Assessment of the impact of onsite sanitary sewage system and agricultural wastes on groundwater quality in Ikem and its environs, south-eastern Nigeria

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ABSTRACT

Physicochemical, multivariate, and bacteriological analyses were integrated to assess the impact of onsite sanitary sewage and agricultural waste on groundwater quality in Ikem and its environs. Results of the physicochemical analysis suggest that groundwater samples in the study area are acidic, with very few samples having electrical conductivity and total dissolved solids exceeding WHO standard for drinking water. The abundance of the major ions are in the following order: Ca\(^{2+}\)-Mg\(^{2+}\)-K\(^+\)-Na\(^+\) - Cl\(^-\) = PO\(_4\)\(^{3-}\) > NO\(_3\)\(^-\) > HCO\(_3\)\(^-\) > SO\(_4\)\(^{2-}\). Fifty-five percent of the stiﬀ plot shows Ca\(^{2+}\)-Cl\(^-\) water type and 45% of the stiﬀ shows Na\(^+\)-R\(^+\)-Cl\(^-\) water type. The dominant hydrochemical facies in the study area are Ca\(^{2+}\)-Mg\(^{2+}\)-Cl\(^-\) SO\(_4\)\(^{2-}\) (83%) and Na\(^+\)+K\(^+\) and SO\(_4\)\(^{2-}\)+Cl\(^-\) (17%). Durov and Piper diagrams illustrated that simple mineral dissolution and ion exchange processes are mainly responsible for variation in the hydrogeochemistry. Bacteriological analysis shows that the groundwater is contaminated with faecal waste. The principal component analysis, correlation, and cluster analysis reﬂect faecal matter contamination through onsite sanitary sewage system, leaching of agricultural waste into the groundwater and weathering and dissolution of host rocks. Groundwater flow direction is local and controlled by topographic highs, weathering and fracturing of the host rock in the study area.

Introduction

Groundwater in urban and semi-urban areas is increasingly contaminated, essentially due to increase in domestic waste and agricultural activities (Kehinde, 1998; Adelana et al., 2003; Adelana, Bale, & Wu, 2004; Adelana, Bale, Olasehinde, & Wu, 2005; Ajala, 2005; Ocheri, 2006; Adelana, Abiye, Nkhuwa, Tindinugaya, & Oga, 2008). Many studies have been conducted on groundwater quality with focus on the effect of onsite sanitary sewage and agricultural wastes on groundwater quality. Ocheri and Odoma (2013) established correlation between coliform and nitrates, total dissolved solids (TDS) and calcium, calcium, lead, and geology, to ascertain groundwater quality in hand-dug wells with close proximity to a sewage and agricultural waste contamination. Ishaku and Ezeigbo (2010) analyzed the quality of groundwater in Jimeta - Yola and found that the concentration of chloride, nitrate, and TDS and coliforms exceeds WHO allowable limits for drinking water and is more abundant in the rainy season. Onwuka, Uma, and Ezeigbo (2004) assessed the potability of shallow groundwater using parameters of waste derivable chemical components such as nitrate, chloride, sulfate, and indicator micro-organism of fecal coliform. Similarly, Omono, Onwuka, and Okogbue (2013) used principal component analysis (PCA) to identify factors controlling groundwater quality in Emene, Enugu State. Ayantobo, Oluwasanya, Idowu, and Eruola (2012) assessed the quality of hand-dug wells and noted nitrate, fecal coliform, and total coliform at objectionable levels and that they were pronounced in wells located close to the sewage systems. Omotoyinbo (2007) stated that the pollution of organic and inorganic waste in Ado-Ekiti is attributed to the location of wells in terms of distance to onsite sewage system and proximity to agricultural waste. Dapo (1990) stated that developing countries do not have adequate sanitation system. Donlagic, Odobasic, and Bratovic (2007) stated that uncontrolled uses of fertilizer and pesticides are responsible for contamination of shallow groundwater; they also highlighted that animal wastes harbor pathogenic organisms which contaminate groundwater. Uma (2003) highlighted that shallow water table and moderate permeability of the lateritic host rock have rendered the perched aquifer around Enugu metropolis, vulnerable to sewage buried in septic tanks and soakaway systems. Concerns over the quality of water harnessed especially from hand-dug wells have received wide attention among the following researchers: Echinola and Cooker (2002), Nnodo and Illo (2002), Ogunbadewa (2002), Omofonmwam and Eseigbe (2009), Onwuka et al. (2004), and Ovrawah and...
Hymore (2001). Their findings consistently showed that water from shallow hand-dug wells is more polluted by anthropogenic activities than by geogenic processes. This work tends to integrate physicochemical analysis, selected heavy metal analysis, and bacteriological and multivariate analyses to access the impact of onsite sanitary sewage system and agricultural wastes on groundwater quality. Within the study area, no work has been done on groundwater quality; about 80% of the population earns their livelihood through commercial agriculture, accomplished by high use of fertilizers, insecticides, and manure to enhance crop yield. These could be a major source of groundwater pollution in the study area. Onsite sanitary sewage system and open defecation are the major sewage systems in the study area; little or no attempt is made to ascertain the porosity and permeability of rocks, topography, direction of groundwater flow, and depth to water table before sitting toilets facilities. Hand-dug wells are designed and located without proper site investigation as to ascertain nearness to pollution source centers. The depth to groundwater in the study area is shallow and based on field examination and survey is prone to contamination.

