Evaluation of Groundwater Quality in Parts of Ondo State, Southwestern, Nigeria

Ali Bakari[1*], Muktar BabaGana[2]

[1]Department of Geology, Faculty of Earth and Environmental Science, Bayero University Kano, Nigeria

[2]Department of Applied Chemistry, College of Science and Technology, Kaduna Polytechnic, Kaduna, Nigeria.

[*]Corresponding Author

ABSTRACT

Groundwater is an essential resource for drinking, and its quality is critical to human health. This study examines the physical and chemical quality of drinking water in eight Local Government Areas (LGAs) in Ondo State. The water quality analysis methodology outlined in the APHA and USGS water standard guidelines was incorporated into the methodology used in this study. On-site parameters such as pH, EC, TDS, and temperature, as well as the primary physical and chemical properties of groundwater samples, were investigated. According to the water analysis results, the study's findings indicate that the water samples' temperatures ranged from 27 to 29 degrees Celsius. The pH ranges from 6 to 7. The turbidity falls between 1.2 and 1.6 NTU. The range of electrical conductivity (EC) is between 80 and 90 µS/cm. Each water sample in the study area has a TSS of 0.01. Idanre had the lowest TDS (40 mg/L), while Okitipupa had the highest (45 mg/L). Idanre has the lowest water hardness, at around 45 mg/L, while Akure and Okitipupa have the highest, at 50 mg/L. Idanre reported 17 mg/L of chloride, while Ikare and Okitipupa reported 20 mg/L. Except for Idanre, all groundwater samples examined had a nitrate concentration of 9 mg/L. Phosphate concentrations were less than 0.01 mg/L in all the samples. Sulphate concentrations were evaluated. Iron concentration ranges from 0.07 mg/L to 0.10 mg/L. The evaluated groundwater falls within the acceptable limit of the World Health Organization's (WHO) Groundwater Quality Index.

Keywords: Groundwater, Quality, Ondo State, Nigeria

INTRODUCTION

The survival of humans, animals, and industries depends on the availability of water resources. This is one of the main objectives of SDG 6 in the UN Agenda 2030. Safe drinking water and sanitation are human rights. Without access to these services, a life of dignity, stability, and good health is virtually impossible (WWR, 2024).

Ondo State lies in southwestern Nigeria. It has a variety of terrain types suitable for agricultural and infrastructural development. The topography features gently undulating plains, occasional hills, and valleys. Elevation ranges from 250 to 600 meters above sea level. This allows for natural drainage and reduces flood risk in well-chosen areas.

The Geology of the State comprises both basement crystalline rocks (inland) and sedimentary/ coastal plain deposits (especially along the coast (Ojo et al., 2024). In the sedimentary/coastal part, the major aquifer units include the Benin Formation, Araromi Formation, and Recent Alluvium in shallow zones. Four aquifer horizons have been identified in the coastal area (Hamil et al., 1986).

Also, in the basement/crystalline rock terrains (inland), groundwater occurs mainly in the weathered/ fractured zones above the bedrock rather than in "classic" sedimentary aquifers. For instance, a study near Akure (in the basement complex) showed depth to bedrock ranges from ~1.8 to 32 m (Obaje et al., 2022).

Studies such as Olatayo (2013; Falawo et al., 2017; Olatunji et al., 2020), Ojo et al. (2024) have conducted different physical, chemical, and biological studies across many areas of Ondo State. Most of them concurred that bitumen-rich communities in Ondo State, such as Agbabu, Ilubinrin, Lodasa, and Boridele, have poor quality water due to bitumen contamination. The major river flowing across these areas has tributaries extending to other villages, rendering them experiencing bitumen pollution in the available water sources (Falawo et al., 2019).

Despite this, water quality issues are a primary source of concern. Groundwater is the primary source of water in many parts of Ondo State. Studies have found contamination/quality issues in urban versus rural dug wells. One study, for instance, found that ~30.8% of measured parameters exceeded WHO limits in selected wells in Ondo State. In urban sites, around 40% of samples were rated as having "poor" water quality (Reference). A heavy metal study: in Ijare (rural) vs Alagbaka (urban) areas, chromium and lead levels in groundwater exceeded WHO limits in some cases (Ojo et al., 2024). In coastal aquifers of Arogbo: shallow water table (~0.37-1.20m) and bacterial, iron/manganese contamination; brackish water intrusion. In bitumen-bearing communities (Agbabu, etc.), groundwater pollution from bitumen/hydrocarbons is noted (Data Bank, 2019).

