 2018 among others). However, little if any, research has been carried out to investigate the characteristics of this very important source of water for the inhabitants of Gembu and its environs. This research is therefore aimed at assessing the hydrogeological and hydrogeochemical characteristics of shallow groundwater in the area, including its suitability for domestic uses.

2. Description of the Study Area

Gembu lies within Mambilla sheet 295SE, north-eastern Nigeria. It is bounded by latitudes 06° 41′ 0″ N and 06° 45′ 0″N and longitudes 11° 13′ 0″E and 11° 17′ 0″E (Figure 1) with an average elevation of about 1,524 meters above mean sea level. The average mean temperature for the town is 21.1 °C, with daytime temperatures hardly exceeding 25 °C and has a minimum temperature of 11 °C. There are two major seasons in Gembu (the rainy and dry season). Rain begins in February to early March and ends in November. The Mambilla Plateau is underlain by undifferentiated Basement Complex rocks which consist mainly of Migmatites, Gneisses and the Older Granites (Grant, 1971, Oyawoye, 1972, Rahman, 1988). Tertiary to Recent basalts also occur in some parts the area, centring on the town of Nguroje (Mubi and Tukur, 2005), while the area around Gembu is underlain mainly by fine to medium grained biotite and alkali granites.

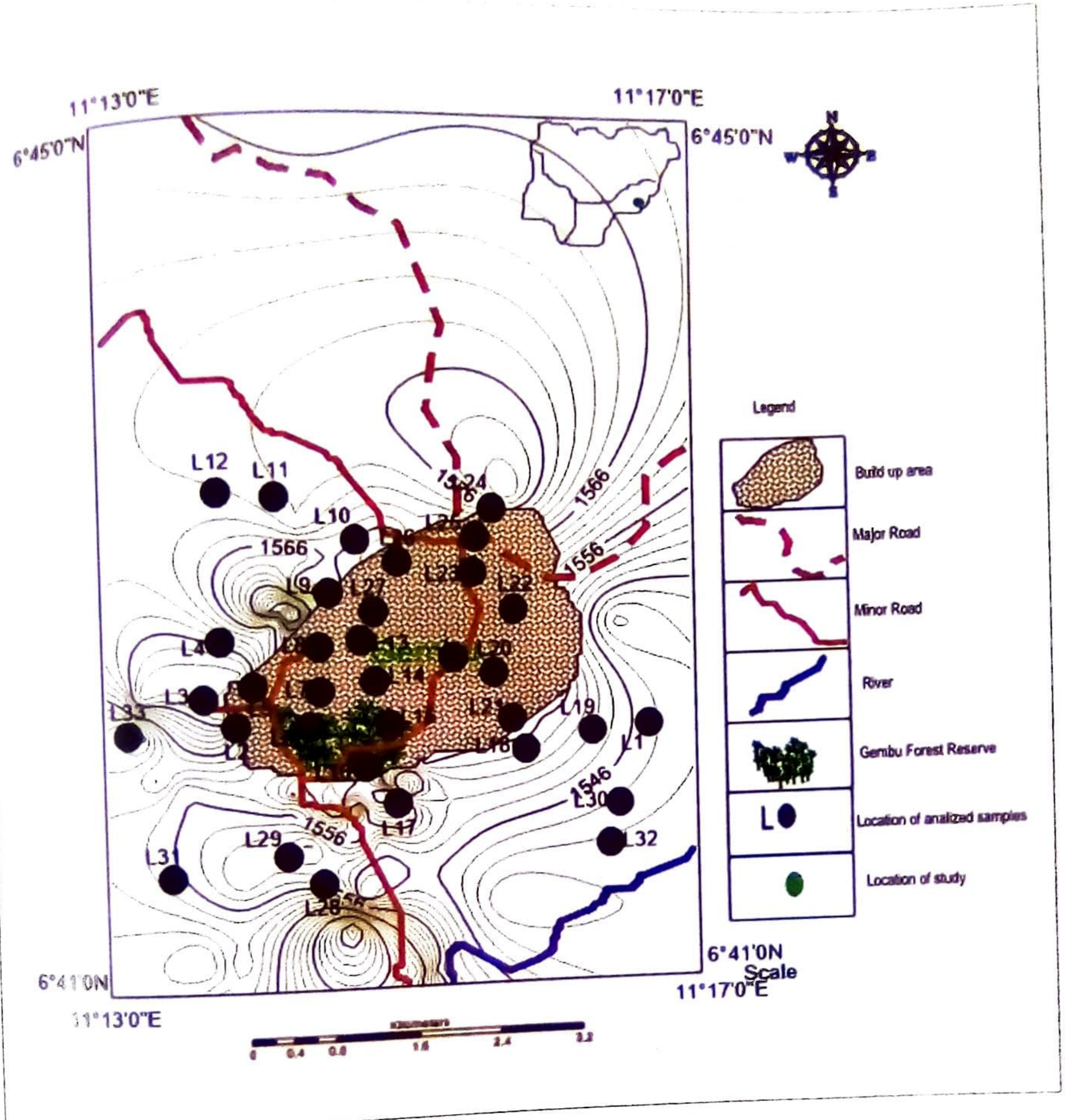

Figure 1: Location of the studied wells in Gembu

3. **Research Methodology**

Geological mapping was carried out to identify the various geological features, mainly lithology and fractures, using traverse method. The geographical coordinates were obtained with the aid of global positioning system to establish location for the suitable position of sampled wells on the map. Hydrogeological mapping was carried out using ninety-nine hand-dug wells, from which depth to water levels, total depths of wells and thickness of the water column were measured. Thirty three (33) representative water samples were collected from the initial ninety-nine hand dug wells in clean plastic bottles with inner cover and a screw-cap for major ions and trace element analyses. Each bottle was first rinsed twice with water from the well in which sample was taken and no preservative was used. At each sampling location the physical parameters were measured with the aid of Miliwaukee pH, EC and TDS smart combined meter. The concentration of major cations and anions and trace elements were determined in the laboratory of National Cereals Research Institute (NCRI), Badeggi, Nigeria, using UV-Visible spectrophotometry, Titrimetry, Flame Photometry and Atomic Absorption Spectrometry. Geostatistical methods, namely, Correlation Analysis (CA) and Principal Component Analysis (PCA) were deployed to identify possible sourcing of major ions in the water using SPSS 16 for windows. For the PCA, Varimax orthogonal rotation, with Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was used.

4. Results

