

# Use of graphical plots to discriminate effects of urbanization on groundwater chemistry in Ado-Ekiti and Ijero-Ekiti, Southwestern Nigeria

A. O. Talabi\*, O. L. Afolagboye and A. A. Oyedele

Department of Geology, Ekiti State University, P. M. B. 5363, Ado-Ekiti, Nigeria.

\*Corresponding author. Email: [abel.talabi@eksu.edu.ng](mailto:abel.talabi@eksu.edu.ng)

Copyright © 2023 Talabi et al. This article remains permanently open access under the terms of the [Creative Commons Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 9th June 2023; Accepted 12th July 2023

**ABSTRACT:** Presentation of chemical analysis in graphical forms makes understanding of complex groundwater system simpler and quicker. This study examined the signatures of graphical plots to unravel the effects of urbanization on the groundwater quality of Ado-Ekiti and Ijero-Ekiti, southwestern Nigeria. In this study, existing data from Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria were employed for the graphical plots. In that study, sixty wells' water samples (30 each from Ado-Ekiti and Ijero-Ekiti respectively) were involved in the chemical analyses. Sampling operation was carried out by collecting water samples in duplicates at each location into a pre-cleansed polyethylene bottles for anions and cations determinations. The samples for cations analysis were acidified by addition of two drops of concentrated Nitric acid to prevent reactions that may come up before analysis. All samples were kept in a refrigerator at a temperature of 4°C before they were analyzed at the Federal University of Technology, Akure Nigeria. Anions were determined employing Ion chromatography while the cations were analyzed using an Atomic Absorption Spectrophotometer Buck 210 model. The graphical plots in this study were obtained from the results of the chemical concentrations of the analyses. Results of the chemical analysis showed that the wells' water was low mineralized with chemical concentrations of all ions within approved standard for drinking water except the  $\text{NO}_3^-$  (mg/L) values with concentrations that range from 95.62 – 405.39 and 13.47 – 382.49 at Ijero-Ekiti and Ado-Ekiti respectively. The Nitrate pollution of water from the two cities came from anthropogenic activities mostly from indiscriminate dumping of waste and fossil fuel. However, Ijero-Ekiti had additional pollutants from the gangues arisen from the mining activities in the area. All the graphical plots (Gibb's diagram, Schoeller diagram, Wilcox plot and Cross plot) except the Piper diagram indicate that the groundwater at Ijero-Ekiti is more polluted than that of Ado-Ekiti. The Piper diagram for both cities reveals almost equal groundwater rate of pollution with 80% of the groundwater having  $\text{NaSO}_4\text{Cl}$  water type. All estimated irrigation quality parameters (sodium absorption ratio (SAR), soluble sodium product (SSP), Residual sodium Bicarbonate (RSBC), Kelly Ratio (KR), Permeability Index (PI) and Magnesium Absorption Ratio (MAR)) indicate that groundwater at Ijero-Ekiti is more prone to pollution and of better irrigation quality than that of Ado-Ekiti. Despite the high population at Ado-Ekiti, the groundwater is less prone to pollution due to intensive sanitation and hygiene activities. In this study, as against the general accepted view, urbanization has no significant impact on groundwater pollution as hygiene/sanitation is its foremost determinant.

**Keywords:** Graphical plots, irrigation quality parameters, piper diagram, pollution.

## INTRODUCTION

Water is the basis of life for both humans and other living things on the earth, it is equally crucial in the formation of non-living things (rocks, soil etc). Water is the most

demanding natural resource needed virtually in all spheres of life because of its usefulness in agriculture, domestic activities, industrial productions, mineral processing and

engineering constructions.

Urbanization and climate change are together exacerbating water scarcity; where water demand exceeds availability for the world's cities (Chunyang *et al.*, 2021). Thus, in many urban cities, groundwater is primary source of freshwater to meet the domestic and agricultural needs of people (Adelana *et al.*, 2008; Ocheri *et al.*, 2014).

Groundwater resources for global drinking water and agricultural activities are derived mainly from precipitation. During such rainfall event, there is increased direct runoff into surface water leading to changes in its hydrochemistry (Zhou *et al.*, 2015). The runoff from rainfall (laden with pollutants from anthropogenic activities) can infiltrate into the groundwater, initiating water-rock interactions that can substantially, modify the quality of groundwater (Li *et al.*, 2018). Hydrochemical characterization of groundwater can reveal pollution and major solute sources since the dissolved solids are consequent of geogenic and anthropogenic processes (Appelo and Postma, 2004, Abdelaziz *et al.*, 2013). Among the geogenic processes are atmospheric inputs and chemical weathering of silicates, carbonates and evaporates while anthropogenic expulsion may include untreated domestic water, urban rainwater, cultivated and returned water from irrigation activity (Li *et al.*, 2014).

The study areas (Ado-Ekiti and Ijero-Ekiti) have different lithologies, but both are of rugged terrains and rainforest vegetation with high runoff. Ado-Ekiti has more influx of humans being the state capital while Ijero-Ekiti has more mining activities as it plays host to some mineral assemblages including feldspar, kaolin, marble, cassiterite, gemstones, columbite and foundry sand (Ale *et al.*, 2014; Akinola *et al.*, 2014; Aliu *et al.*, 2015). Ado-Ekiti has charnockite and granite that can be cut into pave stones or quarried. The illegal mining activities at Ijero-Ekiti have unpalatable consequences on both surface water and groundwater of the area. Wash off from mine tails and mining pits enter directly into surface water and some percolate into the groundwater along with other pollutants from anthropogenic activities. As such, investigations of water quality are important in view of unprecedented increase in recent anthropogenic-induced environmental changes (Çelebi and Özdemir, 2014; Kurwadkar *et al.*, 2020).

Studying the hydrogeochemical characteristics and evolution processes of groundwater in terrains with different lithologies (Ado-Ekiti and Ijero-Ekiti) can elucidate and foster prevention of water-related hazards and ensure sustainable management of groundwater resources. In addition, the two urban centers have different population with Ado-Ekiti having higher population compared to Ijero-Ekiti (Talabi *et al.*, 2022). Ado-Ekiti that is more densely inhabited is expected to have more anthropogenic activities compared to Ijero-Ekiti and there should be reflections of the varied humans' activities on the groundwater chemistry.

Convictional graphical hydrochemical plots employed in

this work includes the Gibbs diagram, Piper Trilinear diagram, Wilcox Plot, Cross Plot and other associated irrigation parameters. The principal objectives of this study are to delineate the hydrochemical facies and assess the effects of the geogenic and anthropogenic activities on the groundwater of the areas. Inadvertently, the effect of urbanization on the groundwater of the two cities is inferred.