This study evaluates 10 groundwater quality samples obtained across the various locations (Ondo Town, Akure, Idanre, Owo, Akungba, Ikhare, Igbara-Oke, Okitipupa, and Ifon) in Ondo State. This is aimed at evaluating the Physical and Chemical parameters in determining their quality status. This can be a useful baseline result for the respective areas.

Study Area Location

The study Area, Ondo State of Nigeria, was one of the seven states created on the 3rd February 1976, by the Federal Military Government of Nigeria. (Fig. 1) It was carved out of the old Western State. The state covers a total area of the former Ondo province, created in 1915 with Akure as the provincial headquarters. It lies between latitude 5° 45' and 7°52' N and longitude 4° 20' and 6° 5' E. Its land area is about 15,500 Square kilometers (Umar and Bolanle, 2015). Ondo State shares common boundaries with Edo and Delta States on its Eastern part, on the West, the state shares a boundary with Ogun and Osun States respectively, on the North, it shares a boundary with Ekiti and Kogi States, and to the South by the Bight of Benin and the Atlantic Ocean (Figures 1 and 2).
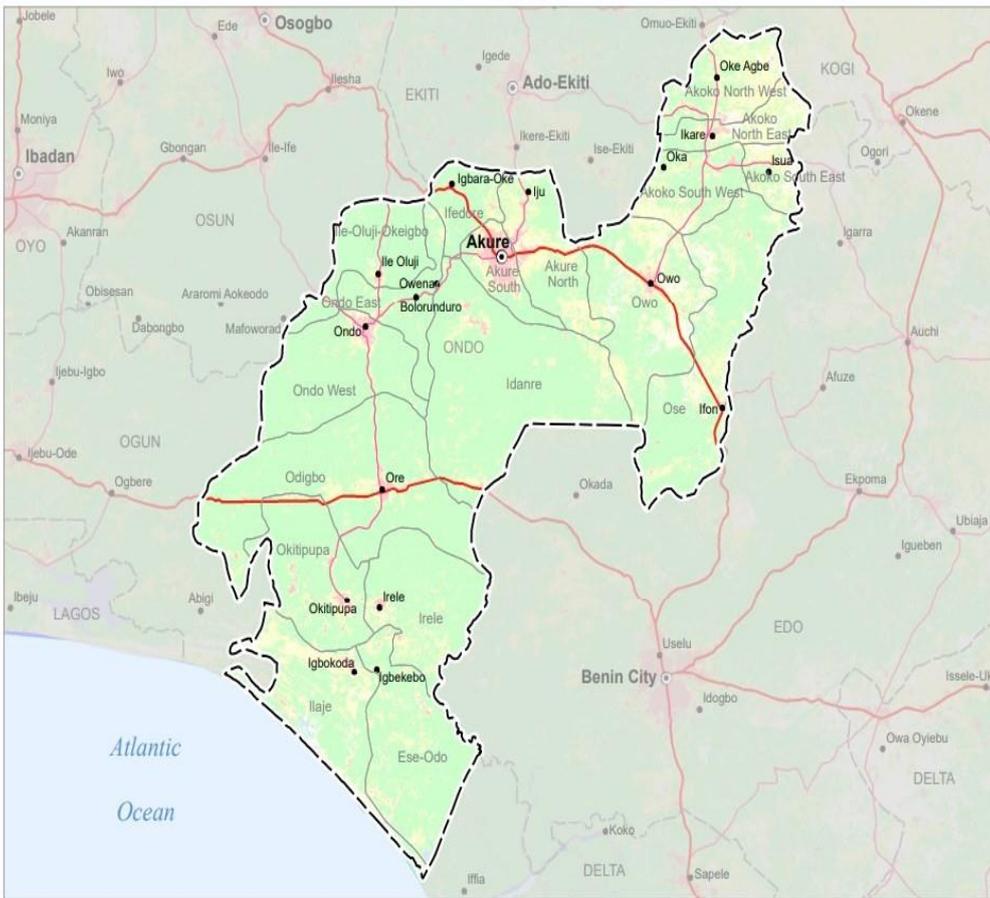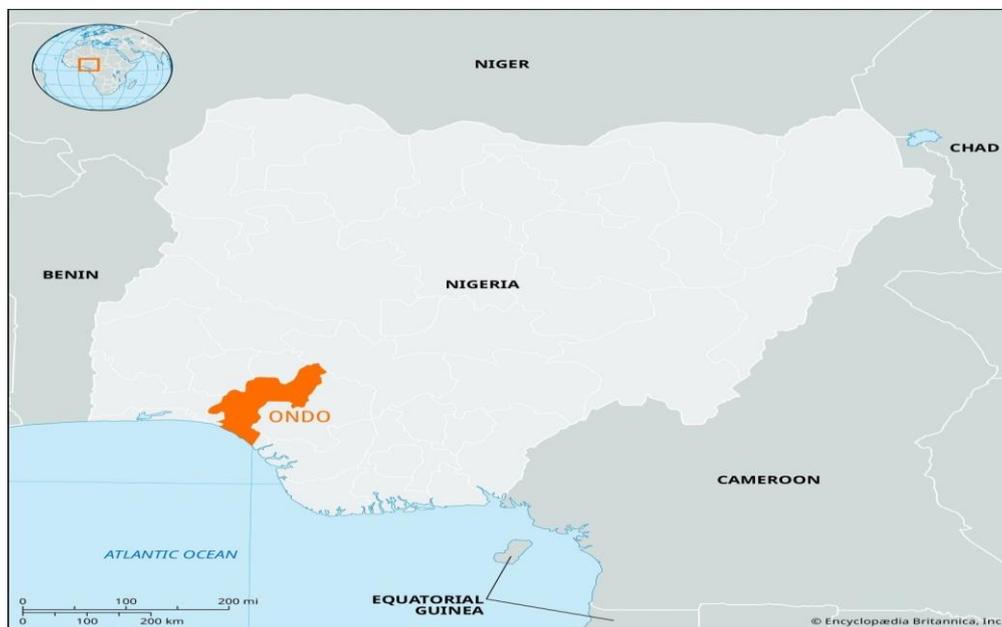
Figure 1 (Source: Adapted from OCHA, 2018)

