Groundwater quality assessment and characterization of shallow basement aquifers in parts of ado ekiti metropolis, Southwestern Nigeria

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Abstract

Groundwater samples were collected randomly from hand-dug wells in parts of Ado Ekiti metropolis and were subjected to its quality assessment and characterization. Physicochemical and bacteriological analyses were carried out following standard methods (APHA 2012). Hydrochemistry of the present study revealed relative mean concentration of the cations in the order: $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$, and that of the anions as $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$, respectively. The microbial test shows that *E. coli* tested positive in all the samples and their colonies are classified dominantly as satisfactory pollutant free state. Pollution index of groundwater results revealed an insignificant state of pollution of the groundwater. Deduction from the Pipers, Gibbs plots and chloro-alkaline indices results revealed the imprints of natural weathering, ion-exchange processes and anthropogenic activities influencing the groundwater quality. Factor analysis result also confirms the prevailing activities of natural geological forces and municipal contaminations acting on the groundwater. The hydrochemical processes coupled with the permeable nature of the aquifer media and high precipitation will influence groundwater flow and ultimately pose pollution risk to the aquifers and eventually the populace of these areas in years to come.

Keywords Groundwater · Hydrochemistry · Bacteriological · Pollution · Ado Ekiti metropolis

1 Introduction

Groundwater quality studies have become necessary due to the negative consequences of consumption of contaminated or polluted water [1–4]. The effect of the contamination of groundwater has resulted in several societal problems and ecologically bad effects of the groundwater discharge into the water bodies [5, 6]. The potability of groundwater cannot be deciphered solely by the general physical parameters such as colourless, odourless and tasteless. Several methods have then been adopted in the evaluation of groundwater pollution. Hydrochemistry has become one of the tools in the evaluation of water suitability for different purposes such as industrial, domestic and agricultural purposes [7–14, 16]. This is due to the

ability of water in dissolving anything (minerals, rocks and solids), and it comes in contact with. Hydrochemistry in groundwater quality evaluation is limited in the overall water quality studies, but the combination of hydrochemistry and bacteriological approach has been adjudged as a comprehensive way of assessing water quality of any area [14]. These hydrogeochemical processes have aided the contamination of aquifers through the introduction of microorganisms such as *P. aeruginosa*, *Salmonella* spp., and *E. coli* [15]. The movement of these microorganisms into aquifers depends on the microorganisms, permeabilities of aquifer materials, proximity to sewage facilities and many more [14, 15]. The invasion of these organisms in urban areas is traceable to several processes such as uncontrolled sewage, grazing and manure spreading with

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attendant outbreak of waterborne diseases [13, 14, 17, 18]. Geographical information system (GIS) has also emerged as another tool employed in developing solutions to several water problems, assessing water quality and managing water resources on a local or regional scale [19–22]. Other methods such as multivariate statistical analysis (factor analysis (FA), hierarchical cluster analysis (HCA), analysis of variance (ANOVA) and ordinary kriging (OK)) have also aided further understanding and interpretation of the hydrogeochemical and bacteriological processes influencing groundwater quality. This is due to their simplicity and straightforwardness interpretation in the characterization of groundwater quality [12, 13, 23, 24]. The contribution of geogenic and anthropogenic inputs in the pollution of groundwater has been recorded in several places [25–28]. The geogenic mode of groundwater pollution arises from the dissolved concentrations of ions from the minerals present in the host rock constituting the aquifer system, low resident time, flow paths and flow rates [11, 26, 29]. Several hydrogeochemical processes that have affected groundwater quality status include silicate weathering, ion-exchange processes, evaporation, precipitation, calcite and dolomite mineral dissolution [30–32]. This mode of water contamination is rare and not frequent. Groundwater pollution is mostly attributed to several anthropogenic activities such as irrigation return flow, industrial effluent, high water table in burial grounds and runoff especially in most urban settings of the world [33–36]. These approaches (hydrochemistry and microbial) have aided the deep understanding and differentiation between rock and water interactions and anthropogenic influences in water systems [37].

