Determination of underground water potential and water supply in some rural villages in Nigeria

Geoscientists without Borders Application

Final Report Follow-up Form

(See GWB Final Report Full Form for complete instructions by logging into your account in Foundant: https://www.grantinterface.com/Home/Logon?urlkey=SEG)

Principal Investigator	
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Basic Project Information	
Lead Organization (Include website links, if applicable.)	Ahmadu Bello University, Zaria, Nigeria http://abu.edu.ng/
Project Primary Contact: Name, email, phone	Joseph Orojah Osumeje, joosumeje@abu.edu.ng, +234-08032919520
Project Location, Country	Zaria, Kaduna State, Nigeria
Project Start Date	3rd October 2022
Project End Date	30th September 2023
Report Authors	Joseph O. Osumeje, Daniel Eshimiakhe, Kolawole M. Lawal

Executive Summary

The Executive Summary section of the report should succinctly yet comprehensively summarize the project and its outcomes. Greater detail on the project will be provided as outlined in the additional sections of the report.

Introduction

Provide a brief, focused introduction to the project and its need (Character Limit: 1500)

The GWB project provides access to safe drinking water as a problem in these two villages which use open hand-dug wells that often get polluted and result in health concerns that hinder development.

Project Goals and Objectives

Describe the project goal(s) and objectives as outlined in the Phase II application or subsequent project revisions approved by the GWB Committee.

The project's goal is to provide clean, safe, and accessible water.

1. Delineate the earth's subsurface layers.
2. Determine the hydraulic and aquifer properties.
3. Provide safe and affordable drinking water.
4. Improve water quality.
5. Increase water-use efficiency to address water scarcity.
6. Implement water resources management by protecting and restoring the aquifers.
7. Support the community in water and sanitation management,

8. Train the students and local youths in capacity building.

Project Participants

List the names of all project participants

Joseph Orojah Osumeje (Principal Investigator) Dept. of Physics, A.B.U. Zaria
Kolawole M. LAWAL(Co-Investigator) Dept. of Phy., NOUN, Abuja
Osaze OMOROGBE(CI) Dept. of Mech. Engr., A.B.U., Zaria
Thomas U. Osumeje(CI) Ammah Contractors limited, Kaduna
Idris ABDULLAHI(CI) Maintenance Dept. NCAT, Zaria
Yusuf A. BELLO(CI) Dept. of Physics, AFIT, Kaduna
Daniel ESHIMIAKHE(CI) Dept. of Physics, A.B.U., Zaria
Umar MOHAMMED(CI) Dept. of Physics,
Blessing O. UZOR(Student) Dept. of Physics, A.B.U.
Abdullahi A. BALA(St.) Dept. of Physics.
Olayinka I. Abdulmalik(St.) Dept. of Physics.
Shamsuddeen Zakari(St.) Dept. of Physics.
Abdulmalik I. Olyinka(St.) Dept. of Physics.
Stella O. OGENYI(St.) Dept. of Physics.
Peter ADENIYI(St.) Dept. of Physics.
Daniel Agbo(St.) Dept. of Physics.
Levi Temple(St.) Dept. of Physics.
Paul A. HINJARI(St.) Dept. of Geology, A.B.U.
Caleb K. NYAJON(St.) Dept. of Geology.
Christopher A. BATON(St.) Dept. of Geology.
Atari Y. Ayiwulu(St.) Dept. of Geology.
Adode D. Loyal(St.) Dept. of Geology.
Sanusi YAHAYA(St.) Dept. of Mech. Eng., A.B.U.
Kabir IMRAN(St.) Dept. of Mech. Engr.
Hassan Musa(St.) Dept. of Mech. Engr.
Ahmed Shehu(St.) Dept. of Mech. Engr.
Aliyu S. Yakubu(St.) Dept. of Mech. Engr.
Blessing Emmanuel(St.) Dept. of Mech. Engr.
Lucky O. Abah(St.) Dept. of Mech. Engr.
Friday O. Akava(St.) Dept. of Mech. Engr.
Joseph Jackson(St.) Dept. of Mech. Engr.
Prince Z. Alasa(St.) Dept. of Mech. Engr.
Zainab Abdullah(St.) Dept. of Guidance & Counselling, A.B.U.
Blessing Adikwu(St.) Dept. Science Education, A.B.U.
Gift E. Ekoja(St.) Dept. Sci. Edu.
Rukayyatu T. Mukhtar(St.) Dept. Sci. Edu.
Farida Magaji(St.) Dept. Sci. Edu.
Salisu A. Ahmed(Locals) Angwan Fulani, Palladan
Yusuf Salihu(Lo.) A/Fulani, Pall.
Musa U. Shehu(Lo.) A/Fulani, Pall.
Sabitu Salisu(Lo.) A/Fulani, Pall.
Mohammad Lawal(Lo.) Angwan Rimi Basawa
Shamsudeen Saidu(Lo.) A/Rimi Bas.