## Location of study

The study locations are Ado-Ekiti and Ijero-Ekiti, southwestern Nigeria. Ado-Ekiti is located within latitudes 7°35' and 7°44.3'N, longitudes 5°7' and 5°20'E while Ijero-Ekiti is within latitudes 7°48'59" and 7°49'30"N and longitudes 5°02'50" and 5°5'30"E (Figure 1). Two main seasons (rainy and dry seasons) are observed in the study areas with the rainy season covering a period spanning from April to October while the dry season is from November to April each year. The periods may have slight variations arising from current climate change. The study areas are in the tropics with annual rainfall ranging from 1200 to 1400 mm and a mean monthly temperature of 27°C (Adebayo and Arohunsoro, 2014). Both the two areas are underlain entirely by crystalline Basement Complex rocks of Precambrian–Cambrian age. Specifically, Ado-Ekiti has lithologic assemblage comprising of migmatites as dominant rock while the quartzites, granite and charnockites are in the minority (Talabi *et al.*, 2020), (Figure 1). In view of the crystalline rocks in Ado-Ekiti, groundwater occurrence is erratic. Groundwater occurrence varies considerably within short distances and development of sustainable groundwater supply system is mostly limited to low yielding shallow hand dug wells. The crystalline rocks lack primary porosity and occurrence of groundwater is through secondary porosity developed from joints, fractures and intergranular porosity (Amadi and Olasehinde, 2010; Ojo *et al.*, 2015; Oyedele, 2019). The major rivers draining the area include Awedale, Ologan, Elemi, Omisajan, Ureje and Alamoji (Olajuyigbe, 2010; Bankole, 2010). According to Oguntimehin and Babatola (2007), Rivers Ologan, Awedale and Ureje were heavily polluted and cannot be consumed untreated. By extension, most surface water is often polluted due to pollutants from anthropogenic activities. However, rain harvested water could be considered to be considerably pure since it is directly from the rainfall. Most of the rivers flow into Rivers Ose and Owena at the southern part of Ekiti State (Agbemuko *et al.*, 2021).

Runoff is high during the rainy season; groundwater is recharged by the rainfall and fractures/fissures rocks as well as their overburdens/saprolites are saturated with water. Occasional flooding sometimes occurs during the rainy season. During the dry season, water table is lowered, desiccation and evapotranspiration result into hardened soil and deforestation through bush burning is

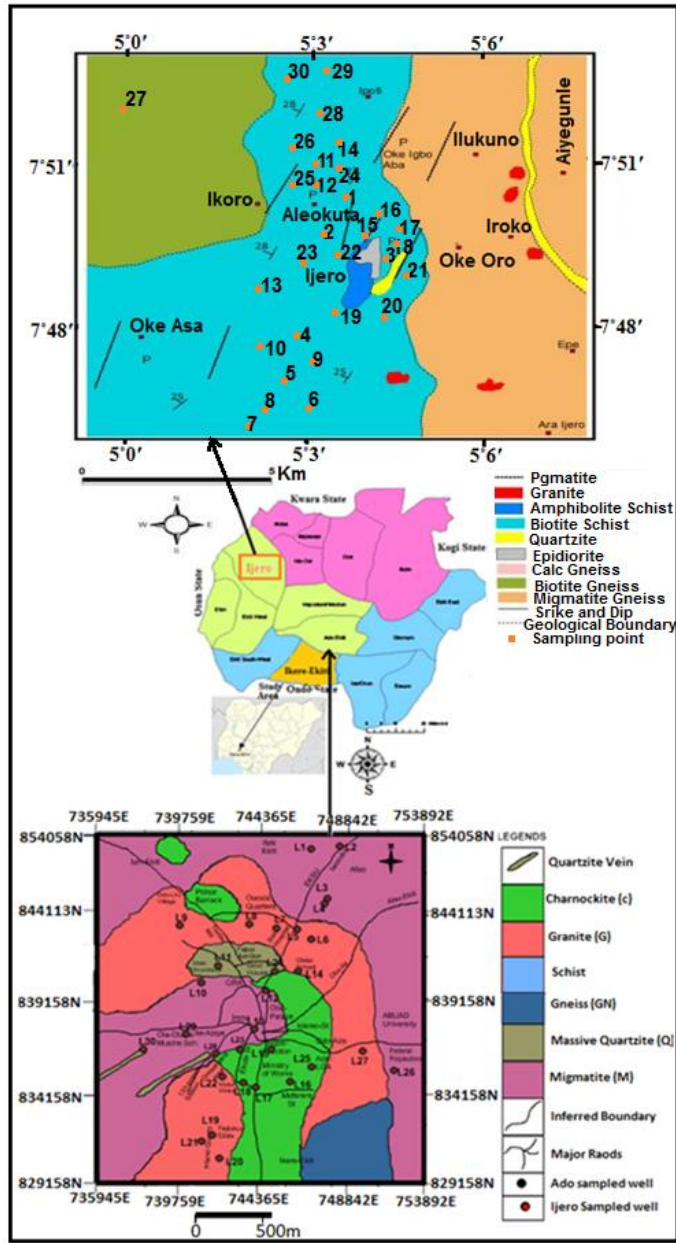


Figure 1. Location map (Modify from Talabi *et al.*, 2022).

rampant during this period (Arohunsoro and Omotoba, 2017).

Ijero-Ekiti, sampling points fall into the schist belt which formed an almost N-S trending metallogenic belt. The entire area of Ijero-Ekiti is not covered only by the schistose rocks (Figure 1) as indicated by by Akinola *et al.* (2014) in which the lithology in the area comprised of the migmatite gneiss, quartzite, biotite gneiss, calc-gneiss, epidiorite, biotite schist, amphibole schist, granite and pegmatite. Research of Ale *et al.* (2014) also revealed that Ijero-Ekiti prgmatite is mineralized with some industrial minerals including feldspar, sheet mica, tantalum-niobium, lithium minerals and gemstones while the intrusive granite

is rich in garnets.

The climatic situation at Ijero-Ekiti is not different from that of Ado-Ekiti but landscape is made up of undulating lowlands separated by hillocks of granite and pegmatite ridges. Some streams drain the area including Awo, Yao, Adaraniwon and Oyi (Ayodele, 2012, Obasi and Madukwe, 2016). Ijero-Ekiti is noted for its mining activities with the mine tails constituting main source of pollutants to surface water and in a lesser degree, groundwater. In view of the fact that surface water is seasonal and more prone to contamination, groundwater is the main source of water for domestic and agricultural activities in the study areas.

**METHODOLOGY**

Data used in this study are from the work of Talabi *et al.* (2022) on “Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria”. Data from the hydrochemical aspect of that research were used for the graphical plots. From the data, Cross Plot, Gibbs diagram, Schoeller Diagram, Piper Trilinear Diagram and Wilcox Diagram were plotted using Excel 2007 version. The listed irrigation parameters were estimated employing:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \text{ (Richards, 1954)} \tag{1}$$

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \text{ (Todd, 1980)} \tag{2}$$

$$RSBC = HCO_3^- - Ca^{2+} + Mg^{2+} \text{ (Gupta, 1983)} \tag{3}$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \text{ (Kelley, 1963)} \tag{4}$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \text{ (Doneen, 1964)} \tag{5}$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \text{ (Ragunath, 1987)} \tag{6}$$

In order to classify the groundwater samples from the study area for irrigation uses sodium percentage (Na %) was estimated for each sample using:

$$Na \% = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \text{ (Wilcox, 1955)} \tag{7}$$

The quantities of all cations are expressed in milliequivalents per litre (epm).