The study area

The study area is Ikem and its environs in the Isi-uzo Local Government area of Enugu State (Figure 1). It is bounded by 6°39’57.25″N and 6°48’37.25″N latitudes and 7°39’41.98″E and 7°50’56.98″E longitudes. It shears boundary on the east with Ado and Okpokwu Local Government Areas of Benue State, Ishielu Local Government Area of Ebonyi State on the south, Akpoga - Imiliki on the north, and Nike in Enugu East Local Government Area on the west both in Enugu State. It has a total land cover of about 1283 km², which is within the Guinea Savanna region of the state. The annual precipitation is about 184 mm. The major towns in the study area include Eha-Amufu, Ikem, Mbu, and Nekeand Umualor. The population of the study area is about 169,811 persons (NPC, 2006).

Topography and drainage

The study area shows varying elevation ranging from 250 m in the northwestern part of the study area to 90 m in the southeastern part of the area (Figure 2). Due to the high elevation in the northern part of the study area, most of rivers took their source there and flow southward forming distributaries along their flow paths. The drainage pattern is dendritic (Figure 3). The main rivers in the study area are Ebonyi and Amanyi Rivers. The Ebonyi River flows northwestward to the central part of the study area, where it joins the Amanyi River. The streams in the study area are seasonal. Water level in hand-dug wells, within or close to the streams and rivers, occurs at an average depth of 6–15 m (Table 1). Some hand-dug wells in the northwestern part of the study area dry up simultaneously with the streams and rivers during dry season.

Geology of the area

The study area is underlain by the Nkporo Formation and Agwu Formation (Figure 4). The Nkporo Formation of late Campanian age is the basal facies of the late Cretaceous sedimentary cycle in the Anambra basin. The lithology of the Nkporo Formation consists mainly of carbonaceous shales,
sandstone, and coals within the upper half deposited in lower flood plain and swampy environments. The sediments are normally associated with siderites and pyrites, which are early diagenetic minerals.
| Latitude (N) | Longitude (E) | Elevation (m) | Water depth (m) | Head value (m) |
|------------|---------------|---------------|----------------|----------------|
| 6°42 04.74 | 7° 38 18.98   | 151           | 11             | 140            |
| 6°44 11.35 | 7°38 02.05    | 190           | 10             | 180            |
| 6°43 35.13 | 7° 38 02.05   | 195           | 15             | 170            |
| 6°42 33.94 | 7° 40 24.19   | 160           | 10             | 150            |
| 6°41 38.42 | 7° 40 39.12   | 151           | 11             | 130            |
| 6°43 21.26 | 7° 41 51.50   | 161           | 11             | 150            |
| 6°40 49.72 | 7° 39 38.53   | 150           | 10             | 140            |
| 6°46 54.25 | 7° 39 23.25   | 170           | 10             | 160            |
| 6°47 19.79 | 7° 40 43.39   | 155           | 15             | 140            |
| 6°46 49.28 | 7° 42 23.34   | 157           | 7              | 150            |
| 6°44 54.17 | 7° 41 26.62   | 190           | 10             | 170            |
| 6°46 08.98 | 7° 42 07.59   | 180           | 10             | 170            |
| 6°49 00.49 | 7° 40 09.92   | 181           | 11             | 170            |
| 6°48 24.87 | 7° 40 01.14   | 111           | 11             | 100            |
| 6°46 04.35 | 7° 41 42.07   | 170           | 10             | 160            |
| 6°48 16.47 | 7° 42 57.32   | 181           | 11             | 170            |
| 6°45 53.37 | 7° 44 49.06   | 170           | 10             | 160            |
| 6°48 22.64 | 7° 44 19.56   | 94            | 9              | 85             |
| 6°47 05.79 | 7° 46 47.50   | 130           | 10             | 130            |
| 6°45 10.79 | 7° 46 40.05   | 147           | 7              | 110            |
| 6°49 27.38 | 7° 46 23.49   | 120           | 10             | 110            |
| 6°45 43.79 | 7° 46 34.32   | 140           | 10             | 130            |
| 6°45 11.79 | 7° 48 16.97   | 131           | 11             | 120            |

Figure 4. Geologic map of the study area.
(Rayment, 1965). The Owelli Sandstone is the major sand member of the Nkporo Formation. The area is also underlain by the Awgu Formation; it overlies the EzeAku Shale conformably. The lithology is bluish-gray well-bedded shale interbedded with fine yellow calcareous sandstone and shaly limestone, with a total thickness of 900 m. The strata are greatly folded and fractured (Rayment, 1965).