Inusa Mohammed(Lo.) A/Rimi Bas.

Methods Used List all methods used, including application and specific instrumentation.

Geophysics Method
Vertical Electrical Sounding (VES)
Schlumberger array
Ohmega Resistivity meter
Geologic mapping
GPS
Inclinometer

Summary of Results and Key Findings Provide a summary of the project's results and key findings

The following results and findings were obtained from the project.

1. The subsurface lithology shows predominantly four layers, the topsoil, the weathered layer, the fractured basement, and the fresh basement.
2. The depth of the weathered layer around the study areas.
3. The depth of the fresh basement around the study areas.
4. The hydrological parameter shows the conductivity and the transmissivity map of the study area.
5. The Transmissivity map for each village shows the location of high groundwater yield.
6. The borehole logs for the two villages.
7. Water quality tests show that the water is certified for drinking.
8. The improved Geologic map of the two villages.

Conclusion and Implications

List the conclusions that the project team derived and the implications those conclusions have
It is expected that at the completion of this project, the following will be achieved;

1. A geophysical information of the earth subsurface was investigated.
2. The underground water potential map of the study areas was produced.
3. A good-yielding borehole was sunk in each of the villages.
4. The water quality was improved by a filtration system.
5. Clean and healthy water for public consumption was made available in the two villages.
6. A functioning and effective water station facility was constructed for each village.
7. The location of the water station is accessible and water is available for free.
8. The risk of water-borne diseases would be reduced.
9. The sanitation and hygiene of the village has been improved.
10. The temptation of open defecation is reduced because water is available for cleaning.
11. Students who participated in the project received an improved knowledge and experience on groundwater investigation and exploration.
12. The knowledge of Geoscientists Without Borders (GWB) and the Society of Exploration Geophysicists (SEG) has reached this grassroots community.
13. UN-SDG goals on "Clean water and Sanitation" have been achieved in these areas.

The following are the implications at the completion of this project, the problem of scarcity of good water has been solved in these communities. The health risk of drinking from hand-dug wells that may be polluted would have been reduced. The result of this project will provide an immediate benefit of water availability, especially during the scarcity period. The project has added to the education and eventually contributed knowledge to the participants of the project. The UN-SDG goals of; providing safe and affordable water for all, improving sanitation, protection of water eco-system, and community support have been achieved at the completion of this project. Also, the awareness of GWB and SEG at the grassroots level has been achieved, this can be a source of motivation to some of the locals.

Deliverables

List all deliverables that will be discussed in the final report, including those given to in-country partners and participants**.** (Character Limit: 1500)

The following is the list of items that make up the water station that was delivered to each of the village Heads,

1. Four (4) Solar panels 320 watt
2. Two 1,500 liters water tanks
3. One submersible solar water pump
4. Water filter vessel with six (6) candle sticks
5. An overhead metal stand structure
6. Four tap heads
7. T-Shirt and P-Caps
8. Safety Helmet.
9. Knowledge and Training.

Students (Involvement of students in the project. Character Limit: 1500)

The participants in this GWB project are the Research Team members, the university students, and the Locals. The majority of the participants were students who were actively involved in the processes from Geological mapping to VES measurements, to Ironwork construction and assembling, then borehole drilling, then water station construction and the installation of the submersible pump, pipes, solar panels, and then test run. It was interesting to work with the students because they showed zeal to understand what is going on, what would be the result of the outcomes, what would be the interpretation of the result how to locate points on the field from interpreted results, and how to correctly estimate into the unseen. The limitation was the availability of all the participating students on the field at any single time. I would love to work with some of the students again but if I have the opportunity to train students again in another project I would select from the first and second-year undergraduate students who would be around longer for me to nurture them during the course of their undergraduate or graduate program.

Final Report

Project Location and Geologic Setting (Character Limit: 500 or attach a file > 5 MB.)

The project area is bound by latitudes 11°00'N and 11°15'N and Longitudes 7°40'E and 7°45'E. It covers the two villages; the Angwan Fulani (Palladan) village, and Angwan Rimi (Basawa) village, (Figure 1), both located under the Sabon-Gari Local Government Area of Kaduna State, Nigeria.). The general geology of these areas comprises migmatites and gneisses, metasediments, and granites overlain by superficial deposits of laterite or alluvium (Bala, 2010).

Project Location continued (KMZ file Limit: 1 MB)

Below is a google map showing the two villages.