Figure 2 Map of Nigeria showing Ondo State (Source: Britannica, 2024)

Until recently, cocoa used to be the major source of wealth for the state, but this has been replaced by petroleum, which is prospected in Ilaje and Ese Odo local government areas. The population of more than 55% in the rural areas of Ondo State lived below the poverty level. This condition of poverty was aggravated due to the poor attention given to the health sector in the state. However, Ondo State is an oil-producing state, but agriculture remains the mainstay of its economy; together, oil and agriculture generate 90% of the State's Gross Domestic Product. Ondo State is responsible for 40% of cocoa export from Nigeria (Lamidi, 2024; Olaniyan, 2025),

Geology and Hydrogeology of Ondo State

The Geology of southwestern Nigeria, including Ondo State, the Nigerian basement complex. The main lithologies include the amphibolites, migmatite gneisses, granites, and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist, talk-tremolite schist, and muscovite schist. The crystalline rocks intrude into these schistose rocks. For this paper, the discussion is limited to southwestern Nigeria.

Ondo State's geology (Figure 3) is characterized by its position in the Precambrian Basement Complex, featuring a rugged and undulating topography with highlands of charnockites, migmatite gneiss, and other gneissic rocks. The state is also rich in mineral resources, notably its large bitumen deposits, and also has deposits of kaolin, limestone, clay, granite, and silica sand (Akinluyi et al., 2018). The Geological Formations found in Ondo State and their characteristics are summarized in Table 1.

Figure 3: Geological Map of Ondo State (Geological Survey of Nigeria, 1989)

With the exclusion of areas with Recent alluvium where the water table is at shallow depths, the study area generally has its water table occurring at depths beyond 30-35 metres (Asiwaju-Bello et al., 2023). The major aquifer units with considerable transmissivity values in the region are those derived from the Ise, Araromi, and Benin formations (Table 1). The annual rainfall intensity in Ondo State ranges from 1151mm in the northern part of the State to more than 2500mm in the southern part (Oladitan and Emiola, 2024). Generally, Ondo State has a low evaporation rate and a very high relative humidity, which makes sufficient rainwater available for infiltration to recharge the underlying aquifers (Oladitan and Emiola, 2024).

Table 1: Geological Formations found in Ondo State and their characteristics.