**Materials and methods**

This study adopted the sample survey method which involves direct observation, collection of water samples, and laboratory analysis of the water samples among others. A 3-day reconnaissance survey of the study environment was conducted from 18th to 21st June 2017. The investigation commenced with the use of global positioning systems to mark out the locations of 25 water wells investigated in the study. Four groundwater samples from each well were collected in 1 L plastic containers from 20th and 24th August 2017. One set of samples was used for the cation determination, the second set for the anion determination, the third set for biological analysis, and the fourth set for selected heavy metal analysis. Physical parameters such as acidity (pH), temperature, and electrical conductivity (EC) that change rapidly with time were measured in the field. Total bacteria and fecal coliform counts were determined by using the Millipore filtration method. The pH was determined by using a Hach portable pH/ISE meter. The meter was calibrated with buffers pH 4.0 and 9.0 prior to measurement. EC and TDS were determined by wissenschaftlich-Technische-Werkstatten (WTW) conductivity meter. 0.8M EDTA titration cartridge was selected and titrated against the water samples. Heavy metals, such as Pb$^{2+}$, Cu$^{2+}$, Zn$^{2+}$, and Mn$^{2+}$, were determined by digital bulk 205 atomic absorption spectrophotometer. SO$_4^{2-}$, NO$_3^{-}$, and Fe$^{2+}$ were determined by Hach DR/2000 spectrophotometer. Multivariate analysis was carried out using Statgraphics software. Three statistical tests carried out are the correlation analysis, cluster analysis (CA), and PCA. Hydrochemical plots were drawn using Rockworks16; maps were made using ArcGIS 10.2 and Surfer10.

**Results and discussion**

**Groundwater flow system**

The hydraulic head data alongside the wells coordinate were used to generate the hydraulic head map (Table 1). On a general note, regional groundwater flow direction is not expected in the area, owing to its shaly lithology, patched sandy aquifer, and the undulating topography. Groundwater flow direction is local and is controlled by topographic highs and fractures in the area (Figure5). In Figure 4, different color shades represent hydraulic heads.

**Groundwater chemistry**

Water samples were taken from 25 hand-dug wells in the study area, and were analyzed for major anions, cations, and four selected heavy metals associated with sewage and agricultural wastes. The physical parameters, major ions analyzed, and selected metals are shown in Tables 2, 3, and 4, respectively. Hydrogen ion concentration (pH) and the TDS of the groundwater in the study area averaged 5.1 and 210 mg/L, respectively, indicating acidic groundwater. The minimum pH was obtained from the groundwater sample at locations 6 and 1 (CK6 and CK1, respectively). The acidic nature of the groundwater can be attributed to oxidation of sulfide minerals, sulfur contained in the host rocks, and the influence of anthropogenic activities (Collin et al. 2018). The EC of the groundwater varied from 0.08 µs/cm at locations CK2 and CK25 to 1.96 µs/cm at location CK6 (Table 2). The variation in EC is attributed to different degrees of enrichment in the deposition environment during accumulation and anthropogenic activities. There is fluctuation in the temperature of groundwater in the area of study. The temperature ranges between 10°C and 31°C. The values confirmed existence of hydraulic connection between the groundwater environment and the ground surface based on the similarity with surface water temperature and wide range of groundwater temperature (10°C – 31°C).

The dominant cations in the groundwater, in order of abundance, are Ca$^{2+}$>Mg$^{2+}$>K$^+$>Na$^+$ (Table 3). The calcium concentrations from hand-dug wells range from 10 mg/L at location CK22 to 195 mg/L at locations CK7 and CK18, respectively. Magnesium ion ranged from 1.65 mg/L at location CK5 to 33.78mg/L at location CK6 (Figure 6). The sources of calcium and magnesium in the water samples from the study area are thought to be from the dissolution of the limestone and shale in the study area. The concentration of sodium varied from 0.188 mg/L at location CK23 to 113 mg/L at location CK12. All the samples have sodium concentrations within the permissible limit of 200 mg/L stipulated by WHO (2017). The concentration of K$^+$ in the groundwater varied from 0.59 mg/L at location CK22 to 39 mg/L at location CK9. The sources of sodium in the water samples are attributed to host rock dissolution, while the source of potassium is thought to be from host rock dissolution and/or leaching of agricultural waste. Different color shades in the diagram (Figure 6) show variation of major
Cations with respect to their location in the study area. Chloride and phosphate are the dominant anions in the groundwater in the study area. The dominant anion in the order of abundance is \( \text{Cl}^- \succ \text{PO}_4^{2-} \succ \text{NO}_3^- \succ \text{HCO}_3^- \succ \text{SO}_4^{2-} \) (Table 3). Nitrate concentration in hand-dug wells is lower than 10 mg/L allowable limit for drinking water, with the exception of CK6, CK14, and CK24. The maximum value is 1.9 mg/L which was recorded in CK6. \( \text{NO}_3^- \) has an average of 0.08996 mg/L and ranges from 0.015 mg/L at CK19 to 1.9 mg/L at CK6. The source of nitrate in the study area could be attributed to onsite sanitary sewage contamination and/or leaching of agricultural waste. It also contributes in lowering the pH by forming weak acids (tetraoxonitrato acid) through oxidation and hydration. In this work, the chloride concentrations from hand-dug wells are within the permissible limit of 250 mg/L for drinking water prescribed by WHO (2017). \( \text{Cl}^- \) has an average of 143.168 mg/L and ranges from 13.49 mg/L at CK8 to 248.5 mg/L at CK1. The source could also be onsite sanitary sewage contamination.