Humanitarian Need and Benefit (Character Limit: 750)

The problem of scarcity of good water is resolved in these communities. The health risk of drinking from hand-dug wells that may be polluted has been reduced. The result of this project will provide an immediate benefit of water availability, especially during the scarcity (dry season) period. The project would have added to the education and eventually contributed knowledge and Training to the graduation of the students who have participated in this project. The UN-SDGs goals of; providing safe and affordable water for all, improving sanitation, protection of water eco-system, and community support have been achieved by the completion of this project. Also, the awareness of GWB and SEG at the grassroots level has been achieved.

Project Goals and Objectives (Character Limit: 1000)

The main goal of this project is to provide clean, safe, and accessible water to the inhabitants of these two villages by achieving the following objectives.

1. To delineate the earth’s subsurface layers using VES data.
2. To determine the hydraulic and aquifer properties from the VES data using the Dar Zarrouk Formula.
3. To provide safe and affordable drinking water by creating a water station.
4. To improve water quality by carrying out a water quality test and analysis.
5. To increase water-use efficiency by the supply of fresh water to address water scarcity by installing an efficient water station facility.
6. To implement water resources management by protecting and restoring the aquifers through the training and education of villagers.
7. To support the community in water and sanitation management by providing and training the villagers in environmental sanitation,
8. To train the students and local youths in capacity building by engaging them through the course of the project.

Previous Studies in the Project Area (Character Limit: 2000)

Prior research includes a study conducted by Jegede et al. 2013 focused on delineating vulnerability to contamination in one of the project areas using Electrical Resistivity and Seismic Refraction tomography at a dump site. Their study shows that the regolith aquifer around the study area is vulnerable to pollution. This research established a baseline understanding of the hydrogeological framework, identifying key aquifer units and their susceptibility to various anthropogenic impacts.

Moreover, Bala, 2010, uses Landsat 5 to delineate areas favorable for groundwater accumulation around Zaria environments. His results provide only general information on positive groundwater potential distribution but no specific details on aquifer characteristics that can lead to borehole drilling. This study not only provided crucial information on regional groundwater distribution but also highlighted potential challenges associated with basement aquifers in complex terrain.

This current GWB project on groundwater potential aims to complement these foundations by bringing innovative integration of geophysical, remote sensing, and geological techniques, to delineate subsurface structures with higher resolution. This technological advancement allows for a more detailed characterization of aquifers and improves our ability to estimate groundwater potential accurately and then drill to validate the result. Additionally, the project introduces a community-engaged approach, involving local residents as stakeholders to enhance social relevance and contribute to the long-term sustainability of the project outcomes.

By combining techniques with community involvement, this current project strives to address the limitations of previous studies and provide a comprehensive assessment of groundwater potential. The insights generated have contributed to academic knowledge and will also inform practical water resource management strategies, ensuring the sustainable use of groundwater resources.

Field Studies (Character Limit: 4000, file size limit 2 MB)

The geological field mapping was led by Joseph O. Osumeje (PI) and assisted by Dr Byami A. Jolly (a geologist). The regional geology map available does not reveal the detailed variation of the rock types or rock boundaries on the ground in the two villages so we had to carry out a geological mapping of the two villages starting with Angwan Rimi on the 20th of October 2022 and Angwan Fulani on the 1st of November 2022. The instruments used include the compass, inclinometer, and GPS. We begin the first day by teaching the students how to operate the instruments and then identifying directions, trajectory, inclination, or dip angles. Using an extracted geologic map for the villages, we commence the day's work by looking for exposed rock outcrops, recording their location, and then identifying their fracture and trending directions. At each location, the students take these records. The same process was repeated for Angwan Fulani.

The VES measurement started on 6th January 2023 at Angwan Rimi, and 8th March 2023 at Angwan Fulani. The VES measurement was led by Joseph O. Osumeje (PI) and assisted by Prof. Kolawole M. Lawal (Geophysicist). The students and interested locals joined the field measurements. The Ohmaga meter with Serial No. 0134, (a product of Allied Associates Geophysical Ltd) was used for the work. The Vertical Electrical Sounding (VES) was chosen because of its ability to probe deeper. The Schlumberger 4-electrode array was used for convenience. The students and locals present were introduced to the equipment and its components. The setup and taking of reading were first done for the participant and subsequent reading was taken by them. At each VES point, we establish a profile line of 200 m length with the Ohmega meter at the center of the spread together with two inner potential electrodes and two outer current electrodes. The GPS coordinate is taken for such a point. To probe deeper, the current electrodes are further separated. At Angwan Rimi, we measured 21 VES points around the village.

The same process was repeated for Angwan Fulani, and a total of 24 VES points were measured around the village.

As a need to check for data quality, we set up the equipment to measure 3 consecutive readings and display its mean for each VES point. We also Implement periodic checks on equipment calibration, verify consistency in measured values, and cross-check against known geologic features in other to reject negative readings.