Groundwater in basement aquifers has been found to be highly vulnerable to contamination due to near to the ground protective capacity and numerous anthropogenic activities [38–40] even though these aquifers (weathered and fractured aquifers) are usually characterized with poor yield and high cost of development [41, 42]. The vulnerability of basement aquifers especially in parts of Ado Ekiti metropolis has spurred the current study in assessing its groundwater quality and characterization. This is achieved by integrating hydrochemistry, bacteriological and multivariate statistical approaches.

2 Location and accessibility

The study area is located between latitudes $7^{\circ} 36'$ and $7^{\circ} 49'$ N of the equator and longitudes $5^{\circ} 13'$ and $5^{\circ} 16'$ E. It is bounded by other local governments of the state and is accessible through roads as well as interconnected footpaths (Fig. 1). The area is generally well drained, but many of the streams are affected by seasonal changes. The

pattern of drainage is controlled by the geology of the area, where most of the streams flow in the southwestern direction is propelled by the direction of the rugged upland [43]. The study area's climate is tropical, average annual temperature is 25.1°C , and its average precipitation is 1334 mm [43].

3 Local geology and hydrogeological setting

The study area is underlain by rocks representative of basement complex of southwestern Nigeria [43, 44]. The dominant lithologies include migmatites gneisses, granites, quartzites and charnockites (Fig. 2). The varieties of granitic rocks occupy about 25% of the total area of Ado Ekiti. The fine-grained granite and medium- to coarse-grained varieties with porphyritic texture. The low-lying charnockitic rocks were found in association with coarse-grained porphyritic granites [45]. Xenoliths are frequently formed in charnockitic and granitic bodies. The quartzites are present in the form of elongated bodies enclosed within the charnockites, granites and migmatitic rocks. The low-lying exposure of migmatites is typically foliated and has been intruded by granitic and charnockitic rocks in some places [46].

Groundwater constitutes the major source of utility water in the Ado Ekiti metropolis with sole reliance on it in meeting several demands or purposes [43, 47]. Due to the ruggedity of the terrain (peculiar to any basement complex terrain), the runoff amount and infiltration rate are postulated to be high and low, respectively [35]. These underlying basement rocks are mechanically competent (granites more so than the gneisses) and therefore responded to imposed strains by brittle fracture. Ado Ekiti metropolis has been adjudged as high groundwater potential area due to its high hydrogeological lineament density using terrain satellite imagery analyses [48]. Weathered basement and fractured aquifers constitute the main aquifer types where the populace tapped their water from the study area, very peculiar to any basement complex terrain [40, 42, 43, 49]. The thickness of the weathered layer is also responsible for the delineation of high potential groundwater formation for borehole development in the study area [44, 50]. The present extent and characteristic of aquifer in the study area are dependent on the depth and degree of weathering and fracturing of the underlying rocks within the area [44]. These aquifers are primarily recharged by surface precipitation (rainfall) usually aided by chemical weathering processes prevailing in humid environment [48]. Groundwater in the study area is under influent flow condition (recharged by lateral flow from rivers (Ureje and Orojuda) and their tributaries)

4 Method of study

and multivariate statistical analysis (factor analysis and correlation matrix) was also employed. The multivariate statistical analysis for all the physiochemical and bacteriological parameters was achieved using IBM SPSS software. The descriptive statistics of all the results is presented in Table 1.

Pollution index of groundwater (PIG) proposed by Rao et al. [51] was employed for this study. This method usually aided quantification of relative impact of individual chemical variables (pH , TDS, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , NO_3^-) on overall groundwater quality (Table 2). To obtain PIG, five sequential steps are required, starting with weightage assignment to each chemical parameter ranging from 1 to 5 in relation to their effect on human health. Weight (1) was assigned to K^+ and weight (5) to pH , TDS, SO_4^{2-} and NO_3^- . Computation of weight parameter (W_p) was achieved for all the chemical parameters so as to evaluate their influence on the overall groundwater quality. Estimation of the status of concentration (S_c) was achieved by dividing each chemical parameter content of each water sample by WHO standard for drinking purpose (D_s ; Eq. 3). Computation for the overall chemical quality of water (O_w) was achieved by multiplying the W_p with the S_c (Eq. 4). Finally, calculation of

Fig. 2 Geological map of Ado Ekiti metropolis [49]