### Table 2. The analyzed physical parameters.

| Sample name       | ID  | EC (µs/cm) | TDS (mg/L) | PH  | Temp (°C) |
|-------------------|-----|------------|------------|-----|-----------|
| UMUALOR AGU       | CK1 | 0.12       | 54         | 6.5 | 25        |
| AMUDAMU           | CK2 | 0.08       | 43         | 6   | 20        |
| IKEM              | CK3 | 0.19       | 82         | 5.7 | 25        |
| OBOGU             | CK4 | 0.19       | 76         | 5.9 | 28        |
| ONUME             | CK5 | 1.11       | 55         | 5.2 | 31        |
| EHA-AMUFU         | CK6 | 1.97       | 1145       | 6.5 | 30        |
| MBU-AMONU         | CK7 | 0.36       | 188        | 6.1 | 10        |
| UGWUOSHIME        | CK8 | 0.85       | 168        | 6.4 | 23        |
| MBU MARKET        | CK9 | 0.13       | 61         | 6.1 | 30        |
| AKPOTI            | CK10| 0.36       | 171        | 5.8 | 31        |
| AGUMEDE           | CK11| 0.22       | 103        | 5.7 | 22        |
| AGU-UMUALOR       | CK12| 0.13       | 59         | 5.5 | 28        |
| NEKE              | CK13| 0.25       | 108        | 5.5 | 30        |
| NKWO-NEKE         | CK14| 0.18       | 93         | 5.3 | 30        |
| IKEM-NKWO         | CK15| 0.14       | 67         | 5.4 | 26        |
| NEKE AGUAMEDE     | CK16| 0.12       | 42         | 5.3 | 28        |
| APKOGA            | CK17| 0.05       | 0.23       | 5.3 | 28        |
| MGBRUI            | CK18| 1.84       | 949        | 6.2 | 25        |
| IHENYI            | CK19| 2.12       | 1066       | 6.4 | 21        |
| EGEDEGEBE         | CK20| 1.92       | 1013       | 6.6 | 26        |
| NEKE-ULOR         | CK21| 0.22       | 106        | 6.4 | 30        |
| UMU-ULOR          | CK22| 0.09       | 40         | 5.7 | 30        |
| AGUAMEDE ULOR     | CK23| 0.18       | 81         | 5.6 | 31        |
| OGO-NDOGO         | CK24| 0.14       | 65         | 6.7 | 28        |
| AGUAMEDE ETITE    | CK25| 0.08       | 33         | 6.1 | 30        |

CK represents groundwater sample at particular location.
and/or leaching of agricultural waste. The concentration of SO\(_4^{2-}\) from hand-dug wells has an average of 9.3 mg/L and ranges from 0.64 to 11.92 mg/L at CK15 and CK14, respectively. All the samples are within the maximum allowable limit of 250 mg/L stipulated by USEPA (1994). The high concentration of sulfate is likely due to dissolution of limestone which underlies the area. It also contributes in lowering the pH by forming weak acids through oxidation and hydration (Colin et al., 2018).

The distribution of bicarbonate in the study area has an average of 0.4448 mg/L and ranges from 0.16 to 10 mg/L at CK24 and CK15, respectively (Figure 7). The concentrations of bicarbonates are thought to be derived from dissolution of limestone and shale from the study area. PO\(_4^{3-}\) has an average of 10.5203 mg/L and ranges from 7.749 mg/L at CK16 to 29.981 mg/L at CK1. The concentration of PO\(_4^{3-}\) in the groundwater could also be attributed to onsite sanitary sewage contamination and/or leaching of agricultural waste. It also contributes in lowering the pH by forming weak tetraoxophosphate (V) acid through oxidation and hydration (Hongbo, Yangyang, & Suyun, 2018). Different color shades in the diagram (Figure 7) show variation of major anions with respect to their location in the study area.

Manganese and iron are the dominant metals in the groundwater of the study area, in the following order of abundance: Mn\(^{2+}\) > Fe\(^{2+}\) > Zn\(^{2+}\) > Pb\(^{2+}\) > Cu\(^{2+}\) (Figure 7). Generally, the low concentrations of the heavy metals reflect majorly geogenic heavy metal contamination of groundwater with little or no contamination from anthropogenic activities (Table 4). The host rocks are associated with siderites and pyrites which are early diagenetic minerals (Rayment, 1965). The concentrations of the metals are below the WHO acceptable limit for drinking water. Variations of selected metals with respect to their location in the study area are shown in Figure 8 as shades of colors.

**Water type and hydrochemical facies**

Hydrochemical data of analyzed samples from the study area are plotted on a piper trilinear, stiff and Durov diagrams for visual comparison, rock type deduction, and delineation of hydrochemical facies.
Hydrochemical facies are different zones that possess similar cation and anion concentration categories.

**Stiff diagram**

The dominant water types in the study area were determined using stiff diagrams. Stiff patterns can be used to show distinctive trends of water composition (Hem, 1985). The size of the pattern is approximately equal to the total ionic content (Hounslow, 1995). From the plots in Figure 8, 55% of the stiff plot shows Ca$^{2+}$ – Cl$^-$ water type and 45% of the stiff shows Na$^+$ + K$^+$ – Cl$^-$ water type (Figure 9(a–e)).

**Piper diagram**

Water types and hydrochemical facies can be unraveled by the use of a piper diagram. The diamond part of the piper diagram shown (Figure 10) can be used to characterize water of different waters (Hounslow, 1995). Water plotted at the corner of diamond is primarily composed of Ca$^{2+}$–Mg$^{2+}$ and Cl$^-$–SO$_4^{2-}$ which depicts areas of permanent hardness and can be classified as calcium/magnesium and chloride/sulfide type, demonstrating the dominance of alkaline earths over alkali (Ca + Mg > Na+ K) and strong acidic anions over weak acidic anions (Cl+ SO$_4$ > HCO$_3$). Water at the right corner of diamond depicts Na$^+$ + K$^+$ and SO$_4^{2-}$ + Cl$^-$ which can be classified as sodium/potassium and
Figure 8. Variation of selected metals with respect to their location in the study area.