The data processing was conducted by Daniel Eshimiakhe (PG student) under the supervision of Joseph O. Osumeje (PI), we utilized IP2Win software. Data input was done directly from field records (VES data consisting of AB/2, V, I, and K), the apparent resistivity was calculated, corrections were done, and then iterative inversion to obtain a resistivity-depth model. The output of the inversion is a log-log plot of apparent resistivity against depth, a log-resistivity graph, and a resistivity-depth table. During the processing, we assess data quality by examining the smoothness and consistency of resistivity-depth curves.

Challenges include unfavorable weather conditions, such as extreme temperatures, especially during the field studies in March. This had an effect on the resistivity meter and forced us to terminate early from the field on some days. Also, the hardness of the soil sometimes causes errors during the field measurements. To mitigate these, we plan fieldwork for mornings and terminate by midday. We add some water at the electrode points to improve its contact. The Ohmega meter sometimes displays error messages, and these were resolved most times by resetting and refreshing the equipment after 3 measurements. Another challenge is the cluster of buildings sometimes makes it difficult to obtain the required 200 m length for the profiles. We sometimes deviate the profile to attain the required length where possible.

Interpretation of Data (Character Limit: 4000, file size limit 2 MB)

The interpretation process involved a comprehensive analysis of various data types. The VES measurements were analyzed to delineate subsurface resistivity variations aiding in the identification of potential aquifer zones. The thickness of the aquifer was used in the Dar-Zarrouk formula to calculate the Hydraulic Conductivity and Transmissivity. The 2D Transmissivity map for the Angwan Fulani village shows variations with the highest value of 480 m2/day (Fig. 3). According to Niwas and Singhal's Classification of Transmissivity Magnitude, this value falls within the Transmissivity range of 100 – 1000 m2/day and hence implies that the aquifer has the capacity to supply groundwater for the whole community's consumption. Similarly, Angwan Rimi village shows variations with the highest value of 7.5 m2/day (Fig. 4) which falls within the Transmissivity range of 1 – 10 m2/day and hence implies that the aquifer has the capacity to supply groundwater for private consumption. This indicated the points of interest in the two villages were then drilled. The depth to drill was inferred from the closest VES point due to the limitation of space for an Imaging measurement. At Angwan Fulani the deepest fresh basement is at 55 m and the borehole was drilled to 60 m. At Angwan Rimi the deepest fresh basement is at 65 m and the borehole was drilled to 70 m. The borehole log at Angwan Fulani shows lithologies of; Lithified Laterite, Silty Clay, Clayish Sandy Siltstone, and then the Greyish Fresh Basement. Likewise, Angwan Rimi lithologies show, Lithified Laterite, Laterite, Silty Clay, Brown sand, Clayish Sandy Siltstone, and Whitish Fresh Basement. The borehole log comparisons were crucial for validating interpretations, enabling a direct comparison between the subsurface resistivity models and actual borehole measurements. The 2D Transmissivity surface provided a holistic understanding of the groundwater system. The Water Quality Index (WQI) for 20 tested parameters at Angwan Rimi is 2,782.594 while that for Angwan Fulani is 1,756.366. These two values showed that the groundwater is within the 'suitable for drinking water' designated based on the WQI ratings (modified after; Tiwari & Mishra, 1985; House & Ellis, 1987; CCME, 2005; Youngu et al., 2022).

Representative final interpretations include Geological maps illustrating the detailed rock type variation with their boundaries, and 1D subsurface resistivity depicting Geo-electric layers. Transmissivity maps highlight areas of high groundwater productivity. The water quality data were presented in tables, verifying the suitability of the water.

Data quality was assessed rigorously, ensuring accurate interpretations. VES measurements exhibited high reliability, validated by borehole log comparisons. Transmissivity and conductivity data were consistent, enhancing confidence in hydraulic property assessments derived from the Dar-Zarrouk formulation. Geological maps provided a solid foundation, while water quality data offered insights into any potential concerns. The usefulness of the data in interpretation was evident in the detailed characterization of aquifers, and the mapping of subsurface structures. The integration of these diverse datasets facilitated an effective drill in these 2 villages.

The data robustly supported the project's goal and objectives. Aquifer delineation, hydraulic property assessments, and certification of the water quality aligned with the project's objectives. The interpretations provided a foundation for informed decision-making in groundwater resource management. The current dataset is extensive, additional data on seasonal groundwater variations, recharge mechanisms, and further water quality parameters would enhance the understanding of aquifer dynamics. Long-term monitoring data would further validate the sustainability of groundwater resources. Incorporating socio-economic data could provide insights into the impact of groundwater use on local communities.