S/No	Name of Formation	Characteristics
1	Ise	Grits and Sandstones
2	Afowo	Coarse to medium-grained sands
3	Araromi	Medium-grained sand
4	Ewekoro	Sand with limestone intercalation
5	Akinbo	Greyish shale
6	Oshosun	Shale
7	Ilaro	Shaley clay
8	Benin	Continental terminal sand
9	Recent Alluvium	Poorly consolidated sand

MATERIALS AND METHODS

Standard Methodology of Water Quality Analysis, outlined in Mohammed (2017), Cahalan et al. (2025), APHA (2004), and Stone et al. (2024) Standard Guideline, was integrated into this methodology. The selection of the onsite parameters, such as pH, EC, TDS, and Temperature, was based on the outlined procedure of USGS (2010). They are measured in the field due to their relatively unstable nature (USGS, 2010). The pH and temperature of the water sample were measured with a digital HANNA pH-meter (Model HI 98129). EC and TDS were measured with a portable conductivity, TDS, and salinity meter (Model EC400 Ex Stik II). Groundwater samples were collected from 8 different Local councils for assessment.

A total of eight groundwater samples (triplicates) were obtained and analyzed from Ore, Ondo Town, Akure, Idanre, Ikare, Igbara-oke, Okitipupa, and Ifon Local Government Areas (L.G.A.s). These groundwater samples (Table 1) were carefully collected in 300 ml plastic bottles for analyses of their major physical and chemical parameters. The reason for selecting some metals and major cations and anions is that they are potential natural and anthropogenic contamination indicator parameters close to residential areas. Detailed justifications on these elements are documented in the APHA (2002) manual of water quality analyses. Also, various experimental and instrumental techniques were employed to analyze the different chemical parameters. Complete descriptions of the methods employed are documented in the American Public Health Association (APHA) Standard Methods for the Examination of Water and Waste Water, 20th Edition (APHA, 1998; 2002) and the USGS (2024) protocol for groundwater quality analysis. The physico-chemical analyses were carried out at the Geochemistry laboratory, the Department of Geology, University of Ibadan, Nigeria.

Table 2: Summary of Physical-Chemical Parameters analyzed in the Groundwater in Ondo State

S/N	Parameter	Unit	Ore	Ondo	Akure	Idanre	Ikare	Igbara-Oke	Okitipupa	Ifon	WHO Guideline
1	Odour	-	UOB	UOB	UOB	UOB	UOB	UOB	UOB	UOB	NS
2	Temp.	°C	29±04	29±1	27.±02	28±08	29±03	29±11	29±04	29±02	NS
3	Colour	Hazen Unit	1.3±03	1.5±09	1.4±06	1.2±01	1.4±02	1.3±05	1.4±04	1.2±04	15.00
4	Turbidit y	NTU	1.4±01	1.5±03	1.6±04	1.2±09	1.4±03	1.5±05	1.6±04	1.3±02	5.00
5	pH	-	6±09	7±01	6±08	6±07	7±10	6±09	7±10	6±03	6.5–8.5
6	EC	µS/cm	85±04	87±02	89±09	80±02	86±02	87±04	90±02	84±06	NS
7	TDS	mg/L	42±07	44±02	43±04	40±0	43±03	43±08	45±02	41±09	500
8	TSS	mg/L	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	NS
9	Hardness	mg/L	46±03	48±1	50±08	45±04	49±09	47±06	50±05	46±07	80–100
10	Chloride	mg/L	18±2	19±02	20±06	17±03	20±05	19±08	20±04	18±03	250

11	Nitrate (NO_3^-)	mg/L	9±0.2	9±0.1	9±0.7	8±0.4	9±0.4	9±0.9	9±0.6	9±0.2	50
12	Sulphate (SO_4^{2-})	mg/L	33±09	35±1	37±09	30±08	34±07	35±1	37±02	33±08	250
12	Phosphat e (PO_4^{3-})	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NS
13	Iron (Fe)	mg/L	0.8±02	0.9±04	0.10±07	0.07±02	0.1±1	0.09±04	0.10±04	0.08±02	0.30
14	Lead (Pb)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
15	E. coli	MPN/100 ml	NG	NG	NG	NG	NG	NG	NG	NG	Nil
16	Total coliforms	CFU/100 mL	0±00	0.1±02	0±00	0.01±00	0.1±00	0±00	0±0.1	0±00	Nil
17	Fecal coliforms	MPN/100 mL	0±00	0±00.1	0±00	00±02	0±01	0±00	0±0.01	0±00	0±00