The area is underlain by rocks of the Older Granite suite, comprising of two major lithologies, namely, biotite granite and alkali feldspar granite, composed mainly of biotite, orthoclase feldspar, quartz, hornblende and opaque minerals. The rocks are generally massive, lacking in fractures or joints. Results of the hydrogeological investigation of shallow groundwater in Gembu, Mambilla plateau, Nigeria show that wells in the area were generally constructed to tap water from the weathered regolith. Observation of lithologies within all wells reveal that no competent rock was penetrated, only weathered regolith was visible. A large number of these wells are productive all year round, with others drying up during the dry season which runs from November to February. Well depths range from 1.2 m to 55.4 m with most of the wells falling between depths of 3.2 m – 7.7 m, representing approximately 87.87 % of the studied wells in the area. Eleven wells (11.11 %) have depths between 10 m and 15 m, except one well which is 55.4 m deep, while 48 wells (48.5 %) are very shallow, with depths of less than 5 m. Depth to water in the wells ranges from 0.4 m to 52.2 m; with ≈ 60 % of these falling below 5 m depth. Hydraulic head was found to range from 1525.9 m to 1575.2 m, with an average of 1550.55 m. A further examination of the data shows that the hydraulic head has two maxima in the northwest and southwest part of the area, leading to groundwater flow generally towards the eastern portion of the central part of the area (Figure 2). This major flow direction is accompanied by localized minor low head areas in western part of the area.

Table 1 shows the physic-chemical parameters of the sampled hand dug wells. The results show that Cl^- ranged between 0.00 – 1555.61mg/L, SO_4^{2-} ranged between 0.77 – 67.04 mg/L, NO_3^- ranged between 0.54 – 7.85 mg/L, PO_4^{-3} ranged between 0.96 – 234.96 mg/L, HCO_3^- ranged between 0.00-347.46 mg/L, Mg^{2+}ranged between 0.04 – 5.83 mg/L, Na^+,Ca^{2+} ranged between 7.01-78.80 mg/L, K^+ ranged between 1.22–26.50 mg/L, Zn ranged between 0.27-1.16m g/L. Fe ranged between 0.84-0.92 mg/L. Compared with the World Health Organization (WHO. 2011) and Nigerian Standard for Drinking Water Quality (NDWQS, 2007), all the parameters were found to be within the permissible limits (Table 1), with the exception of iron (Fe) and magnesium(Mg^{++}) that generally exceed the limits. However, on a sample-by-sample basis, one out of the thirty-three locations had concentration of bicarbonate above the permissible limit, while another one had phosphate level beyond the set limits. Thus, the water in the two wells is considered not safe for drinking. The result of analysis showed that 94% of the wells have high iron concentration above WHO and NSDWQ guide limit for drinking water. The maximum permissible NSDWQ concentration for iron is 0.3mg/L. The iron concentration can be traced to the geology, dissolution of iron minerals from rock and soil, precipitation/run off and infiltration activities and agricultural land use activities.