Table 1 Descriptive statistics

Parameters	Range	Minimum	Maximum	Mean	SD	WHO [57]
WTDEPTH (metres)	9.53	0.5	10.03	4.06	2.7242	NA
Turbidity (mg/l)	23.92	1.88	25.8	7.5554	5.80816	5
Total solids	73.2	12	85.2	50.1357	18.85856	
Suspended solids	65.5	4.5	70	27.1543	16.59202	
TDS (mg/l)	62.5	6	68.5	22.9814	14.15998	1500
pH	3.5	4.5	8	5.9929	0.8726	7.5
Calcium (mg/l)	128.2	12	140.2	61.05	31.36534	200
Magnesium (mg/l)	69.5	14.5	84	45.9857	16.74802	150
Potassium (mg/l)	15.9	0	15.9	7.7846	3.11193	12
Sodium (mg/l)	51.5	0.5	52	12.6775	11.36822	200
Nitrates (mg/l)	60	0	60	3.4343	11.24975	45
Bicarbonates (mg/l)	159.7	10.3	170	54.6918	41.60701	500
Sulphates (mg/l)	60	0	60	4.9032	11.23838	250
Chlorides (mg/l)	163.1	8.9	172	58.5536	51.59461	600
Total hardness	290	50	340	136.0714	58.33107	200
Coliform count	1160	40	1200	278.5714	328.14534	
Colonies	117	3	120	27.4643	33.04036	

pollution index of groundwater (PIG) was through summation of all the O_w values (ΣO_w ; Eq. 5).

$$W_p = \frac{(R_w)}{\sum R_w} \quad (1)$$

Table 2 Particulars of relative weight (R_w), weight parameter (W_p) and drinking water quality standard (D_s) Rao et al. [51]

Chemical Parameter	R_w	W_p	D_s
pH	5	0.1388889	7.5
TDS	5	0.1388889	1500
Ca ²⁺	2	0.0555556	200
Mg ²⁺	2	0.0555556	150
Na ⁺	4	0.1111111	200
K ⁺	1	0.0277778	12
HCO ₃ ⁻	3	0.0833333	500
Cl ⁻	4	0.1111111	600
SO ₄ ²⁻	5	0.1388889	250
NO ₃ ⁻	5	0.1388889	45
Sum	36	1	

$$S_c = \frac{C}{D_s} \quad (2)$$

$$O_w = W_p * S_c \quad (3)$$

$$PIG = \sum O_w \quad (4)$$

In the assessment of PIG, the relative contribution of chemical variables from each groundwater sample was taken into account. If the overall chemical quality of water (O_w) of any of the chemical parameter is more than 0.1, it accounts for 10% of PIG value. This tends to give clear cut information on the influence of contamination of groundwater body [51]. Classification of PIG was found applicable to this study and is presented in Table 4.

The chloro-alkaline index (CAI) is calculated using Eq. 5:

$$\text{Chloro} - \text{Alkaline Indices (CAI-1)} = \frac{(\text{Cl} - (\text{Na} + \text{K}))}{\text{Cl}} \quad (5)$$

Gibbs [53] plot is achieved by plotting the ratios of Na⁺/(Na⁺/Ca²⁺) are (Cl⁻/(Cl⁻ + HCO₃)) as a function of TDS.

Multivariate statistical analysis: This analysis is comprised of principal component analysis (PCA) and correlation matrix. This analysis has the capacity of reducing the number of the ten chemical variables (pH, TDS, Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, SO₄²⁻, NO₃⁻) to a smaller number without loss of essential information. Transformation and determination of data matrix and variance–covariance matrix were achieved. PCs with eigenvalues greater than 1 were only extracted while those lower than 1 were eliminated following the assumption of [55, 56]. Calculated extraction and presentation of components loadings, eigenvalues, % total variance and cumulative variance of observed principal components aided accurate interpretation of the

chemical variables [26, 57]. Classification of positive PC loadings was employed in the classification and interpretation of the delineated PCs loading. PC loadings greater than 0.75, 0.5 to 0.50 and lower than 0.50 are classified as strong loading, moderate and weak loading, respectively.

5 Results and discussion

The minimum, maximum, mean and standard deviation of physicochemical and bacteriological parameters obtained for the groundwater samples of the shallow hand-dug wells representative of Adebayo, Ado Ekiti, are presented in Table 1.