RESULT

The water analysis results show that the water samples ranged from 27 to 29 degrees Celsius. The pH is in the range of 6-7. The Turbidity is in the range of 1.2 to 1.6 NTU. The Electrical Conductivity (EC) is between 8090 µS/cm. The TSS of 0.01 applies to all water samples of the study area (Table 1). Likewise, the highest TDS of 45 mg/L was recorded in Okitipupa, while the lowest TDS of 40 mg/L was reported at Idanre (Table 2). The hardness of the water is lowest in Idanre, with about 45 mg/L, and hardest (50mg/L) in Akure and Okitipupa, respectively. The concentration of Chloride of 17 mg/L was recorded in Idanre, while 20 mg/L was reported at Ikare and Okitipupa, respectively. Except for Idanre, where a Nitrate concentration of 8 mg/L was recorded, all other locations have a concentration of 9 mg/L individually. Phosphate concentration is less than 0.01 mg/L in all the water samples analyzed (Table 1). The concentration of sulphate ranged between 33 and 37 mg/L, respectively (Table 2). An iron concentration of 0.07 mg/L was reported in Idanre, while the concentration of 0.10 mg/L was reported in Ikare and Ifon, respectively. The concentration of lead was less than 0.01mg/L in all the samples. Also, the concentration of E. coli was not detected in all the water samples. Other biological parameters, such as total coliforms and faecal coliforms, are all below the WHO standard for sanitary water conditions in the groundwater tested in Ondo State.

DISCUSSIONS

Groundwater temperature is a fundamental Variable that influences nearly all physical, chemical, and biological processes, with significant implications for water quality, ecosystem health, and human use. Since the first edition of the GDWQ, WHO has published information on health criteria and other supporting information to the GDWQ, describing the approaches used in deriving guideline values and presenting critical reviews and evaluations of the effects on human health of the substances or contaminants examined in drinking water (WHO, 2003).

Groundwater temperatures are generally more stable than surface water temperatures due to the insulating effects of soil and rock. Shallow groundwater temperature typically approximates the local mean annual air temperature, plus a few degrees, with seasonal variations decreasing with depth. At greater depths (e.g., below 12-15 meters) (WHO, 2023). Likewise, Water temperature is critical because it is an important quality in

environmental parameters. It is important to measure water temperature as it affects the characteristics of the water (such as the chemical, biological, and physical properties) of the water, as well as the possible health effects. Water temperature is an important factor in determining whether a body of water is acceptable for human consumption and use (WHO, 2011).

Chloride is a naturally occurring anionic (negatively charged) component found in most natural waters. It does not easily react with other substances, so it remains dissolved and moves freely with groundwater flow. Chloride can enter groundwater through both natural and anthropogenic (human-made) sources. Chlorides are leached from various rocks into soil and water by weathering. The chloride ion is highly mobile and is transported to closed basins or oceans (Cooper et al, 2014; Guo, 2021).

Nitrate concentration in groundwater refers to the amount of nitrate ions (NO_3^-). Nitrate is one of the most important indicators of groundwater pollution, especially from agricultural and domestic sources. Nitrate levels below 10 mg/L are generally safe and natural. While those in the range of 10–50 mg/L are due to anthropogenic influence, and lastly, water with chloride >50 mg/L is unsafe for drinking; indicates pollution from fertilizers, sewage, or wastewater (USEPA, 2021; UN, 2014; Huang et al., 2025).

Sulphate is a naturally occurring constituent of water, but elevated levels can indicate geological sources or human-induced pollution. The three sulphate concentration increases confirmed previous studies (Pantazidou et al., 2012; Schiffmacher et al., 2016). High levels of sulphate in groundwater can cause a bitter taste, lead to a laxative effect, and increase pipe corrosion (Sharma and Kumar, 2020; Al-Ruwaih et al., 2025). While generally not a major health hazard, it is regulated as a "secondary" contaminant due to its aesthetic effects on drinking water. High concentrations can also be linked to gastrointestinal issues and can impact the health of aquatic ecosystems.