**RESULTS AND DISCUSSION**

Data obtained from the work of Talabi *et al.* (2022) are presented in Tables 1a and 1b while the graphical plots are presented in Figures 2 to 6. Gibbs diagram is an effective tool to identify the major natural geochemical

**Table 1a.** Data on physicochemical characteristics of groundwater in Ado-Ekiti (Talabi et al., 2022).

Location	Ado-Ekiti wells										
	Northing	Easting	EC ( $\mu\text{S}/\text{cm}$ )	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO <sub>3</sub> (mg/L)	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
1	7.71169	5.25127	80	12.83	2.92	5.42	2.32	3.00	10.98	26.67	37.71
2	7.71295	5.26356	529	28.86	9.73	69.50	8.40	5.00	84.14	32.00	285.52
3	7.68794	5.25830	260	25.65	8.76	41.00	4.98	5.40	18.29	117.33	242.42
4	7.68547	5.25702	274	32.06	3.00	19.00	7.06	4.90	21.95	21.33	18.86
5	7.67327	5.24531	380	31.50	17.51	13.00	3.07	1.70	32.93	10.67	193.94
6	7.66852	5.25131	239	31.90	1.95	29.00	2.58	2.00	18.55	32.00	71.38
7	7.67381	5.23639	306	19.24	4.86	49.00	9.01	2.10	43.90	277.33	51.18
8	7.67571	5.22470	237	27.25	2.90	30.50	5.26	1.90	21.26	545.33	141.41
9	7.67515	5.19487	397	36.87	5.84	43.50	32.50	2.30	36.58	106.67	253.20
10	7.64771	5.20415	363	30.46	6.02	8.44	67.50	1.50	29.27	288.00	250.51
11	7.65589	5.21132	287	22.44	1.68	43.00	6.62	1.20	32.90	37.30	202.02
12	7.64394	5.23188	206	20.84	4.96	30.50	2.56	1.10	25.61	64.00	88.89
13	7.62560	5.22689	882	64.13	32.10	102.00	2.98	3.20	131.70	794.67	180.47
14	7.61760	5.22691	1008	67.33	21.40	129.00	51.50	3.00	147.99	426.66	202.02
15	7.61590	5.23406	525	52.91	7.78	53.00	5.44	0.80	76.83	16.00	296.30
16	7.60045	5.24220	195	17.64	1.94	47.00	2.79	1.50	29.26	138.67	102.36
17	7.59777	5.22750	502	41.68	2.98	72.50	8.01	1.20	62.19	250.67	142.76
18	7.60001	5.22217	533	44.89	6.81	69.00	51.50	1.10	51.22	506.00	118.52
19	7.57497	5.20882	267	24.05	2.91	44.00	8.18	2.00	32.96	37.33	153.54
20	7.56385	5.21187	367	20.60	3.89	56.00	70.00	3.50	36.60	112.00	21.55
21	7.57202	5.2042	158	16.03	5.80	7.69	43.00	1.00	10.96	74.67	13.47
22	7.60285	5.21316	120	9.62	3.68	40.00	1.06	1.50	14.63	31.00	36.36
23	7.61575	5.22071	349	24.08	4.94	55.50	0.59	1.60	43.90	234.67	145.45
24	7.61436	5.22084	106	16.80	4.86	6.98	4.12	2.50	7.32	165.33	60.60
25	7.60753	5.25143	194	18.00	3.80	30.50	2.43	2.00	18.20	75.00	107.74
26	7.60582	5.28680	766	70.54	9.92	77.00	20.00	1.00	120.73	32.60	382.49
27	7.61507	5.27342	718	48.10	14.59	128.00	6.11	9.90	25.61	36.67	25.59
28	7.61399	5.21031	295	19.58	1.92	57.50	8.03	2.10	44.90	28.00	193.94
29	7.62320	5.19744	136	11.22	0.97	27.00	8.39	2.00	7.68	34.33	71.30
30	7.61601	5.17918	299	32.66	2.98	31.00	4.45	1.80	29.67	42.67	173.74

processes with reverence to atmospheric precipitation, rock–water interaction, and evaporation controlling the hydrogeochemical characteristics of groundwater in the aquifer. Gibbs plots are the graph of ratio of cations  $[(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})]$  and anions  $[\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)]$  against TDS (Madhav *et al.*, 2018). In Ado-Ekiti groundwater,  $\text{Ca}^{2+}$ (mg/L) ranges from 9.62 – 67.33,  $\text{Mg}^{2+}$ (mg/L) from 1.68 – 32.10,  $\text{Na}^+$ (mg/L) from 5.42 – 129.00,  $\text{K}^+$ (mg/L) from 0.59 – 70.00 and TDS (mg/L) from 60.00 – 725.76. The cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) mg/L at Ijero – Ekiti range from 9.62 – 88.81, 0.97 – 23.35, 7.00 – 74.50 and 16.00 – 185.50 respectively while the TDS (mg/L) is between 75.80 – 756.00. The Gibbs' diagram (Figure 2) indicates that the chemical evolutions of groundwater in both areas are controlled principally by precipitation with weathering playing a minor role. Eighty percent of groundwater from Ado-Ekiti evolved from precipitation while the remaining 20% is from weathering. As for the

Ijero-Ekiti, about 87% of groundwater evolved from precipitation while the remaining 13% is due to weathering. The chemical evolution of groundwater depends on many factors including; availability and solubility of its minerals (Freeze and Cherry, 1979), the geochemical environment (pH and Eh) and ions exchange processes. The low TDS values of the groundwater in the study areas are indicative of groundwater evolution from rainwater. The precipitation dominance constitutes the low salinity water zone in which rainfall is high, the solute from dissolved rocks are low and residence time for rock-water interaction is equally low. Weathering describes the breaking down or dissolving of rocks and minerals on the surface of the earth. During rainfall, the carbon dioxide in the air mixes with precipitation to form carbonic acid that is capable of triggering chemical action between rocks and the infiltrating groundwater. The weathering results into the formation of clay minerals and other soluble byproducts