Human Element (Character Limit: 750)

The project saw active participation that fostered a collaborative and inclusive approach. The project was led by the PI and a College professor who played crucial roles in guiding the research. Professional consultants brought specialized expertise, enhancing the project's depth of training.

The university students and local residents, keen on gaining hands-on experience, actively engaged in fieldwork. They were trained in instrument operation, contributing to data collection on geological features and geophysical subsurface investigations. This involvement provided a unique learning opportunity and added manpower to the project. This synergy created a holistic and impactful groundwater exploration at Angwan Fulani and Angwan Rimi.

Project Sustainability (Character Limit: 1000)

Each villager has shown their commitment to secure and maintain the water station facility. The village Head of Angwan Rimi has set up a monitoring, maintenance, and security committee that will be responsible for the supervision of the water facility. In Angwan Fulani village, a vigilante security outpost was created together with a committee to maintain the water facility.

Apart from this, we have conducted a training session to build the capacity of community members to operate and maintain the water station facility in such a way that hygiene is practiced. We have also trained in each village, a local who is experienced in plumbing and electricals, to be the first point of call should any sudden breakdown or minor malfunction occur such as replacements of damaged components, replacement of filter candles, cleaning of filter vessels, etc.

The sustainability of this project is built into the work plan via knowledge transfer training and capacity building of the community members.

Education (Character Limit: 1000)

The Ahmadu Bello University, Zaria has been involved in the project. The training of students and locals was done by experts from Ahmadu Bello University. Professionals from Geophysics, Geology, Mechanical Engineering, and Civil Engineering were resource persons used in the field supervision and training of the participants of the project.

The geophysical field measurement of Vertical Electrical Sounding (VES) was conducted under the supervision of Dr. Joseph O. Osumeje (PI) and Prof. Kolawole M. Lawal.

The geological field mapping was conducted under the supervision of Joseph O. Osumeje (PI) and Dr Baymi A. Jolly.

The Iron and metal fabrication and construction was done under the supervision of Joseph O. Osumeje (PI) and Engr. Omorge Osaze and Engr. Thomas U. Osumeje.

This project will be a data source for one undergraduate student and two geophysics graduate students to carry out their project and thesis.

Lessons Learned (Character Limit: 1000)

Integration of subsurface investigation techniques can yield a desired result that can solve communities' problems.

Geophysical field experiences can help students develop the desire to build a career in geophysics.

The responsibility of managing people to achieve desired goals and objectives in a project.

The ability to manage funds for effective execution of community projects.

Financials (Character Limit: 1000, file size limit 2 MB)

The approved budget was not sufficient to sustain the project mainly because of the sudden inflation as a result of the exchange rate in my country. We had to prioritize the budget merge some items and forgo others to effectively finance the project. Some additional expenses were incurred for the success of the project and to help us achieve the aim and objective of the project. Please see the attached document for some details.

Deliverables

Access to Data (Character Limit: 500)

Data associated with this project are available and can be obtained by contacting the project lead through joosumeje@abu.edu.ng or josumejeh@yahoo.com

Photos and Videos (Character Limit: 250)

I will send the photos and videos through weTransfer and send the link to the project manager Pallavi.

References

References (Character Limit: 2000)

Bala A.E. (2008). Optimum depth for boreholes in regolith aquifer in parts of Northern Nigeria. Savannah, 21(1):81 – 90.

Bala, A. E., (2010). An appraisal of the usefulness of landsat5_tm imageries in groundwater reconnaissance studies in Zaria – Kaduna area, north-central Nigeria, Global Journal of Geological Sciences, 8(1): 81-89.

CCME (2005). Canadian environmental sustainability indicators. Freshwater quality indicator: Data sources and methods. Catalog no. 16-256-XIE. Retrieved 02 January 2022 from http://www.statcan.ca/bsolc/english/bsolc?catno=16-256-XIE#formatdisp.

House, M. A. & Ellis, J. B. (1987). The development of water quality indices for operational management, Water Science and Technology, 19: 145–154.

Jegede, S.I., Iserhien-Emekeme, R.E., Iyoha, A. and Amadasun, C.V.O. (2013). Near-Surface Investigation of Groundwater Contamination in the Regolith Aquifer of Palladan, Zaria using Borehole log and Tomography Techniques, Research Journal of Applied Sciences, Engineering and Technology 6(4): 537-544, ISSN: 2040-7459; e-ISSN: 2040-7467 © Maxwell Scientific Organization, 2013.

Tiwari, T. N. & Mishra, M. (1985). A preliminary assignment of water quality index to major rivers, Indian Journal of Environmental Protection, 5: 276.

World Health Organization [WHO] (2017). Guidelines for drinking-water quality. Retrieved 16 June 2023 from https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/.