5.1 Physiochemical aspect

The total dissolved solids (TDS) concentration in the study area ranges from 6 to 68.5 mg/l with a mean value of 22.9814 mg/l (Table 1). All the water samples fall within the [57] recommended total dissolved solids (TDS) limit of 1500 mg/l and classified as freshwater according to [58, 59] total dissolved solids (TDS) groundwater classification. The concentration of total hardness (TH) in the study area's groundwater ranges from 50 to 340 mg/l with mean values of 136.0714 mg/l (Table 1). The groundwater's hardness ranges from soft to very hard category following [60] total hardness (TH) classification. Those water with very high hard category tend to cause encrustation on water supply distribution systems. Long-term consumption of this hard water may also lead to an increased incidence of urolithiasis, anencephaly, prenatal mortality, cardiovascular disorders and some types of cancer [61].

The water table depth of the twenty-eight hand-dug wells ranges from 0.5 m to 10.0 metres. The variability revealed the variation in the thickness of the soil overburden attributed to weathering and leaching activities. This is very typical of basement aquifers (regolith and fractured aquifers) in any basement terrain [40–42, 62, 63]. The water in the Adebayo area is believed to be tapped from the shallow basement aquifer systems making it more prone to pollution.

Results revealed that turbidity of the groundwater ranges from 1.88 to 25.6 with a mean value of 7.5554, higher than the 5 mg/l accepted limit. These turbidity values of the groundwater indicate the presence of inorganic particulate matter and non-soluble metal oxides [14]. Consumption of this type of water may pose a health risk, and excessive drinking of turbid water will inhibit the action of disinfectants, thereby protecting the pathogens [64, 65].

The total suspended solids (TSS) ranges from 12 to 85.2 with a mean value of 50.1357 (Table 1). The concentration of total suspended solids (TSS) in groundwater is

otherwise known as turbidity induced by the presence of silt and organic matter. The TSS value for the present study poses no health risk since there has been no specific maximum permissible limit of TSS in any literature or text. However, the presence of suspended solids poses vulnerability of groundwater resulting from several anthropogenic activities.

5.2 Anions

The concentration of sulphate ranges from 0 to 60 mg/l with a mean value of 4.90 mg/l (Table 1). The mean values are within the recommended limit for [57] standard of 250 mg/l. The source of sulphate ions has been attributed to both atmospheric deposition and urban utilities. Only atmospheric precipitation process was postulated to accountable for sulphate concentration in Ado Ekiti area (Hem [67]). The concentration of chloride in groundwater ranges from 8.9 to 172 mg/l with mean values of 58.5536 mg/l (Table 1). The mean values are within the recommended limit for [57] standard of 250 mg/l. Chloride usually occurs in lower concentration in natural waters [58, 66, 67]. The sources of chloride in groundwater can be related to the weathering of basement rocks such as granite gneiss and quartzite. The concentration of nitrates ranges from 0 to 60 mg/l with mean values of 3.43 mg/l. The mean values fall within the accepted maximum value of 45 mg/l [57]. However, the water samples with nitrates greater than 10 mg/l pose contamination traceable to urban anthropogenic activities [68]. Samples with nitrates concentration more than 45 mg/l pose the severe health risks [69, 70]. The concentration of bicarbonates ranges from 10.3 to 170 mg/l with the average value of 54.69 mg/l fall within acceptable limit of World Health Organization [57] standard of 500 mg/l. The source of bicarbonates ions has been attributed to chemical interaction of carbon dioxide with water in the soil media and in the atmospheric dissolution [71]. The dissolved anionic species in the groundwater of the study area are in this order $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$.

5.3 Cations

The ranges of the concentration of calcium, magnesium, sodium and potassium are 12–140.2, 14.5–84, 0.5–52 and 0–15.9 mg/l with the following mean values of 61.05, 45.9857, 12.6775 and 7.7846, respectively. The mean values of the cationic species fall within the [57] acceptable permissible limit of 200 mg/l, 150 mg/l, 200 mg/l and 12 mg/l for calcium, magnesium, sodium and potassium, respectively. The sources of the cationic species in the groundwater under study have been traceable to the silicate weathering, orthoclase weathering and