**Table 1b.** Data on chemical parameters of groundwater in Ado-Ekiti (Talabi *et al.*, 2022).

Location	Ijero-Ekiti Wells										
	Northing	Easting	EC ( $\mu\text{S/cm}$ )	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO <sub>3</sub> (mg/L)	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
1	7° 49' 01"	5° 04' 01"	1008	67.33	11.67	64.50	185.50	5.00	116.62	885.33	356.90
2	7° 49' 01"	5° 04' 08"	457	52.91	18.48	23.00	26.00	3.30	47.38	208.00	338.05
3	7° 48' 52"	5° 04' 16"	790	88.81	2.92	46.50	91.00	3.20	91.11	357.37	323.23
4	7° 48' 37"	5° 04' 06"	312	27.25	8.76	25.50	16.00	2.10	58.31	106.67	250.51
5	7° 48' 22"	5° 03' 56"	440	44.89	1.95	28.00	40.00	7.00	61.95	90.66	389.23
6	7° 48' 07"	5° 03' 51"	135	14.43	2.91	7.00	40.00	2.00	18.22	85.33	153.54
7	7° 47' 55"	5° 03' 36"	226	24.05	2.68	21.00	30.00	3.10	7.29	80.00	278.79
8	7° 48' 05"	5° 03' 41"	162	16.03	6.81	25.00	60.50	4.50	3.64	101.33	160.27
9	7° 48' 23"	5° 03' 55"	232	19.24	6.88	34.00	62.00	3.40	25.51	378.67	153.54
10	7° 48' 41"	5° 03' 49"	308	24.05	0.97	28.50	62.50	2.20	40.09	128.00	390.57
11	7° 48' 54"	5° 03' 49"	392	32.06	3.89	33.00	44.50	2.60	47.38	379.00	281.48
12	7° 49' 04"	5° 03' 57"	790	60.92	1.94	68.00	158.00	2.10	98.40	170.66	280.13
13	7° 49' 16"	5° 03' 55"	701	66.34	5.84	58.50	66.00	2.50	91.10	309.33	405.39
14	7° 49' 15"	5° 03' 59"	532	51.30	9.73	57.50	79.00	3.00	99.50	373.33	331.31
15	7° 49' 06"	5° 04' 23"	402	41.68	3.80	25.50	34.50	2.40	21.87	549.30	266.67
16	7° 49' 11"	5° 04' 34"	315	33.67	10.71	48.00	34.50	2.30	14.58	96.00	257.24
17	7° 49' 03"	5° 04' 40"	367	22.44	8.75	62.00	31.00	2.00	47.30	16.00	188.55
18	7° 48' 51"	5° 04' 26"	261	16.10	9.72	45.00	41.50	1.60	36.44	106.66	276.09
19	7° 48' 47"	5° 04' 21"	419	33.80	2.92	44.50	115.50	2.30	32.80	352.00	298.99
20	7° 48' 37"	5° 04' 31"	124	16.30	2.90	46.50	31.50	1.50	10.93	229.33	191.25
21	7° 48' 52"	5° 04' 31"	292	16.03	4.86	44.00	31.00	2.50	47.30	256.00	164.31
22	7° 48' 59"	5° 04' 09"	894	68.94	17.59	47.00	131.50	3.20	51.02	101.30	351.52
23	7° 48' 56"	5° 03' 60"	1001	72.14	2.92	63.50	146.00	2.90	102.04	506.66	261.28
24	7° 49' 11"	5° 04' 01"	765	64.12	23.35	74.50	54.00	4.80	112.97	448.67	354.21
25	7° 49' 20"	5° 03' 50"	165	14.43	7.78	36.50	25.50	2.40	29.15	149.33	145.45
26	7° 49' 08"	5° 03' 43"	333	33.06	9.73	33.00	25.50	2.80	18.22	16.22	272.05
27	7° 49' 21"	5° 03' 41"	151	9.62	3.87	48.00	23.50	2.00	21.87	37.33	95.62
28	7° 49' 27"	5° 03' 38"	108	17.64	3.98	33.00	21.00	2.20	10.93	21.30	111.78
29	7° 49' 40"	5° 03' 33"	117	16.00	1.94	23.50	21.00	2.50	14.58	10.67	107.74
30	7° 49' 37"	5° 03' 29"	101	16.02	3.85	37.50	30.50	1.70	7.29	58.66	145.54

that modify the chemistry of the groundwater. A place with high rate of precipitation signifies higher runoff and possible high pollution. Thus, the Gibbs' plot reveals that Ijero-Ekiti is more susceptible to pollution compare to the highly populated Ado-Ekiti.

The Schoeller diagrams (Figure 3) indicates Ca(Na)SO<sub>4</sub> as the dominant groundwater type in the two cities. However, NO<sub>3</sub><sup>-</sup> (mg/L) concentrations ranging from 95.62 – 405.39 in the groundwater of Ijero-Ekiti are more than that of Ado-Ekiti with NO<sub>3</sub><sup>-</sup> (mg/L) concentrations range of 13.47 – 382.49. Research by Adeyemi *et al.* (2003) indicates that Nitrate pollution is mostly from surface phenomena and the NO<sub>3</sub><sup>-</sup> concentrations in groundwater can be reasonably used to determine level of its pollution. The Schoeller diagrams clearly show that Ijero-Ekiti with higher NO<sub>3</sub><sup>-</sup> concentrations in its groundwater is more prone to pollution than Ado-Ekiti.

Open dump of refuse and mine tails is common practice

at Ijero-Ekiti. The high precipitation in the area leads to rainstorm that watches the refuse dumps into surface water that can subsequently percolate into the groundwater apart from leachates from the waste dumps. Surface water containing high concentrations of sulfate ions can infiltrate the groundwater contributing to the pollution of groundwater in the study areas. Sulfate in groundwater could be from mineral dissolution, atmospheric deposition and other anthropogenic sources (mining, fertilizer, etc.) (Sharma and Kumar, 2020). If the sulfate-contaminated groundwater is not treated, it remains a major human-health because excessive loading of sulfate in groundwater can cause diarrhea, dehydration, and gastrointestinal disturbances in humans (Miao *et al.*, 2013).

Piper diagrams are one of the most useful ways of representing and comparing water quality (Al-Khatib and Al-Najar, 2011). Reasonable deductions could not be

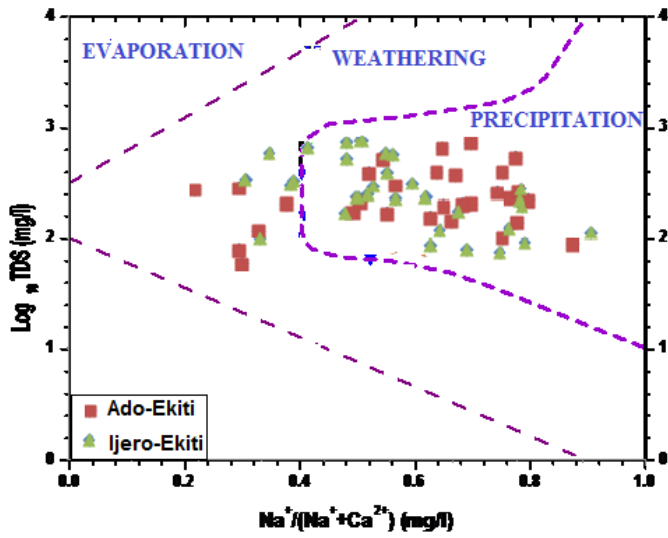


Figure 2. Gibbs' diagram of indicating groundwater evolution in the study areas.