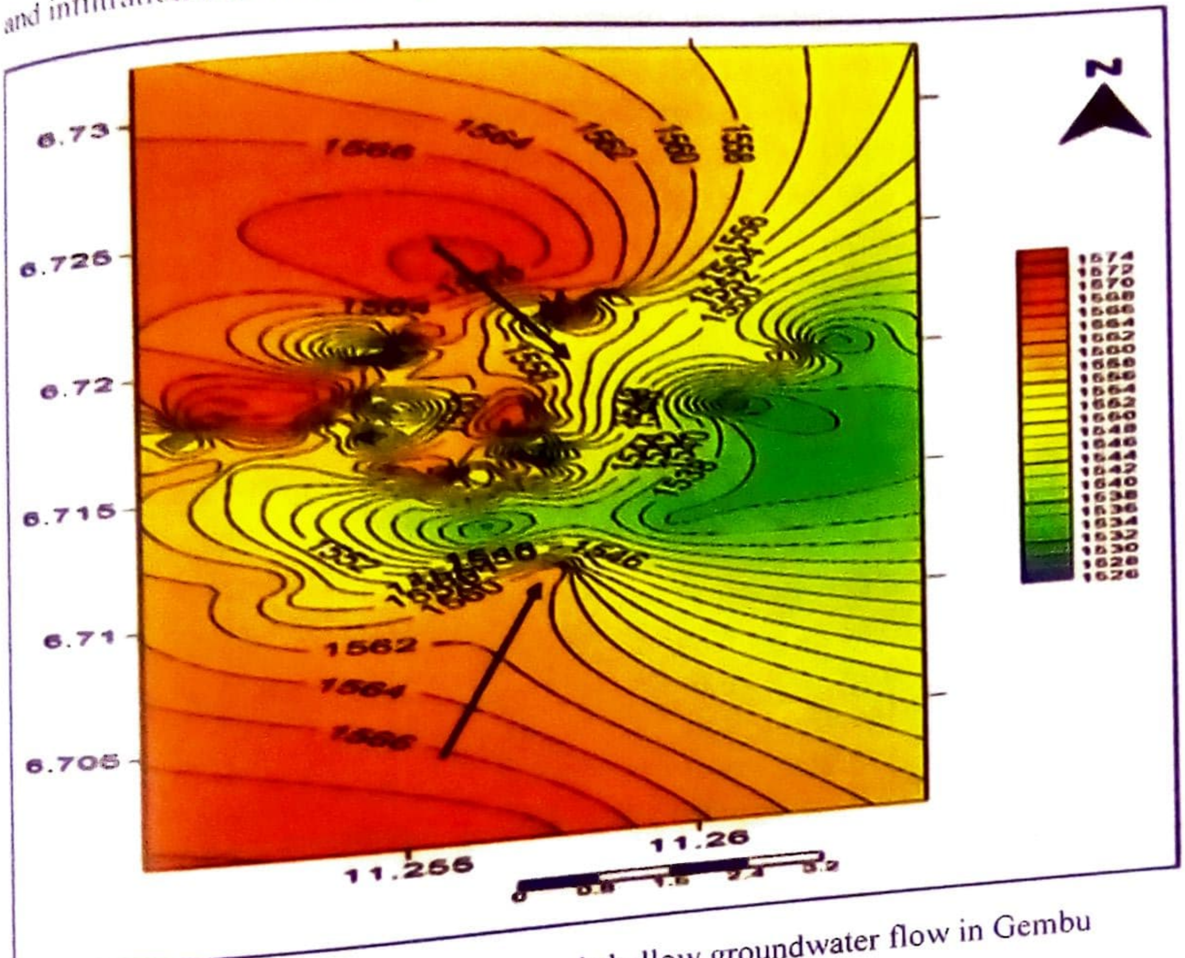

Figure 2: Hydraulic head distribution and shallow groundwater flow in Gembu

Similarly, 71% of sampled wells have high magnesium concentration which is above the 0.2mg/L permissible limit set by WHO and NSDWQ.