Table 3 Descriptive statistics

	Minimum	Maximum	Mean	SD
OWTDS	0.0006	0.0063	0.002128	0.0013111
OWpH	0.0833	0.1481	0.110979	0.0161592
OWCa	0.0033	0.0389	0.016958	0.0087127
OWMg	0.0054	0.0311	0.017032	0.006203
OWK	0	0.0368	0.01802	0.0072036
OWNa	0.0003	0.0289	0.007043	0.0063157
OWNIO3	0	0.1852	0.0106	0.0347215
OWHCO3	0	0.0283	0.008774	0.007144
OWSO4	0	0.0333	0.002724	0.0062435
OWCI	0.0016	0.0319	0.010843	0.0095545
PIG	0.1438	0.5085	0.205101	0.065186
CAI	−2.2178	0.9278	0.06945	0.9966096

ionic exchange processes in the aquifer media makeup [28]. The dissolved cationic species in the groundwater of the study area in the following order is as follows: $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$.

5.4 Chloro-alkaline index

The chloro-alkaline index results range from −2.2178 to 0.9278 with a mean value of 0.06945 (Table 3). Twenty-five percentage (25%) of the samples have negative CAI values. This portends that calcium and magnesium have been absorbed into the shallow basement aquifers through weathering and leaching activities. Sodium and potassium have been released in groundwater in the study area. This depicts reverse ion-exchange reaction. The remaining seventy-five percentage (75%) have positive CAI values that reflected direct ion exchange. This became evident through the release of alkali earth ions (Ca^{2+} and Mg^{2+}) in the groundwater and retention of alkalis by the aquifer materials of the basement aquifer.

5.5 Pollution index of groundwater (PIG)

The pollution index of groundwater (PIG) values range from 0.1438 to 0.5085 with a mean value of 0.205101, falling into insignificant pollution category according to [51] (PIG) category. OWpH has more than ten percentage contribution to the overall pollution index of groundwater. This reveals the impact of pH on the concentration of the dissolved ions with imprints of rock–water interaction and anthropogenic activities. This is achieved by the ability of the water to take in more solutes from geogenic and anthropogenic sources.

Table 4 Principal component analysis (PCA)

Chemical parameters	Extraction communalities	Component			
		PC1	PC2	PC3	PC4
TDS	0.73	0.43 [−]	0.73 ⁺		
PH	0.822	0.407 [−]	−0.596 [−]		0.497 [−]
Ca	0.658	0.454 [−]	0.479 [−]	0.403 [−]	
Mg	0.742	0.462 [−]			0.671 ⁺
K	0.86		−0.466 [−]	0.734 ⁺	−0.324 [−]
Na	0.744	0.509 ⁺	0.639 ⁺		
NO3	0.85	0.823 [*]	−0.382 [−]		
HCO3	0.83	0.689 ⁺		0.554 ⁺	
SO4	0.892	0.866 [*]			
Cl	0.753	0.6 ⁺		−0.567 [−]	
Eigenvalues		3.292	2.002	1.513	1.074
% of variance		32.293	20.023	15.126	10.739
Cumulative %		32.293	52.946	68.072	78.81

where [−]weak loading, ⁺moderate loading and ^{*}strong loading

5.6 Principal component analysis (PCA)

Four principal components were extracted with the following eigenvalues of 3.292, 2.002, 1.513 and 1.074 for the four PCS 1, 2, 3 and 4, respectively (Table 4). The extracted communalities values for all the parameters range from 0.658 to 0.892 signifying variation in the contribution in the sources influencing the concentration of dissolved ions in the groundwater following [51] classification of principal loading factors. PC1 which explained 32.923% of the total variance has very strong loadings of sulphates (0.866) and nitrates (0.853). This could be related to the present effect of anthropogenic activities influenced through surface pollution in the study area. Moderate loadings of bicarbonates (0.689) and sodium (0.509) were also observed suggesting the geogenic inputs from the degree of weathering of the basement rocks of the study area. PC2 which explained 20.023% of the total variance shows moderate loading of sodium (0.639) and total dissolved solids (0.73) signifying the geogenic inputs. This indicates the base exchange process of the replacement of sodium ion by calcium ion. There is a sole moderate loading of potassium (0.734) on the third principal component (PC3) which explained 15.126% of the total variance. The origin of potassium could be related to the breakdown of the feldspar minerals in the basement rocks (granite gneiss). The sole moderate loading of magnesium (0.671) on the fourth principal component (PC4) explained 10.739%, the smallest out of the total variance. Magnesium in this study was attributed to the ion-exchange process on clay minerals. Deduction from the four principal components suggests the following prevailing hydrogeochemical processes

such as silicate weathering and leaching activities, ion-exchange processes and anthropogenic inputs.