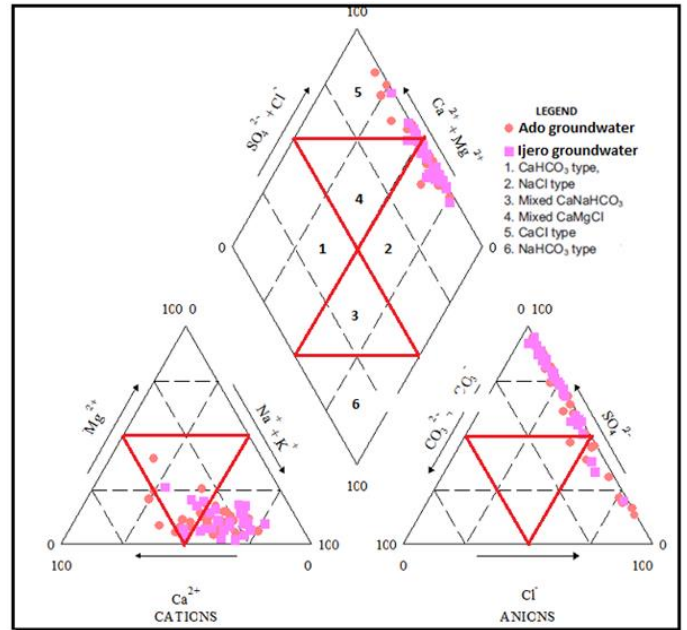


Figure 4. Piper diagram of groundwater in the study area.

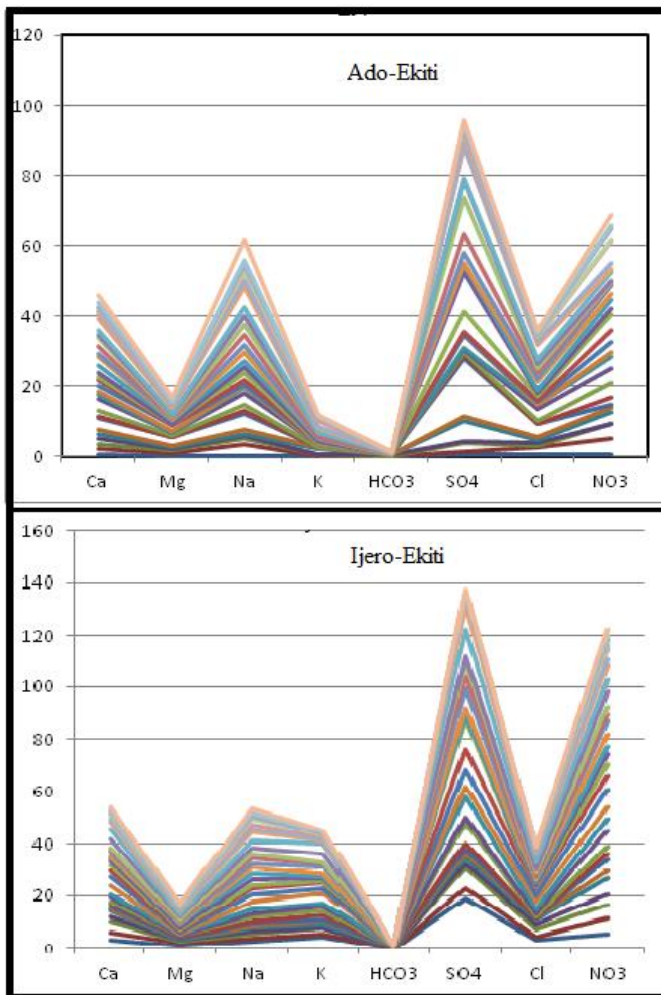


Figure 3. Schoeller diagram of groundwater in the study areas.

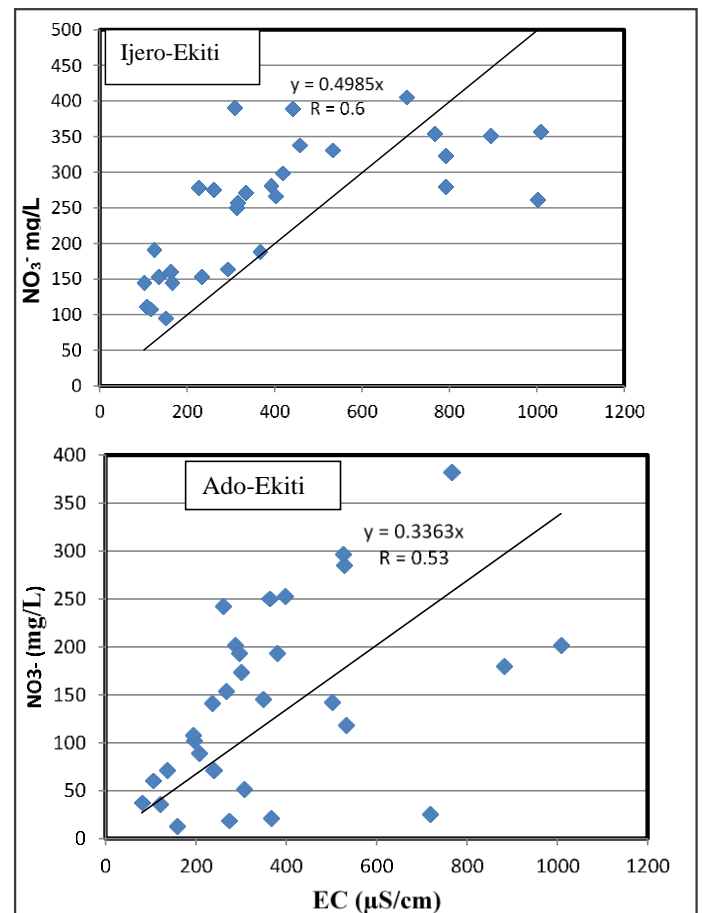
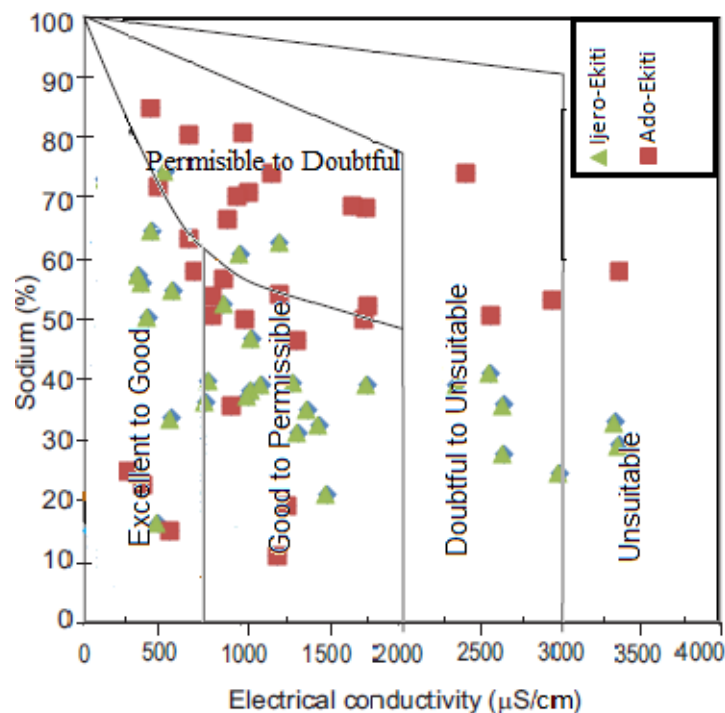


Figure 5. Cross plot of EC ( $\mu\text{S}/\text{cm}$ ) vs.  $\text{NO}_3^-$  ( $\text{mg}/\text{L}$ ).