Figure 9. (a) Variation in the stiff diagram for CK1–CK6. (b) Variation in the stiff diagram for CK7–CK12. (c) Variation in the stiff diagram for CK13–CK18. (d) Stiff diagram for CK19–CK24. (e) Stiff diagram for CK25.
Figure 9. (Continued).
sulfate/chloride type. Figure 9 shows that 60% of the cations in the water samples fall within Ca$^{+}$ water type of the piper trilinear plot, 30% plotted within Na$^{+}$ + K$^{+}$ section, and 10% indicate mixed water type having no cation–anion pair (Figure 10). The anions plot within the chloride section. This shows that the dominant water types in the study area are Ca$^{2+}$–Cl$^{-}$ and Na$^{+}$ + K–Cl$^{-}$; this is inconformity with the results obtained from the Stiff diagrams.

**Durov diagram**

Durov diagram (Figure 11) shows that 83% of the samples plot in the fields 1 and 4, along the ion exchange line, while 17% of the samples plot in field 7, along the dissolution or mixing line. Based on the classification of Lloyd and Heathcote (1985), the trend of groundwater in the study area can be attributed Na$^{+}$ and Cl$^{-}$ as dominant anion/cation, indicating that the waters can be related to ion exchange of Na$^{+}$-Cl$^{-}$ waters.

**Bacteriological analysis**

**Coliforms**

Biological analysis of groundwater samples obtained from the study area shows significant concentration of coliform (Table 5). The concentration ranges from 120 to 2500 mpu/100 mL (Figure 10), which is above WHO (2017) standard for drinking water. Coliform...
concentration in the groundwater is an indication that the groundwater is associated with human waste or animal intestine tract and its presence in the groundwater strongly indicates sewage contamination (Nan, Li, Linqiong, Longfei, & Lihua, 2018).

Samples collected from CK6, CK8, CK9, CK11, and CK12 have fecal coliform concentration above 1000 mpn/100 mL. The sample CK6 around Eha-Amufu collage of Education has the highest coliform count of 2600 mpn/100 mL (Figure 12).
Environments associated with sewage contamination are breeding grounds for bacterial activities and can be used to identify sewage pollution by testing for Faecal coliform (Ocheri, 2006).

**Escherichia coli** (E. coli)
The confirmation of E. coli in the groundwater sample in the study area also indicates fecal contamination. E. coli concentration in the study area ranges from 01 to 35 mpn/100 mL (Figure 13) which is above the 0 mpn/100 mL WHO (2017) standard for drinking water. It source is attributed to sewage contamination.

**Multivariate analysis**
Correlation analysis, PCA, and CA tests were carried out on the geochemical data (Tables 2 and 4).

### Table 5. Bacteriological parameters from the study area.

| S/N | Sample name             | Coliform mpn/100 mL | E. coli mpn/100 mL |
|-----|-------------------------|---------------------|-------------------|
| 1   | UMUALOR AGU             | 500                 | 01                |
| 2   | AMUDAMU                 | 200                 | 13                |
| 3   | IKEM                    | 170                 | 11                |
| 4   | OBOGU                   | 400                 | 22                |
| 5   | ONUME                   | 130                 | 3                 |
| 6   | EHA-AMUFU               | 2600                | 35                |
| 7   | MBU-AMONU               | 160                 | 6                 |
| 8   | UGWUOSHIME              | 1400                | 9                 |
| 9   | MBU MARKET              | 1600                | 13                |
| 10  | AKPOTI                  | 130                 | 8                 |
| 11  | AGUAMEDE                | 2400                | 20                |
| 12  | AGU-UMUALOR             | 1800                | 8                 |
| 13  | NEKE                    | 140                 | 3                 |
| 14  | NKWO-NEKE               | 210                 | 9                 |
| 15  | IKEM-NKWO              | 460                 | 4                 |
| 16  | NEKE AGUAMEDE           | 190                 | 13                |
| 17  | APKOGA                  | 200                 | 8                 |
| 18  | MGBUJI                  | 220                 | 7                 |
| 19  | IHENYI                  | 485                 | 6                 |
| 20  | EGEDEGEBE              | 160                 | 3                 |
| 21  | NEKE-ULOR              | 130                 | 6                 |
| 22  | UMU-ULOR               | 150                 | 5                 |
| 23  | AGUAMEDE ULOR           | 550                 | 4                 |
| 24  | OGO-NDOGO               | 220                 | 9                 |
| 25  | AGUAMEDE ETITE          | 120                 | 11                |

**Correlation analysis**
Correlation coefficient is used to establish the relationships between parameters (Danijele, Milovan, Lijijana, & Ivana, 2015). It helps to know how one parameter predicts the other. The correlation scores for TDS, major ions, and heavy metals are presented and significant correlation between parameters was taken at values equal to or greater than 0.5 (Table 6). From Table 6, Ca$^{2+}$, Mg$^{2+}$, K$^+$, and SO$_4^{2-}$ appear to be the main contributors of the groundwater TDS. Ca$^{2+}$ shows a high correlation (0.9998) with Mg, indicating that the two cations are from the same source (Omono et al., 2013). Ca$^{2+}$-SO$_4^{2-}$, Mg$^{2+}$-K$^+$, and SO$_4^{2-}$-Mg$^{2+}$ are also more significant pairs. The correlation analysis also reveals no significant correlation between the selected metal types studied.