Youngu, T. T., Aliyu, Y. A., Bala, A., Azua, S., Abubakar, A. Z. & Akpa, S. E. (2022). Examining the effect of spatial proximity of geo-located dumpsites on groundwater quality in Samaru-Nigeria. International Journal of Environment and Geoinformatics (IJEGEO), 9(1), 40-51, Doi: 10.30897/ijeogeo.896638.

Current and Planned Abstracts, Articles, and Presentations (Character Limit: 2000)

1. An article is been reviewed for publication
Application of Remote Sensing and Geophysical Methods for Delineating Groundwater Potential at Northwestern Nigeria
Joseph Osumeje1; Daniel Eshimiakhe1; Kola Lawal1
2. A webinar presented at Earth Science Week in October 2023 organized by AGU.

Groundwater Potential Evaluation Based on Geophysical and Remote Sensing Techniques: Providing Safe Drinking Water to Two Communities.
Speaker(s): Joseph O. Osumeje and Daniel Eshimiakhe
3. IMAGE 2023 Conference Oral Presentation (Paper withdrawn because I could not get a VISA to attend the conference)
Groundwater Prospectivity mapping using an integration of geophysical and remote sensing techniques: A case study of Angwan Rimi in Nigeria
presenter: Joseph O. Osumeje
Affiliate: Ahmadu Bello University