5.7 Gibbs plot

The Gibbs plot of the study area shows that the water falls into both the rock and atmospheric/precipitation dominances regions, with majority in the precipitation-induced region. The concentration of dissolved ions in groundwater was initially derived from the rock–water interaction in the soil media of regolith aquifer system due to high resident time in the subsurface media. This was recharged and diluted by the humid conditions resulting from precipitation. The majority of the water falling into the precipitation dominance suggests the vulnerability of the shallow aquifers to contamination through runoff and flash flood events peculiar to any urban setting. No water sample falls into the evaporation dominance category reflecting the permeable nature of the basement aquifer of the study area.

5.8 Piper diagram

Three hydrochemical facies, namely CaHCO₃, mixed CaNaHCO₃ type and CaCl type with this order CaCl > CaHCO₃ > mixed CaNaHCO₃, were delineated for the water of the study area (Fig. 3). Ca–Cl, the most dominant water-type facie, occupies about 61% of the study area suggesting the presence of ion-exchange process and introduction of domestic effluent in groundwater. The absence of halites and carbonate-bearing minerals in this area limits the geogenic contribution to the CaCl water type. The domestic effluent discharged was suggested to

Fig. 3 Gibbs plot

Fig. 4 Gibbs plot

be induced by several urban activities such as irrigation return flow, domestic wastewater and septic tank effluents near with existing water sources. This is usually associated with groundwater contamination [72]. Ca-HCO₃ type is the second most dominant water facies, occupying about 28% of the study area, which depicts mineral dissolution from interaction between rock and water and recharge of rainfall [73]. Water of this facies is usually pure, natural and safe groundwater [31]. This type of water typified any water tapped from continental basement (weathered and fractured) aquifers [12].

Mixed CaNaHCO₃ type occupies the smallest water type (11%) of the study area which is usually formed from the recharge water (precipitation) and dissolution of minerals along the flow path [32, 74]. Silicate weathering of albite mineral (NaAlSi₃O₈) in the aquifer media is believed to be responsible to this water type (Figs. 4, 5).

5.9 Correlations matrix of the physicochemical and bacteriological parameters

Pearson correlation (*r*) was employed in the identification of interactions within and between the physicochemical and bacteriological parameters. Pearson's correlation value can fall between 0.00 (no correlation) and 1.00 (perfect correlation). Strong correlation arises when *r* is greater than 0.7; whereas when *r* has a value between 0.5 and 0.7, a moderate correlation is shown to exist [75, 76]. The correlation matrix revealed several significant interactions among the physicochemical and

bacteriological variables in the water samples of the study area. The correlation of the physicochemical and bacteriological parameters showed weak, moderate and strong correlations with each other (Table 5).

Cl correlated moderately with sulphates (0.527), total hardness (0.517), coliform (0.563), colonies (0.563). This interaction suggests non-lithological source (anthropogenic inputs) into the groundwater system of the study area. The moderate correlation relationship was observed between the following physicochemical and bacteriological parameters: HCO₃-NO₃ (0.530), SO₄-HCO₃ (0.554), Na turbidity (0.610), total suspended solid-suspended solid (0.687), turbidity-total dissolved solids (TDS) (0.563), total suspended solids-total dissolved solids (0.525) and strong correlation between SO₄ and NO₃ (0.938). This also depicts the input of anthropogenic activities influencing the groundwater quality of the study area.

Weak and negative correlation exists between Ca and Mg (0.279), Ca and K (-0.019), Ca and Na (0.462), Na and Mg (0.219), Na and K (-0.139), and Ca and HCO₃ (0.426) which depicts the contribution of silicate weathering and leaching activities of the aquifer materials (weathered rocks), thereby releasing the dissolving cationic and anionic species in the groundwater. These activities have been masked by the prevailing anthropogenic activities evident in any urban setting.