**Figure 6.** Plot of Na% and EC ( $\mu\text{S}/\text{cm}$ ) (Wilcox, 1955) for classification of Groundwater for irrigation uses.

**Table 2.** Summary of irrigation parameters of groundwater in the study areas.

Indices	Ado - Ekiti				Ijero - Ekiti			
	Min.	Max.	Mean	Std.dev.	Min.	Max.	Mean	Std.dev.
%Na	8.93	68.24	43.99	16.08	13.31	59.87	33.65	11.01
SAR	1.37	16.17	7.52	3.97	1.68	13.07	6.69	2.52
SSP	40.70	84.13	69.75	9.95	24.69	82.73	60.14	13.82
MAR	10.16	92.41	35.59	21.43	5.37	99.61	38.42	25.55
KR	0.61	4.01	1.97	0.94	0.66	4.66	1.86	0.92
TH	32.02	291.67	104.39	63.09	39.88	255.84	117.97	66.19
RSBC	-5.78	-0.76	-2.08	1.25	-5.04	-0.76	-2.31	1.32
PI	21.17	65.07	38.10	11.31	12.75	74.40	49.43	15.44

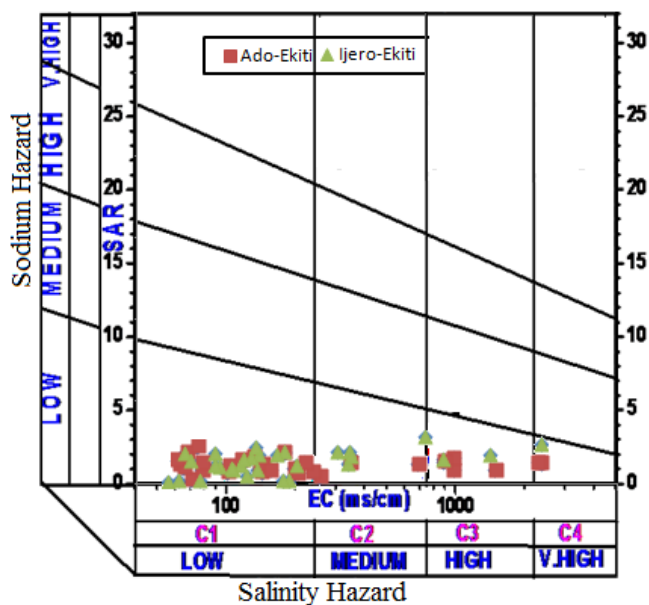
made from the Piper diagrams (Figure 4.) of the two cities though the diagrams reveal that 24 out of the 30 samples representing 80% of groundwater in Ado-Ekiti and Ijero-Ekiti fall into  $\text{NaSO}_4\text{Cl}$  water type. The remaining 20% (6 out of 30 samples) in Ado-Ekiti groundwater, 13.33% (4 out of 30 samples) and 6.67% (2 out of 30 samples) of Ijero-Ekiti groundwater belongs to the  $\text{CaCl}$  water,  $\text{CaCl}$  and mixed  $\text{CaMgCl}$  water type respectively. The Piper diagrams in both cities reveal significant pollution in respect of the groundwater but such characteristics could not be used to decipher effects of urbanization on the groundwater because of difficulty distinguishing between certain water types and data clustering obscuring interpretations.

Considering susceptibility to pollution employing the cross plot of  $\text{NO}_3^-$  ( $\text{mg}/\text{L}$ ) vs.  $\text{EC}$  ( $\mu\text{S}/\text{cm}$ ) (Figure 5), Ado-Ekiti is less prone to pollution compared to Ijero-Ekiti. The assertion is as revealed by the cross plot of  $\text{NO}_3^-$  ( $\text{mg}/\text{L}$ ) vs.  $\text{EC}$  ( $\mu\text{S}/\text{cm}$ ) in which Ado-Ekiti has correlation of 0.53 while at Ijero-Ekiti, it was 0.6. In view of the high population at Ado-Ekiti, the correlation coefficient of  $\text{EC}$  with  $\text{NO}_3^-$  is expected to be higher than that of Ijero-Ekiti. In this study the reverse is the case. This observation supports the submission of the research of Talabi *et al.* (2022) that Ado-Ekiti is less susceptible to pollution compared to Ijero-Ekiti.

Assessment of effects of urbanization on groundwater irrigation quality is presented in Table 2. The sodium percentage (%Na) at Ado-Ekiti ranged between 8.93 and

**Table 3.** Irrigation quality parameter (Salinity Hazard).

Class of hazard	EC ( $\mu\text{S}/\text{cm}$ )	Ado-Ekiti		Ijero-Ekiti	
		No of samples	% of samples	No of samples	% of samples
Low (C1)	<550	26	86.67	23	76.67
Medium (C2)	<500EC<1000	3	10.00	5	16.67
High (C3)	EC>1000	1	3.33	2	6.66
Total		30	100	30	100

**Figure 7.** Salinity diagram for classification of irrigation waters (Based on Richards, 1954).

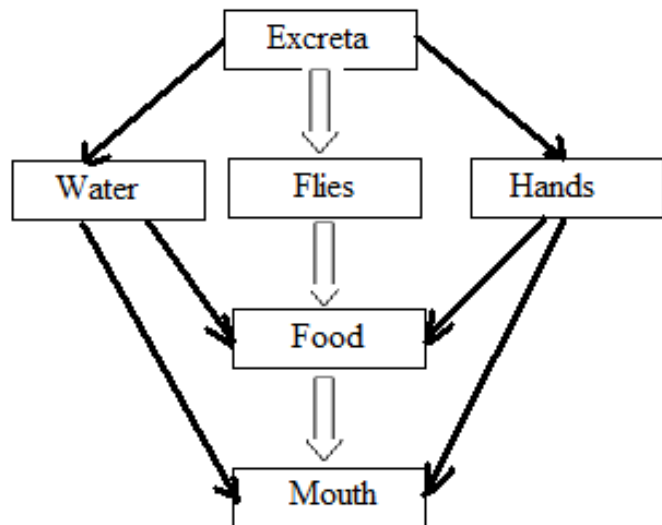
68.24% while at Ijero-Ekiti it ranged between 13.31 and 59.87. The %Na values show that groundwater at Ijero-Ekiti is of better irrigation quality compare to Ado-Ekiti because of its lower sodium percentage. According to Sadashivaiah *et al.* (2008), groundwater for irrigation uses is classified with %Na<20% in the excellent category, 20-40% (good class), 40-60% (permissible group) while 60-80% and > 80% are in the doubtful and unsuitable categories respectively. From the estimated %Na of the two cities, 23% and 73% of groundwater in Ado-Ekiti and Ijero-Ekiti fall into excellent to good irrigation quality category respectively. Majority of groundwater at Ado-Ekiti (76.67%) fall into the permissible to doubtful classes while at Ijero-Ekiti, 26.67% fall into the permissible class and none in the doubtful and unsuitable categories. The result of percentage sodium clearly indicates that groundwater in Ijero-Ekiti is of better quality for irrigation purposes compared with Ado-Ekiti. Justification of this observation is linked to the differences in lithology of the two areas. Ijero-Ekiti falls on the schist belt with pegmatite intrusion apart from the intensive on-going mining activities in the area while in Ado-Ekiti, migmatite, quartzite, granite and

charnockite are the principal rock units. There is intensive sanitation and hygiene education at Ado-Ekiti compared to Ijero-Ekiti and this may be responsible for the observed trend of %Na in the area. The Wilcox plot (Figure 6) (Wilcox, 1955), support the earlier submission that groundwater at Ijero-Ekiti is of better irrigation quality than that of Ado-Ekiti. Twenty samples representing 66.67% of groundwater at Ijero-Ekiti is in the excellent to permissible class of Wilcox plot (Figure 6) compare to Ado-Ekiti in which only 16 samples (53.33%) fall into this category.