Given the above, the effect of sulphate (SO_4^{2-}) in groundwater depends on its concentration. While small amounts are naturally present and generally harmless, high sulphate levels can cause several environmental, health, and technical problems (Al-Ruwaih et al., 2025).

Phosphate is an essential nutrient for plants and animals, but its presence in groundwater is usually low under natural conditions. Elevated levels often indicate pollution from human activities (Cooper et al., 2014). Phosphate (PO_4^{3-}) in groundwater mainly originates from agricultural fertilizers, detergents, sewage, and industrial wastes. While phosphate is an essential nutrient for plants and animals, excessive concentrations in groundwater can lead to several environmental and health effects (Feng et. al., 2025). An excess amount of Phosphate can lead to Eutrophication, Water Quality Deterioration, and Aesthetic and Operational Problems (Wei et. al., 2024; Feng et al., 2025).

Iron is one of the most common elements in the Earth's crust, and its presence in groundwater is mainly due to geochemical and redox processes. While it is not usually harmful to health, excessive iron affects aesthetic quality (colour, taste, staining) and can indicate anoxic (oxygen-depleted) conditions underground.

Likewise, iron (Fe) is one of the most common elements found in the Earth's crust, and it easily dissolves into groundwater, especially under reducing (low-oxygen) conditions. While small amounts are natural and often harmless, elevated iron concentrations can cause several aesthetic, operational, and health-related problems (Urme et al., 2025).

CONCLUSION

In conclusion, groundwater is a vital component of the hydrogeological system in Ondo State and the entire Southwestern Nigeria as a whole. It is a precious natural resource in the country and the continent at large. where it serves more than 80% of the populace. Naturally occurring and anthropogenic contaminants, high population, and urban growth increasingly exert a very high pressure on the quality of groundwater in Ondo State. The costs of poor water quality can undesirably affect human health, fauna and flora, and the environment at large (WHO, 2006; 2011). Hence, the need for protection of groundwater in both rural and urban settings in the State is the only sustainable model that seeks to ensure the safety of the citizenry and the attainment of Sustainable Development Goal 6 in Ondo State. Lastly, the sustainability of groundwater

management entails that water quality is not degraded and its physical, chemical and biological parameters are not affected.

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Conflict of Interests

Both authors declare that there are no potential conflicts of interest with respect to this study, and/or publication thereof.

REFERENCES

1. Akindele O. Oyinloye. Geology and Geotectonic Setting of the Basement Complex Rocks in South Western Nigeria: Implications on Provenance and Evolution. Earth and Environmental Science.
2. Akinluyi, F.O., Olorunfemi, M.O. & Bayowa, O.G. Investigation of the influence of lineaments, lineament intersections and geology on groundwater yield in the basement complex terrain of Ondo State, Southwestern Nigeria. Appl Water Sci **8**, 49 (2018).
3. Al-Ruwaih, F., Aliewi, A., Sabarathinam, C., Bhandary, H., Rashid, T., Abdulhadi, A., ... & Hadi, K. (2025). Sources and evolution of sulfate in groundwater systems of northern Kuwait. Environmental Monitoring and Assessment, 197(8), 881.
4. APHA (2013). Standards Methods for the Examination of water and wastewater (20th Ed.) Washington, DC: Am. Public Health Assoc.
5. Cooper, C. A., Mayer, P. M., & Faulkner, B. R. (2014). Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream. Biogeochemistry, 121(1), 149-166.
6. Falowo, O. O., Akindureni, Y., & Ojo, O. (2017). Irrigation and drinking water quality index determination for groundwater quality evaluation in Akoko Northwest and Northeast Areas of Ondo State, Southwestern Nigeria. American Journal of Water Science and Engineering, 3(5), 50-60.
7. Falowo, O., Oluwasegunfunmi, V., Akindureni, Y., Olabisi, W., & Aliu, A. (2019). Groundwater physicochemical characteristics and water quality index determination from selected water wells in Akure, Ondo State, Nigeria. American Journal of Water Resources, 7(2), 76-88.
8. Feng, Y., Ptacek, C. J., Blowes, D. W., Gan, Y., Xie, X., Finfrock, Y. Z., & Liu, P. (2025). Interactions between phosphate and arsenic in iron/biochar-treated groundwater: Corrosion control insights from column experiments. Water Research, 273, 123072.
9. Guo, H., Li, M., Wang, L., Wang, Y., Zang, X., Zhao, X., ... & Zhu, J. (2021). Evaluation of groundwater suitability for irrigation and drinking purposes in an agricultural region of the North China Plain. Water, 13(23), 3426.
10. Hamill, L. & Bell F. U. (1986). Groundwater Resources Development. British Library Cataloging in Publication Data: London. pp. 151-158.
11. Lamidi, H. S. (2024). Cocoa Production in the Era of Crude Oil Economy: The Case Study of Ondo State, Nigeria. Western Michigan University.
12. Mohammed, A. B. (2017) Methodologies for Sustainable Groundwater Management in Nigeria. An Unpublished PhD thesis. University of Dundee, UK.
13. Obaje, N. G., Bomai, A., Zanna, M., Adeoye, J., Yusuf, I., Adamu, S., ... & Naibi, H. S. (2022, June). New Insights on Potential Petroleum Systems in the Middle Benue trough of Nigeria. In 83rd EAGE Annual Conference & Exhibition (Vol. 2022, No. 1, pp. 1-5). European Association of Geoscientists & Engineers.
14. OCHA (2018). Map of Ondo State: Nigeria: Reference Map of Ondo state. nga_atlas_admin1 [Accessed online via https://www.unocha.org on 28/10/2025].
15. Ojo, J. T., Ojo, O. M., Olabanji, T. O., & Aluko, R. T. (2024). Impact of urbanization on groundwater quality in selected rural and urban areas of Ondo State, Nigeria, using the Water Quality Index. Discover Water, 4(1), 19.1