The Piper diagram (Figure 3) reveals that most of the water samples in Gembu can be classified as sodium-potassium-sulphate-chloride type (Na-K+ SO_4^{2-} + Cl^-). Stiff diagrams (Figure 4) revealed three water types, sodium+potassium-chloride+sulphate (Na+K-Cl^-+ SO_4^{2-}), calcium-chloride+sulphate (Ca^{2+}-Cl^-+SO_4^{2-}) and calcium-carbonate+bicarbonate (Ca^{2+}- CO_3 +HCO_3) types of water in the area

Table 1 Summary of Physico-chemical parameters in groundwater of Gembu

	Range	Mean	Median	StDev	WHO	NSDWQ
Cl^-	0.00-155.61	60.72	56.85	31.37	250	250
SO_4^{2-}	0.77-67.04	6.64	3.04	12.73	100	100
NO_3^-	0.54-7.85	5.64	5.64	1.16	50	50
PO_4^{3-}	0.96-234.96	8.14	1.06	40.72	2.0	
HCO_3^-	0.00-347.46	20.18	4.88	60.4		100
Mg^{2+}	0.04-5.83	1.26	0.53	1.5	0.20	0.20
Na^+	3.40-26.58	26.58	23.7	15.12	200	200
Ca^{2+}	7.01-78.80	24.63	19.8	16.47	200	
K^+	1.22-26.50	7.03	5.1	6.31	200	160
Zn	0.27-1.16	0.5	0.45	0.2	3.00	3.00
Fe	0.84-0.92	0.88	0.89	0.02		0.3
pH	5.4-8.1	6.96	6.9	0.68		6.5-8.6
EC(µS)	0-480	146.97	120	134.18		1000
TDS(ppm)	0-460	137.58	110	126.17	1000	500

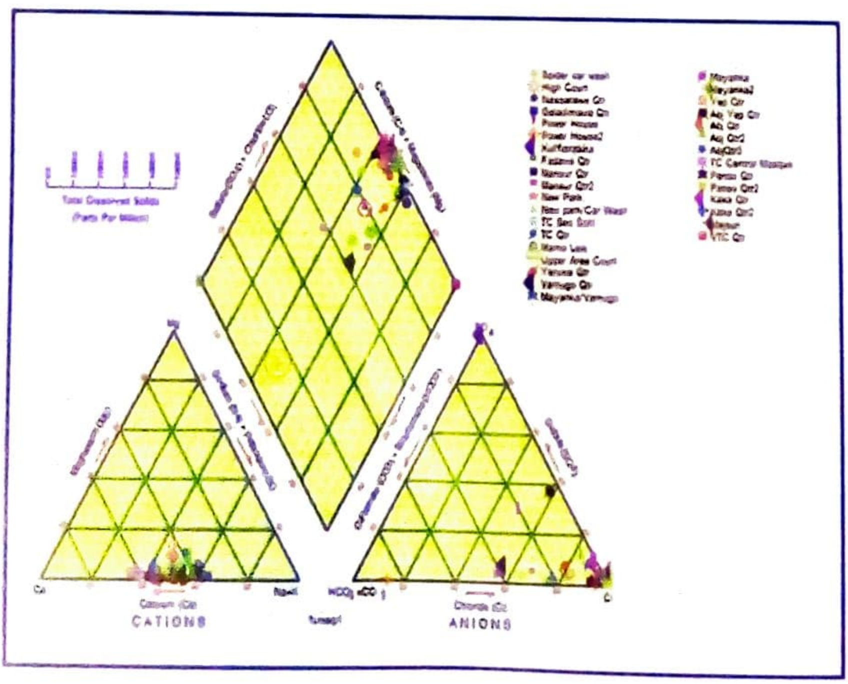

Figure 3: Piper trilinear classification of groundwater in Gembu, Mambilla Plateau, Nigeria

4.1 Source Apportionment

Correlation analysis (Table 2) and Principal Component Analysis (Table 3) were used to study major ion distribution in the water in order to identify possible sources of ionic species. A weak positive correlation was observed between Na and Cl^- ($r^2 = 0.49$), which may indicate minimal contribution from untreated effluents to the water chemistry. Similarly, an extremely weak positive correlation between $SO4^{2-}$ and Cl ($r^2 = 0.081$) and its negative correlation with K ($r^2 = -0.49$) is an indication that anthropogenic input plays a minimal role in the area. This is further buttressed by the weak correlation between nitrate and Mg ($r^2 = 0.259$), Cl^- ($r^2 = 0.019$) and Na ($r^2 = 0.05$) (Sajil Kumar, 2020). There is a strong positive correlation between K, Na and Ca on the one and between each of these species and EC and TDS (Table 2) on the other. This indicates common sourcing of these ions and their influence on the conductivity of groundwater is dominant.