Electrical conductivity EC ( $\mu\text{S}/\text{cm}$ ) of groundwater is the most appropriate means of assessing salinity hazard of crops productivity. All crops require water for their growth. Salinity hazard signifies the inability of the plant to compete with ions in the soil solution for water (physiological drought) as available water for plants reduces with increasing EC, even though the soil may appear wet. In this study, at Ado-Ekiti, the EC ( $\mu\text{S}/\text{cm}$ ) ranged from 80 – 1008 while at Ijero-Ekiti it was from 101 – 1008. Based on the Richards (1954), the salinity hazard for groundwater samples in the study areas are classified into three classes; low (C1), medium (C2) and high (C3) as presented in Table 3 and Figure 7. Seven (23.33%) out of 30 groundwater samples from Ijero-Ekiti are in medium to very high classes while only 9 (30%) samples from Ado-Ekiti groundwater samples are in the same categories (Table 3). Normally, irrigation water with an EC < 700  $\mu\text{S}/\text{cm}$  causes little or no threat to most crops while EC > 3000  $\mu\text{S}/\text{cm}$  may limit their growth (Tijani, 1994). Thus, groundwater in the low salinity hazard category can be used as irrigation water on all soils while those in the medium salinity hazard can be used in most cases as irrigation water without any special practices for salinity control. However, water samples that fall in the high salinity hazard class (C3) may have detrimental effects on salt sensitive crops and in certain cases; it may adversely affect many plants except careful irrigation management practices are adopted. Groundwater in both cities is good for irrigation purposes though the groundwater at Ijero-Ekiti is of better irrigation quality.

### Hygiene/sanitation education

Research of Talabi (2018) revealed that most water borne diseases are transmitted through principal element faecal oral disease transmission (Figure 8). In Ado-Ekiti, there is



**Figure 8.** Diagram of the principal elements of faecal-oral disease transmission (Talabi, 2018).

intensive hygiene/sanitation education which is impacting the quality of groundwater in the town positively. As a matter of policy, each house hold must have toilet facility while open defecation is prohibited. In addition, proper waste disposal management practices are embarked upon at Ado-Ekiti so that groundwater pollution can be reduced. The shallow wells' water used in this study can be polluted easily from anthropogenic activities compared to deep aquifers obtainable in boreholes whose water are safer for human consumption (Press and Siever, 1985). There are effective drainage systems at Ado-Ekiti compared to Ijero-Ekiti. Thus, improvement in hygiene/sanitation generally could reduce pollution of groundwater system in any area of the world to the barest minimum.

## Conclusion

This study indicates that groundwater is used in both cities for domestic and irrigation purposes. Most of the graphical plots except the Piper diagram clearly show that groundwater at Ijero-Ekiti is more susceptible to pollution compared to Ado-Ekiti. Groundwater evolution in both cities is controlled by precipitation. Evaluation based on Wilcox and Salinity diagram indicate that groundwater at Ijero-Ekiti is of better irrigation quality than Ado-Ekiti. Other estimated irrigation parameters also support this assertion. Apart from geogenic factors (lithologic complexities of the Basement terrains), anthropogenic activities dictate level of pollution in the two cities as shown in the graphical plots of the chemical data in the areas. This study shows that groundwater that is good for irrigation may be more polluted by anthropogenic contaminants as exemplified by the groundwater in the two cities under consideration. Urbanization has no significant impact on the groundwater quality of the two cities as Ijero-Ekiti with low population

compared to Ado-Ekiti is more susceptible to pollution. Intensive hygiene/sanitation education is significant in controlling groundwater quality.

## CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

## ACKNOWLEDGEMENT

The authors of this manuscript acknowledge with thanks Dr. A. O. Talabi, Dr. L. O. Afolagboye, Mr. C. A. Ajayi and Mrs. O. Kolawole for granting us permission to use their data in the published paper; Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria. *Journal of Geoscience and Environment Protection*, 10, 159-185. <https://doi.org/10.4236/gep.2022.107011>.

## REFERENCES

- Abdelaziz, R., Pearson, A. J., & Merkel, B. J. (2013). Lattice Boltzmann modeling for tracer test analysis in a fractured gneiss aquifer. *Natural Science*, 5(3), 368-374.
- Adebayo, W., & Arohunsoro, J. S. (2014). Environmental Effects of Urbanization of River Ajilosun Drainage Basin in Ado-Ekiti, Ekiti State, Nigeria. *Journal of Natural Science Research*, 4(2), 113-124.
- Adelana, S. M. A., Abiye, T. A., Nkhuwa, D. C. W., Tindinugaya, C., & Oga, M. S. (2008). Urban groundwater management and protection in Sub-Saharan Africa. In: Adelana, S. M. A., & MacDonald, A. M. (eds.). *Applied groundwater studies in Africa*. International Association of Hydrogeologists, selected papers. Pp. 222-259.
- Adeyemi, G. O., Adesile, A. O., & Obayomi, O. B. (2003). Chemical characteristics of some well waters in Ikire, Southwestern Nigeria. *Water Resources (Journal of the Nigerian Association of Hydrogeologists)*, 14, 12-18.
- Agbemuko, O., S., Abam, T. K., Tamunobereton-Ari, I., & Amakiri, A. R. C. (2021). Hydrogeological and geophysical investigation of ground water potentials in basement terrain of Ado Ekiti, Southwestern Nigeria. *IOSR Journal of Applied Geology and Geophysics*, 9(4 Ser. II), 11-25.
- Akinola, O. O., Okunlola, O. A., & Obasi, R. A. (2014). Physico-chemical characteristics and industrial potentials of Lepidolite from Ijero—Aramoko pegmatite field, South Western Nigeria. *International Journal of Scientific & Technology Research*, 3(3), 278-283.
- Ale, P. T., Dada, J. A., & Adewumi, A. J. (2014). Industrial minerals potentials of Ijero pegmatite in Ekiti state, Southwestern Nigeria. *World Applied Sciences Journal*, 29(3), 415-420.
- Aliu, O. O., Ologe, O., & Ogungbemi, S. O. (2015). Hydrogeophysical investigation of Kusa mining hill, Ijero-Ekiti, Nigeria, using geo-electrical and electromagnetic methods. *Al-Hikmah Journal of Pure & Applied Sciences*, 1, 18-26.
- Al-Khatib, M., & Al-Najar, H. (2011). Hydro-geochemical characteristics of groundwater beneath the Gaza Strip. *Journal of Water Resource and Protection*, 3(5), 341-348.