**Principal component analysis (PCA)**
PCA was used to identify the most significant parameters from the groundwater and the relationship between them (Danijele et al., 2015). In this study, 14 variables (parameters) from 25 groundwater samples were used for the PCA, and 5 principal components extracted (Table 7) which explain 79.105% of the total sample variance. The number of significant PCs for interpretation was selected on the basis of listwise missing value treatment method, with minimum eigenvalue of 1 (Table 8). The first PC (PC1) explains 33% of the total variance and has loading for Ca$^{2+}$, Mg$^{2+}$, and SO$_4^{2-}$ are thought to be released from rock mineral dissolution of shale and limestone within the study area. The second PC (PC2) which accounts for 15.036% of the total variance has high loading for NO$_3^-$, Cl$^-$, PO$_4^{3-}$, and Pb$^{2+}$. Cl$^-$, NO$_3^-$, and PO$_4^{2-}$ are thought to be released from sewage waste through onsite sanitary sewage system. PC3 accounts for 11.961% of the total variance.

**Figure 12.** Variation in coliform count in the study area.
variance and has high loading for Fe$^{2+}$, K$^+$, and Na$^+$ which are thought to be released from leaching of agricultural wastes. PC4 accounts for 10.779% of the total variance and has loading for Mn$^{2+}$ and Zn$^{2+}$; PC5 accounts for 7.948% of the total variance and has high loading for Mn$^{2+}$ and Pb$^{2+}$. Both PC4 and PC5 reflect geogenic heavy metal contamination. The heavy metal contamination is due to the fact that the host rocks are associated with siderites and pyrites.

The controlling processes of the principal components (PC1, PC2, PC3, PC4, and PC5) are shown in Table 9. With a minimum score of 1.5 (Table 9), PC1 has high loading on samples CK6, CK18, CK19, and CK20 which indicates that they are controlled by the influence of weathering of host rocks. PC2 has high loading for samples CK1, CK2, CK6, CK17, and CK24 which indicates that they are controlled by sanitary Sewage waste and PC3 reflects agricultural waste contamination with high loading for CK3, CK7, CK8, CK17, CK19, and CK8. PC4 and PC5 have high loading for samples CK3, CK7, CK8, CK17, CK19, and CK12 which indicates host rock dissolution and weathering (geogenic contamination).

### Figure 13. Variation in E. coli count in the study area.

### Table 6. Correlations scores for TDS, major ions, and heavy metals.

|          | NO$_3^-$ | Cl$^-$ | Ca$^{2+}$ | Mg$^{2+}$ | Mn$^{2+}$ | Fe$^{2+}$ | Zn$^{2+}$ | K$^+$ | HCO$_3^-$ | SO$_4^{2-}$ |
|----------|----------|--------|-----------|-----------|-----------|-----------|-----------|------|-----------|-----------|
| NO$_3^-$ | 0.1931   | 0.0677 | 0.0616    | 0.1022    | 0.1312    | −0.0045   | 0.0722    | −0.0863| −0.0124   |
| Cl$^-$   | 0.3550   | 0.7479 | 0.7699    | 0.6268    | 0.5318    | 0.9831    | 0.7317    | 0.6818| 0.9531    |
| Ca$^{2+}$| 0.0677   | 0.4620 | 0.4654    | 0.1908    | 0.0072    | −0.1866   | 0.0374    | 0.0146| 0.3326    |
| Mg$^{2+}$| 0.3550   | 0.0201 | 0.0191    | 0.3610    | 0.9726    | 0.3717    | 0.8591    | 0.9448| 0.1043    |
| Mn$^{2+}$| 0.0722   | 0.0677 | 0.0616    | 0.1022    | 0.1312    | −0.0045   | 0.0722    | −0.0863| −0.0124   |
| Fe$^{2+}$| 0.1312   | 0.0072 | 0.0399    | 0.0396    | 0.1333    | −0.0485   | 0.6056    | 0.4067| 0.7977    |
| Zn$^{2+}$| 0.5318   | 0.9726 | 0.8498    | 0.8511    | 0.5552    | 0.1089    | −0.1239   | −0.1134| −0.1750   |
| K$^+$    | 0.9831   | 0.3717 | 0.8179    | 0.8259    | 0.5895    | 0.6042    | 0.7984    | 0.1367| 0.5373    |
| HCO$_3^-$| 0.0978   | 0.0374 | 0.6056    | 0.6058    | −0.1750   | 0.1219    | 0.0538    | 0.0156| 0.4434    |
| SO$_4^{2-}$| 0.0863  | 0.0146 | 0.4067    | 0.4031    | −0.1986   | −0.4006   | 0.3061    | 0.1232| 0.4802    |
| Pb$^{2+}$| 0.6818   | 0.9448 | 0.0437    | 0.0457    | 0.3413    | 0.0472    | 0.1367    | 0.5575| 0.0151    |
| TDS      | −0.0124  | 0.3326 | 0.7977    | 0.7916    | −0.0257   | −0.1174   | −0.1295   | 0.4434| 0.4802    |
| Na$^+$   | 0.9531   | 0.1043 | 0.0000    | 0.0000    | 0.9028    | 0.5762    | 0.5373    | 0.0264| 0.0151    |
| PO$_4^{3-}$| 0.8177  | 0.1183 | 0.1210    | 0.1294    | 0.5565    | 0.3718    | 0.0469    | 0.3754| 0.0027    |
| E. coli  | 0.0156   | 0.3742 | 0.9706    | 0.9698    | −0.0980   | 0.0349    | −0.0328   | 0.7163| 0.3588    |
| NO$_3^-$ | 0.9409   | 0.0654 | 0.0000    | 0.0000    | 0.6413    | 0.8686    | 0.8764    | 0.0001| 0.0782    |
| Cl$^-$   | 0.1654   | −0.1612| −0.0428   | −0.0447   | −0.0476   | 0.1148    | 0.0155    | 0.3891| −0.2038   |
| Ca$^{2+}$| 0.4295   | 0.4414 | 0.8391    | 0.8320    | 0.8211    | 0.5847    | 0.9414    | 0.3286| 0.7226    |
| Mg$^{2+}$| 0.4643   | 0.4082 | 0.0862    | 0.0877    | −0.0086   | 0.2062    | 0.2803    | −0.0261| −0.0477   |
| Mn$^{2+}$| 0.0194   | 0.0428 | 0.6819    | 0.6766    | 0.9673    | 0.3228    | 0.1747    | 0.9016| 0.8208    |
distance. Three clusters were observed: the first cluster (NO\textsubscript{3}\textsuperscript{-}, PO\textsubscript{4}\textsuperscript{3-}, and Cl\textsuperscript{-}) contains the same parameters as in PC2 and reflects the influence of fecal waste contamination of groundwater in the study area. The second cluster (Ca\textsuperscript{2+}, Mg\textsuperscript{2+}, SO\textsubscript{4}\textsuperscript{2-}, K\textsuperscript{+}, Pb\textsuperscript{2+}) contains the same parameters PC1 and PC3, and reflects the influence of host rock dissolution/weathering and agricultural waste contamination, respectively. The third cluster (Mn\textsuperscript{2+}, Cu\textsuperscript{2+}, Zn\textsuperscript{2+}, HCO\textsubscript{3}\textsuperscript{-}, Fe\textsuperscript{2+}, and Na\textsuperscript{+}) is contained in PC3, PC4, and PC5 reflects geogenic contamination of groundwater, with the exception of Fe\textsuperscript{2+} and Na\textsuperscript{+} (Figure 14).