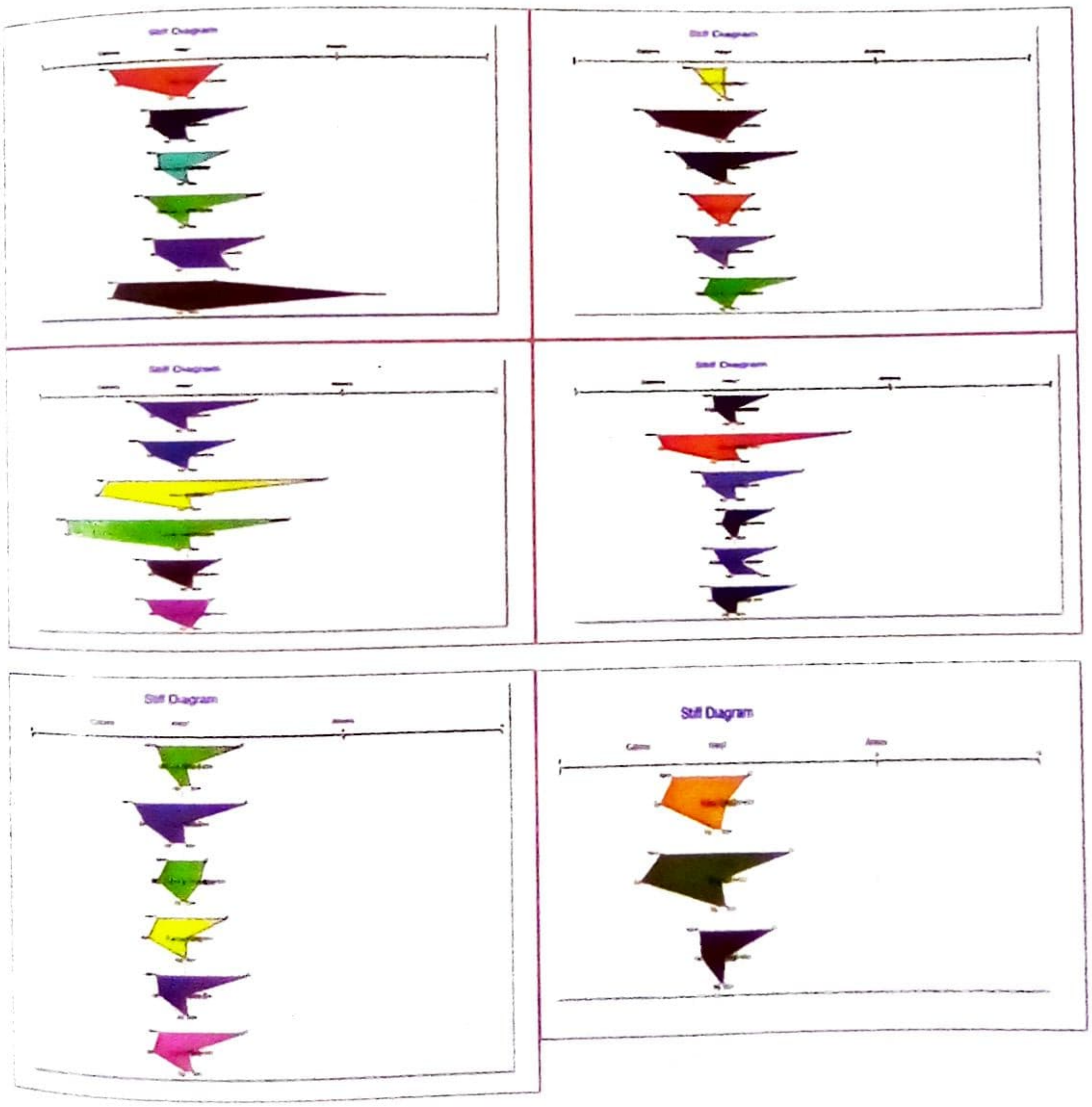

Figure 4: Stiff plots of shallow groundwater in Gembu

Four principal components (PC), explaining about 75 % of total variance were extracted using Varimax rotation with KMO test of sample adequacy of about 0.67. PC 1 accounts for 37.71 % of the variance and is associated with strong positive loadings for TDS, EC, K, Na and Ca, along with weak positive loading for HCO^- and Cl^-. This shows that the three cations are the dominant controls on the conductivity of the water and their association with bicarbonate in this component indicates a geogenic control on groundwater chemistry in the area. CP2 accounts for 14.89 % of the variance and has a high positive loading for Cl^-, accompanied by weak positive loadings for Na, SO_4^{2-} and Mg and may be an indication of slight influence of domestic effluents on the groundwater of Gembu.