Figures for Interpretation

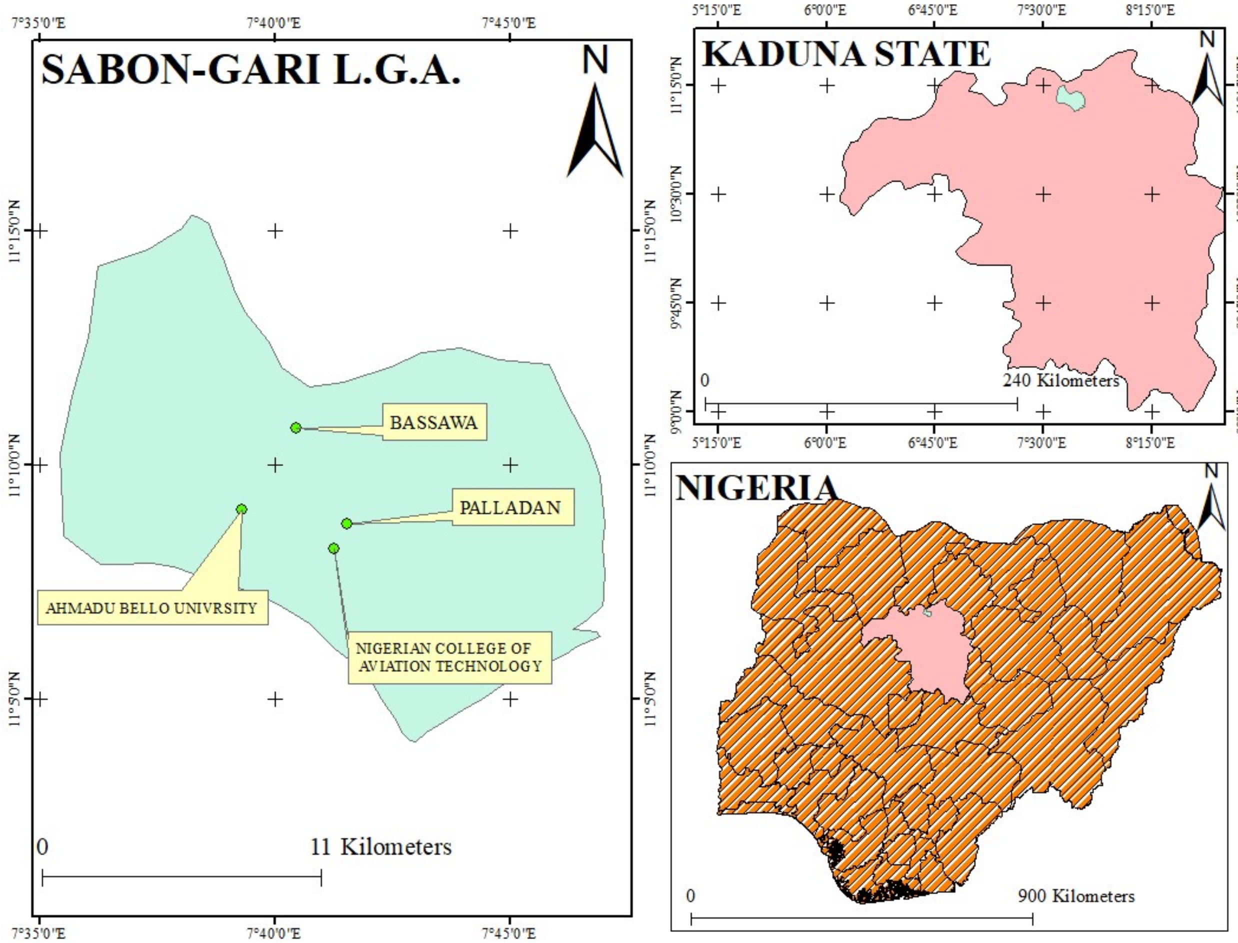

Fig. 1: Location Map of the Project sites

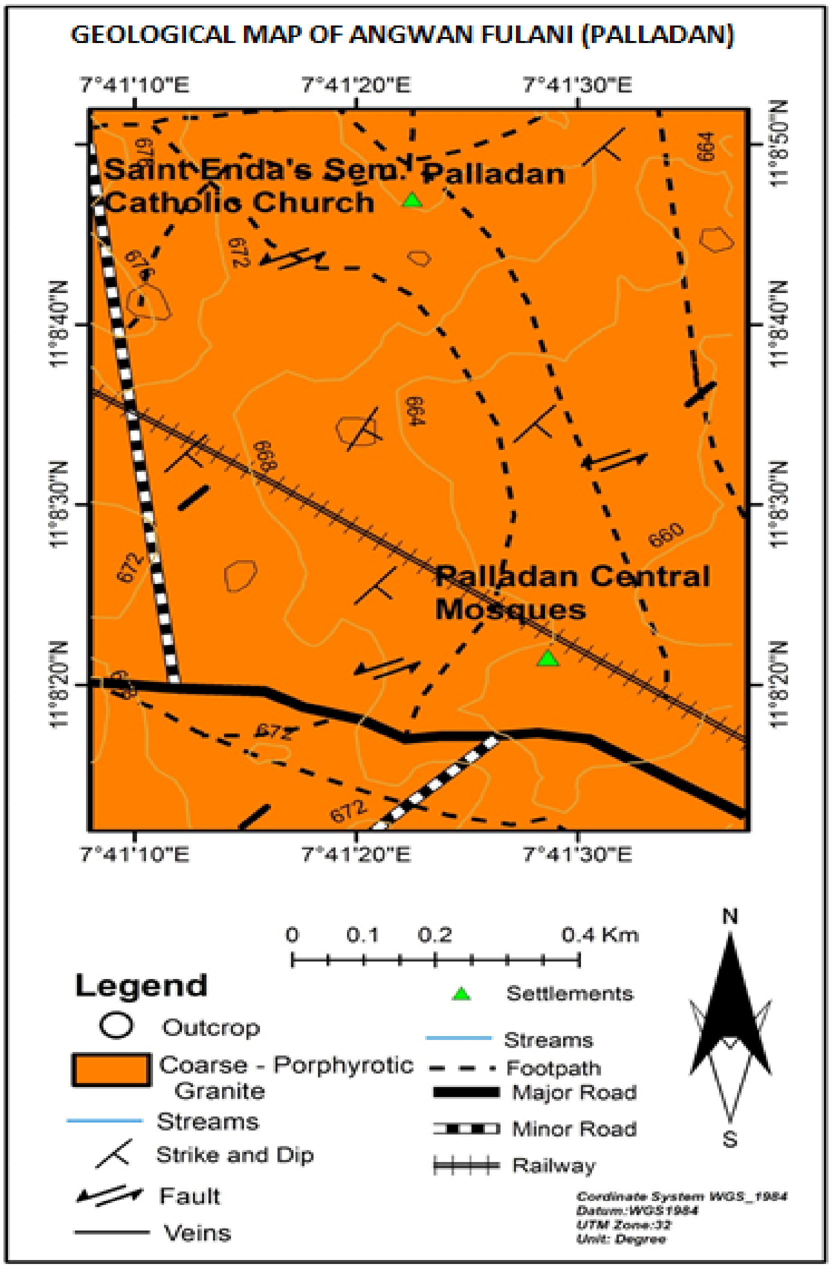

Fig. 2: Created Geologic Map of Angwan Fulani (Palladan)