16. Olaniyan, O. A. (2025). Effect of Agricultural Cooperatives on Cocoa Marketing among Farmers in AkureNorth Local Government Area, Ondo State, Nigeria. International Journal of Economic, Finance and Business Statistics, 3(3), 169-180.

17. Oladitan, T. O., & Emiola, A. (2024). Impact of rainfall and temperature trend on the yield of maize production in Ondo State. In Proceedings of the 14th Nigeria Association of Hydrological Sciences Conference (Okitipupa 2024), Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria (pp. 519-524).

18. Olatayo, A. A. (2014). Assessment of physico-chemical parameters of waters in Ilaje local government area of Ondo State, Nigeria. International Journal of Fisheries and Aquatic Studies, 1(5), 84-92.

19. Olatunji, O., Omogbehin, S., Agunbiade, O., & Umar, I. S. (2020). Assessment of Seasonal Variation in Physicochemical and Heavy Metals Concentration in Surface and Ground Water in Ondo, Ondo State, Nigeria. COAST JOURNAL OF THE SCHOOL OF SCIENCE OAUSTECH OKITIPUPA, 2(2).

20. Oyedotun, T.D. and Obatoyinbo, O., 2012. Hydro-geochemical evaluation of groundwater quality in Akoko North West local government area of Ondo State, Nigeria. Revista Ambiente & Água, 7, pp.67-80.

21. United Nations, (2015). The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO.

22. United States Environment Protection Agency, (2001). Risk Assessment Guidelines for Superfund (RAGS), vol. 1, part D, US Government Printing office, Washington, DC.

23. United States Geological Survey (USGS) (2025). Protocols for Groundwater evaluation and characteristics drive variability in per-and polyfluoroalkyl substances (PFAS) loading across a stream-wetland system. USGS, Washington, 964, 178533.

24. Urme, O., Reza, A. S., Adham, M. I., & Sattar, G. S. (2025). Arsenic, manganese, and iron concentration in groundwater of northwestern part of Bangladesh using self-organizing maps: Implication for health risk assessment. Heliyon, 11(2).

25. Wei, X., Shi, X., Yang, M., Tan, Q., Xu, Z., Ma, B., ... & Wu, W. (2024). Phosphate and illite colloid pose a synergistic risk of enhanced uranium transport in groundwater: A challenge for phosphate immobilization remediation of uranium contaminated environmental water. Water Research, 255, 121514.

26. World Health Organization (2006). Guidelines for Drinking-water Quality, 3rd edition, incorporating first addendum. World Health Organization.

27. World Health Organization (2011). Guidelines for drinking-water quality. WHO chronicle, 38(4), 104-8.

28. World Health Organization, & United Nations Children's Fund. (2025). Water, sanitation, hygiene, environmental cleaning and waste management in health care facilities: 2023 data update and special focus on primary health care. World Health Organization.