Table 8. Component weights of the variables.

| Component | Component | Component | Component | Component |
|-----------|-----------|-----------|-----------|-----------|
| NO\textsubscript{3} | 0.0256655 | -0.377815 | 0.141854 | 0.0684572 |
| Cl | 0.186095 | -0.403235 | -0.312763 | -0.303561 |
| Ca | 0.4499 | -0.0679805 | -0.00777586 | -0.0181252 |
| Mg | 0.44895 | -0.0700243 | -0.00890025 | -0.01763 |
| Mn | -0.0701047 | -0.0135142 | -0.26074 | -0.389645 |
| Fe | -0.0187944 | -0.317935 | -0.389649 | -0.0076472 |
| Zn | -0.0346689 | -0.219899 | -0.0242947 | 0.67324 |
| K | 0.306844 | -0.0202928 | 0.425256 | 0.0579949 |
| HCO\textsubscript{3} | 0.219514 | 0.159876 | -0.299003 | 0.501587 |
| SO\textsubscript{4} | 0.410064 | 0.0906314 | -0.118424 | -0.0518187 |
| Pb | 0.200643 | 0.441748 | 0.0690927 | -0.154068 |
| TDS | 0.449989 | -0.0135663 | 0.0689911 | -0.0216194 |
| Na | -0.00462057 | 0.00569684 | 0.587398 | -0.0516027 |
| PO\textsubscript{4} | 0.0318357 | -0.55241 | -0.154125 | 0.0831554 |

Table 9. The controlling processes of the principal components with minimum score of 1.5.

| Row | Component | Component | Component | Component | Component |
|-----|-----------|-----------|-----------|-----------|-----------|
| 1 | -0.47643 | -5.1226 | -1.0349 | 0.203091 | -2.39837 |
| 2 | -0.93121 | -1.66034 | -0.366119 | 0.246363 | 0.831449 |
| 3 | -0.663769 | -0.48646 | -1.724 | 4.78788 | 1.1874 |
| 4 | -1.45322 | -0.186542 | 0.969995 | 0.756267 | 0.291793 |
| 5 | -1.40003 | -0.296373 | -1.51622 | -0.979722 | 1.36853 |
| 6 | 3.85881 | -2.02993 | 1.67439 | -0.034882 | 1.47115 |
| 7 | -0.387305 | 0.540532 | 1.8066 | 0.843272 | 0.518746 |
| 8 | -0.812873 | 0.601349 | 3.22149 | 0.917647 | 0.852004 |
| 9 | -0.090622 | 0.0136959 | 0.927444 | -0.612327 | -0.282679 |
| 10 | 0.860756 | 0.314662 | 0.366815 | 0.003098 | 0.147895 |
| 11 | -0.765923 | -0.10517 | -0.303649 | -0.157464 | 0.0679004 |
| 12 | -1.44143 | -0.323277 | -1.43679 | -2.50721 | 2.06807 |
| 13 | -0.499512 | -1.16534 | 1.21766 | -1.17073 | 0.474306 |
| 14 | -0.813189 | -0.461153 | -0.468971 | -1.07331 | 0.353585 |
| 15 | -1.00388 | -0.339135 | 0.077707 | -0.424539 | -0.561162 |
| 16 | 0.88263 | 1.38068 | -0.240843 | 0.409815 | -0.835511 |
| 17 | -0.6813 | 1.90206 | -2.12731 | 0.382389 | -0.980213 |
| 18 | 5.21795 | 0.15448 | -0.130909 | -0.226381 | -0.775428 |
| 19 | 4.82952 | 1.28956 | -1.75375 | -0.016434 | 1.29366 |
| 20 | 5.17273 | 0.57217 | 0.334075 | -0.212278 | -1.29228 |
| 21 | -0.603066 | 0.613566 | -0.58962 | -0.301009 | -0.247937 |
| 22 | -0.12411 | 0.627798 | 1.35207 | 0.049952 | 1.08674 |
| 23 | -0.106961 | 1.44181 | -0.419373 | -0.290293 | 1.14364 |
| 24 | -0.068635 | 1.80458 | 0.611321 | -0.157507 | -0.727365 |
| 25 | -1.2722 | 0.91755 | -0.547121 | -0.498679 | -0.405401 |