Fig. 5 Piper plot

5.10 Bacteriological aspect

Coliform bacteria are described and grouped, based on their common origin or characteristics, as either total or faecal coliform. Faecal coliform bacteria such as *Escherichia coli* (*E. coli*), as well as other types of coliform bacteria, are naturally found in the intestines of warm blooded animals and humans, bodily waste, animal droppings and soil [77–80]. All the twenty-eight water samples tested positive to *E. coli* presence, an indicator of faecal contamination and occurrence of waterborne diseases [81, 82]. The results obtained from the bacteriological test on the groundwaters revealed that the number of faecal coliform colonies ranges from 3 to 120 with only three (3) and twenty-five (25) samples falling under slightly polluted and polluted, and satisfactory and accepted category of WHO 2004 and BIS 1995 water pollution status. This, however, calls for immediate attention and close monitoring of the wells. This is traceable to shallowness of the well making it vulnerable to improper disposal and infiltration of effluent

from solid waste, organic wastes, septic tanks and latrines into the groundwater system.

6 Conclusion

Groundwater quality assessment of groundwater tapped from shallow basement aquifer in parts of Ado Ekiti metropolis has been carried out. This exposes that the waters are presently in satisfactory pollution status according to pollution index of groundwater (PIG) and bacteriological results. The presence of *E. coli* poses health risk to the citizens depending on groundwater for drinking and irrigation purposes. The relative mean concentration of the cations in the order is as follows: $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$, and that of the anions as $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$, respectively. Deduction from the Pipers, Gibbs plots and chloro-alkaline indices results indicates several prevailing hydrogeochemical processes on the groundwater from Adebayo area. These processes include imprints of natural (silicate) weathering and anthropogenic activities,

Table 5 Correlation table for the physiochemical and bacteriological parameters

	Ca	Mg	K	Na	NO ₃	HCO ₃	SO ₄	Cl	Turbidity	Total solid	Suspended solid	TDS	pH	Total harden	Coliform count	Colonies
Ca	1															
Mg	0.279214	1														
K	-0.01989	-0.01077	1													
Na	0.462003	0.219732	-0.1391	1												
NO ₃	0.123423	0.234338	0.052066	0.102064	1											
HCO ₃	0.426337	0.369151	0.401657	0.392142	0.530058	1										
SO ₄	0.139047	0.216601	0.032618	0.265459	0.938227	0.554572	1									
Cl	-0.00555	0.007487	-0.21501	0.399131	0.438372	0.186877	0.527915	1								
Turbidity	0.389304	0.493212	-0.15107	0.612172	0.404919	0.494505	0.458826	0.450325	1							
Total solid	0.07606	0.33255	-0.1852	0.008916	-0.09801	0.072467	-0.0042	0.114157	0.23884	1						
Suspended solid	-0.28782	0.16678	0.113248	-0.38148	-0.2269	-0.067	-0.1595	-0.10363	-0.20942	0.687813	1					
TDS	0.438551	0.247472	-0.37935	0.458878	0.135339	0.175023	0.181301	0.27347	0.563476	0.525874	-0.25571	1				
pH	0.048649	0.28206	-0.0178	-0.25811	0.440613	0.204975	0.386466	0.328803	-0.02095	0.009244	0.230096	-0.2573	1			
Total hardness	-0.16435	-0.07596	0.072027	0.106931	0.04247	0.08545	0.017314	0.51701	0.158097	0.232043	0.202621	0.071618	0.030717	1		
Coliform count	-0.25596	0.003487	0.157456	-0.14589	0.15094	0.168993	0.203306	0.563912	0.192373	0.179294	0.250983	-0.0553	0.378949	0.478983	1	
Colonies	-0.24661	0.030359	0.16273	-0.14629	0.154099	0.172003	0.200125	0.563819	0.203401	0.195871	0.259787	-0.04354	0.39116	0.465655	0.997621	1

facilitated by the rainfall regime of the area. This will make the groundwater vulnerable to pollution. Factor analysis result also confirms the prevailing processes (natural geological forces and municipal contamination) on this water. Continued hydrochemical and bacteriological processes coupled with the permeable nature and high precipitation which will influence groundwater flow. This will ultimately increase pollution risk to the waters and the populace of these areas in years to come. The following chemical parameters, lead, cadmium, zinc, iron and other pollution indicators, should be tested in the groundwater from the study area to further ascertain the pollution status of the groundwater.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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