- Amadi, A. N., & Olasehinde, P. I. (2010). Application of remote sensing techniques in hydrogeological mapping of parts of Bosso Area, Minna, North-Central Nigeria. *International Journal of the Physical Sciences*, 5(9), 1465-1474.
- Appelo, C. A. J., & Postma, D. (2004). *Geochemistry, groundwater and pollution*, 2nd edition. Balkema, Rotterdam, The Netherlands. p. 647.
- Arohunsoro, S. J., & Omotoba, N. I. (2017). Causes, Effect and Abatement Measures of Flooding in River Ajilosun Drainage Basin in Ado-Ekiti, Nigeria. *Donnish Journals of Ecology and the Natural Environment*, 4(1), 1-10
- Ayodele, O. S. (2012). Stream sediment geochemical survey of Ijero and Ikoro area, Southwestern Nigeria. *Journal of Applied Sciences Research*, 8(1), 215-223.
- Bankole, B. O. (2010). The geographical distribution of water supply in Ekiti State. *African Research Review*, 4(2), 71-79.
- Çelebi, A., & Özdemir, S. (2014). Mining wastewater management and its effects on groundwater and ecosystems. *Water science and technology*, 70(9), 1481-1487.
- Chunyang, H., Zhifeng, L., Jianguo, W., Xinhao, P., Zihang, F., Jingwei, Li., & Brett, A. B. (2021). Future global urban water scarcity and potential solutions. *Nature Communications*, 12, Article number 4667.
- Doneen, L. D. (1962, June). The influence of crop and soil on percolating water. In *Proc. 1961 Biennial conference on Groundwater recharge* (pp. 156-163).
- Freeze, R. A., & Cherry, J. A. (1979). Ground water contamination. In: *Groundwater*. Prentice-Hall, Englewood Cliffs, NJ USA, 383-456.
- Gupta, S. K., & Gupta, I. C. (1987). *Management of saline soils and waters*. Oxford & IBH Publishing Co. New Delhi, India. p. 399.
- Kelley, W. P. (1963). Use of saline irrigation water. *Soil Science*, 95(6), 385-391.
- Kurwadkar, S., Kanel, S. R., & Nakarmi, A. (2020). Groundwater pollution: Occurrence, detection, and remediation of organic and inorganic pollutants. *Water Environment Research*, 92(10), 1659-1668.
- Li, C., Liu, M., Hu, Y., Shi, T., Zong, M., & Walter, M. T. (2018). Assessing the impact of urbanization on direct runoff using improved composite CN method in a large urban area. *International journal of environmental research and public health*, 15(4), Article number 775.
- Li, S., Lu, X. X., & Bush, R. T. (2014). Chemical weathering and CO<sub>2</sub> consumption in the Lower Mekong River. *Science of the Total Environment*, 472, 162-177.
- Madhav, S., Ahamad, A., Kumar, A., Kushawaha, J., Singh, P., & Mishra, P. K. (2018). Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi), Uttar Pradesh. *Geology, Ecology, and Landscapes*, 2(2), 127-136.
- Miao, Z., Carroll, K. C., & Brusseau, M. L. (2013). Characterization and quantification of groundwater sulfate sources at a mining site in an arid climate: The Monument Valley site in Arizona, USA. *Journal of Hydrology*, 504, 207-215.
- Obasi, R. A., & Madukwe, H. (2016). Geochemistry, Classification Characteristics of Pegmatites from Ijero-Ekiti, Ekiti-State, Southwest Nigeria. *International research journal of Natural sciences*, 4(4), 1-18.
- Ocheri, M. I., Odoma, L. A., & Umar, N. D. (2014). Groundwater quality in Nigerian urban areas: a review. *Global Journal of Science Frontier Research*, 14(3), 35-46.
- Oguntimehin, I. I., & Babatola, J. O. (2007). The pollution status of some selected rivers in Ado-Ekiti, Nigeria. *Pakistan Journal of Scientific and Industrial Research*, 50(1), 22-26.
- Ojo, J. S., Olorunfemi, M. O., Akintorinwa, O. J., Bayode, S., Omosuyi, G. O., & Akinluyi, F. O. (2015). GIS integrated geomorphological, geological and geoelectrical assessment of the groundwater potential of Akure Metropolis, southwest Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 5(14), 85-101.
- Olajuyigbe, A. E. (2010). Sustainable water service delivery: an assessment of a water agency in a rapidly urbanizing city in Nigeria. *Journal of Sustainable Development*, 3(4), 210-219.
- Oyedele, A. A. (2019). Use of remote sensing and GIS techniques for groundwater exploration in the basement complex terrain of Ado-Ekiti, SW Nigeria. *Applied Water Science*, 9(3), 1-13.
- Press, F., & Siever, R., 1985. *Earth*. New York: Freeman and Co.
- Raghunath, I. I. M. (1987). *Groundwater*. Second edition; Wiley Eastern Ltd, New Delhi, India.
- Richards, L. A., (1954). *Diagnosis and improvement of saline and alkali soils*. Agricultural Handbook 60, USDA and IBH Publishing Co. Ltd. New Delhi, India. Pp. 98-99.
- Sadashivaiah, C. R. R. C., Ramakrishnaiah, C. R., & Ranganna, G. (2008). Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India. *International journal of Environmental Research and Public Health*, 5(3), 158-164.
- Sharma, M. K., & Kumar, M. (2020). Sulphate contamination in groundwater and its remediation: an overview. *Environmental Monitoring and Assessment*, 192, Article number 74.
- Talabi, A. O. (2018). Estimated volume of water in shallow wells of Ekiti State, Southwestern Nigeria: implications on groundwater sustainability. *Arabian Journal of Geosciences*, 11(21), Article number 681.
- Talabi, A. O., Abdu-Raheem, Y. A., Afolagboye, L. O., Oguntuase, M. A., & Akinola, O. O. (2020). Hydrogeochemistry of shallow groundwater in Ado-Ekiti Area, Southwestern Nigeria. *Groundwater for sustainable development*, 11, 100386.
- Talabi, A. O., Afolagboye, L. O., Ajayi, C. A., & Kolawole, O. (2022). Sanitary Surveys and Hydrochemistry of Groundwater in Two Urban Towns (Ado-Ekiti and Ijero-Ekiti), Southwestern Nigeria. *Journal of Geoscience and Environment Protection*, 10(7), 159-185.
- Tijani, M. N. (1994). Hydrogeochemical assessment of groundwater in Moro area, Kwara State, Nigeria. *Environmental geology*, 24, 194-202.
- Todd, K. D. (1980). *Ground water hydrology*. 2nd ed. New York: John Wiley and Sons.
- Wilcox, L. V. (1955). *Classification and use of irrigation waters* (No. 969). US Department of Agriculture. 19p.
- Zhou, Z. Z., Huang, T. L., Ma, W. X., Li, Y., & Zeng, K. (2015). Impacts of water quality variation and rainfall runoff on Jinpen Reservoir, in Northwest China. *Water Science and Engineering*, 8(4), 301-308.