Table 2: Correlation matrix for major ions in shallow groundwater of Gembu

	Cl	SO_4^{2-}	NO_3^-	PO_4^{3-}	HCO_3^-	Mg	Na	Ca	K	Fe	pH	EC	TDS
Cl^-	1.000	.081	.019	-.208	-.233	.314	.479	.486	.355	-.045	-.370	.428	.416
SO_4^{2-}	.081	1.000	-.163	-.064	-.097	-.014	-.133	-.118	-.149	.217	-.066	-.104	-.120
NO_3^-	.019	-.163	1.000	-.011	.023	.259	.050	-.112	-.034	-.324	.049	-.094	-.091
PO_4^{3-}	-.208	-.064	-.011	1.000	.033	-.086	-.213	-.103	-.130	.053	.196	-.161	-.158
HCO_3^-	-.233	-.097	.023	.033	1.000	.009	.138	.273	.467	-.164	.384	.416	.417
Mg	.314	-.014	.259	-.086	.009	1.00	.459	.369	.349	.049	-.310	.420	.407
Na	.479	-.133	.050	-.213	.138	.459	1.000	**.907**	**.884**	-.218	-.313	**.902**	**.908**
Ca	.486	-.118	-.112	-.103	.273	.369	**.907**	1.000	**.892**	-.001	-.191	**.937**	**.942**
K	.355	-.149	-.034	-.130	.467	.349	**.884**	**.892**	1.000	-.135	-.083	**.954**	**.957**
Fe	-.045	.217	-.324	.053	-.164	.049	-.218	-.001	-.135	1.000	.314	-.090	-.096
pH	-.370	-.066	.049	.196	.384	-.310	-.313	-.191	-.083	.314	1.000	-.195	-.187
EC	.428	-.104	-.094	-.161	.416	.420	**.902**	**.937**	**.954**	-.090	-.195	1.000	**.999**
TDS	.416	-.120	-.091	-.158	.417	.407	**.908**	**.942**	**.957**	-.096	-.187	**.999**	1.000

While PC3 may be difficult to explain in terms of operative processes, PC4 with a strong loading for nitrate and Mg could be due to nitrate pollution of water. Gembu metropolis is known for vegetable farming on the banks of streams and the application of fertilizer in these areas, may be the source nitrate to groundwater.

Table 3: Rotated Component matrix for major ions in groundwater in Gembu

Variables	Component 1	Component 2	Component 3	Component 4
TDS	**.985**	.080	-.100	.017
EC	**.984**	.091	-.088	.021
K	**.963**	-.028	-.138	.035
Ca	**.948**	.147	-.006	.014
Na	**.880**	.290	-.203	.140
pH	-.075	**-.816**	.288	.000
HCO^{3-}	.467	-.686	-.174	-.053
Cl^-	.401	**.633**	.083	.155
PO_4^{3-}	-.136	-.362	.015	.021
Fe	.000	-.103	**.907**	-.060
SO_4^{2-}	-.100	.267	.477	-.190
NO_3^-	-.141	-.106	-.314	**.838**
Mg	.401	.285	.166	**.683**
% Variance	**37.71**	**14.89**	**13.93**	**9.02**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Kaiser–Meyer–Olkin measure of sampling adequacy = 0.67

5. Conclusion

Comparing the value of the analysed parameters with the World Health Organization (WHO)and Nigerian Standard Drinking Water Quality (NSDWQ), all of the parameters analysed in the water samples fell within the permissible limits, with the exception of iron, magnesium that generally exceed the limits. The concentration of bicarbonate was found to be elevated in only one location, thus raising concern about the potability of water in that well. It is concluded from the results of this study that shallow groundwater in Gembu is safe for domestic drinking and other consumption uses. The results further show that the major source of ions in the groundwater in Gembu is geogenic input, mainly through the interaction of rock and water. Anthropogenic sources are a minor source, through the agency of domestic effluents and vegetable farming along flood plains of streams in the metropolis.

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