Cluster analysis

Cluster analysis (CA) was used to cluster the geochemical variables according to their similarities using Ward’s method and squared Euclidean distance. Three clusters were observed: the first cluster (NO\textsubscript{3}\textsuperscript{-}, PO\textsubscript{4}\textsuperscript{3-}, and Cl\textsuperscript{-}) contains the same parameters as in PC2 and reflects the influence of fecal waste contamination of groundwater in the study area. The second cluster (Ca\textsuperscript{2+}, Mg\textsuperscript{2+}, SO\textsubscript{4}\textsuperscript{2-}, K\textsuperscript{+}, Pb\textsuperscript{2+}) contains the same parameters PC1 and PC3, and reflects the influence of host rock dissolution/weathering and agricultural waste contamination, respectively. The third cluster (Mn\textsuperscript{2+}, Cu\textsuperscript{2+}, Zn\textsuperscript{2+}, HCO\textsubscript{3}\textsuperscript{-}, Fe\textsuperscript{2+}, and Na\textsuperscript{+}) is contained in PC3, PC4, and PC5 reflects geogenic contamination of groundwater, with the exception of Fe\textsuperscript{2+} and Na\textsuperscript{+} (Figure 14).

Conclusion

Results of the physicochemical analysis suggest that all the water samples in the study area are acidic, with...
very few samples having EC and TDS above their standard limit. The alkaline earths were dominant over alkali and strong acidic anions over weak acidic anions in the present study, due to ion exchange and simple mineral dissolution or mixing. The temperature range confirmed existence of hydraulic connection between the groundwater environment and the ground surface. Fifty-five percent of the stiff plot shows Ca$^{2+}$ – Cl$^-$ water type and 45% of the stiff shows Na$^+$ K$^+$ – Cl$^-$ water type. The dominant hydrochemical facies in the study area is Ca$^{2+}$-Mg$^{2+}$ – Cl$^-$ – SO$_4^{2-}$ (83%) and Na$^+$ K$^+$ and SO$_4^{2-}$ + Cl$^-$ (17%).

Groundwater types assessed and compared with Durov and Piper diagrams illustrated that simple mineral dissolution or mixing and ion exchange processes are mainly responsible for variation in hydrogeochemistry of ground in the study area. Bacteriological analysis shows that the groundwater is contaminated with fecal waste. Five principal components were extracted from the PCA which explains 79.105% of the total sample variance. PC1 could be said to reflect the presence of the weathering and dissolution of host rocks, PC2 could be said to reflect the influence of anthropogenic activities (contamination from onsite sewage systems), PC3 generally reflects leaching of agricultural waste, and PC4 and PC5 both generally reflect geogenic heavy metal contamination. From the CA (Figure 14), three clusters were observed: the first cluster (NO$_3^-$, PO$_4^{3-}$, and Cl$^-$) contains the same parameters in PC2 which reflects the influence of fecal waste contamination of the groundwater in the study area. The second cluster (Ca$^{2+}$, Mg$^{2+}$, SO$_4^{2-}$, K$^+$, and Pb$^{2+}$) contains the same parameters with PC1 and PC3, which reflects the influence of host rock dissolution/weathering and agricultural waste contamination, respectively. The third cluster (Mn$^{2+}$, Cu$^{2+}$, Zn$^{2+}$, HCO$_3^-$, Fe$^{2+}$, and Na$^{2+}$) is contained in PC3, PC4, and PC5, which reflects geogenic contamination of groundwater with the exception that Fe$^{2+}$ and Na$^{2+}$ could also reflect anthropogenic activities. From the correlation analysis, Ca$^{2+}$, Mg$^{2+}$, K$^+$, and SO$_4^{2-}$ appear to be the main contributors of the groundwater TDS. Ca$^{2+}$ shows a high correlation (0.9998) with Mg, indicating that the two cations are from the same source. The correlation analysis also revealed no significant correlation between the selected metal types studied. Groundwater flow direction is local and is controlled by topographic highs, weathering and fracturing of the host rock in the area.

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Disclosure statement
No potential conflict of interest was reported by the authors.

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