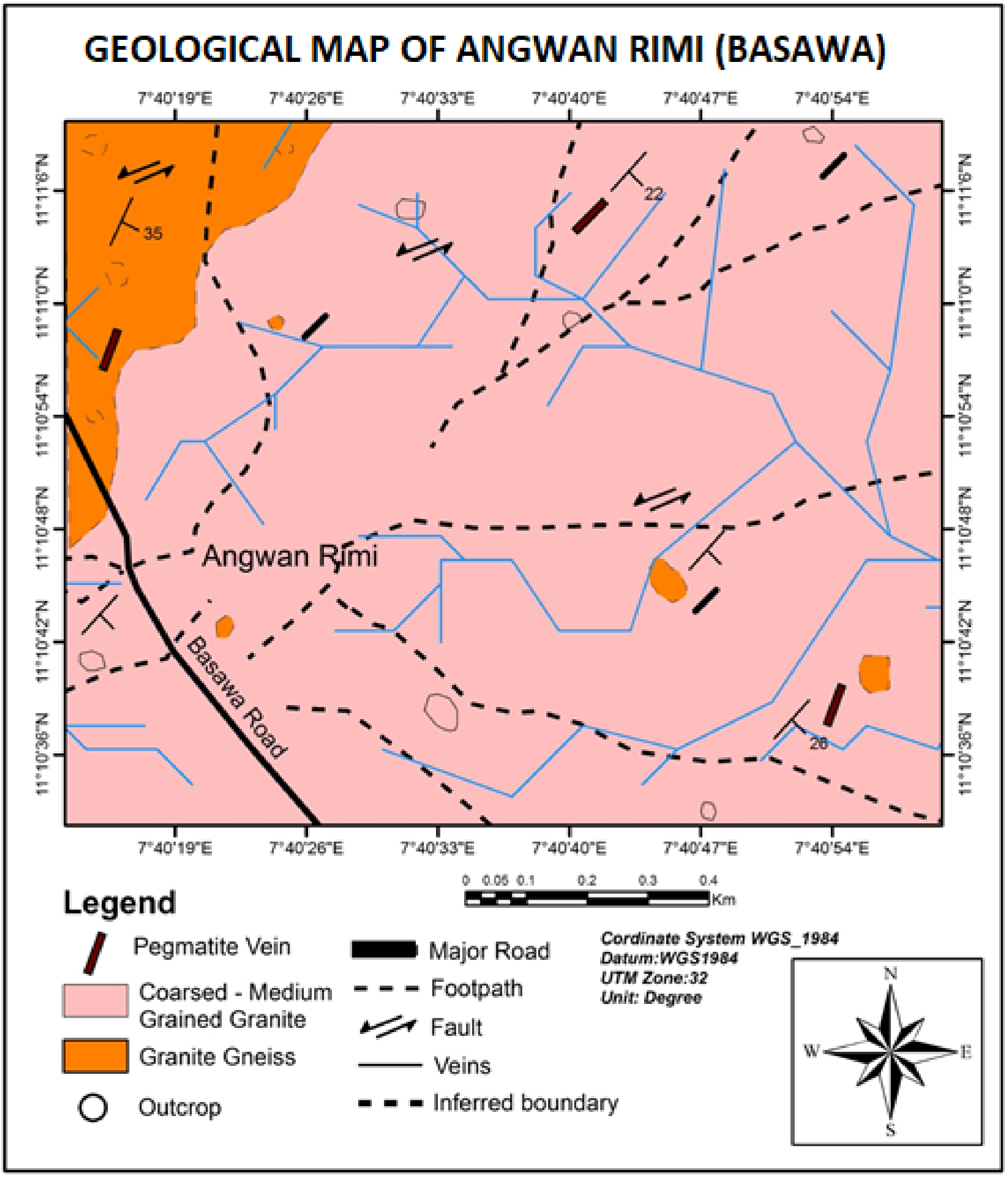

Fig. 3: Created Geologic Map of Angwan Rimi (Basawa)

VES Points	Y-coord (Lat.)	X-coord (Long.)	Aquifer Resistivity	Aquifer Thickness	Conductivity (m^2/s)	Transmissivity (m^2/s)	Transmissivity (m^2/day)
1	7.6885	11.145	29.1	1.58	1.21708E-05	1.92298E-05	1.661454847
2	7.689	11.146	114	1.99	1.37272E-05	2.7317E-05	2.360192577
3	7.688	11.147	102	7.93	5.55617E-05	0.000440604	38.06822748
4	7.688	11.148	35.7	5.36	4.09354E-05	0.000219414	18.95735321
5	7.689	11.148	102	4.58	3.20899E-05	0.000146972	12.69834836
6	7.689	11.149	124	1.8	1.22562E-05	2.20611E-05	1.906077124
7	7.69	11.149	106	1.5	1.04553E-05	1.56829E-05	1.355003659
8	7.69015	11.1475	53	13.8	0.00010305	0.001422084	122.8680632
9	7.691	11.147	33.4	1.45	1.11071E-05	1.61053E-05	1.39149826
10	7.691	11.146	104	2.72	1.90083E-05	5.17025E-05	4.467092275
11	7.689	11.145	19.6	4.06	3.16629E-05	0.000128551	11.10682613
12	7.692	11.146	68.4	3.48	2.54713E-05	8.86403E-05	7.658518258
13	7.6925	11.1458	158	14.9	9.70671E-05	0.0014463	124.9603347
14	7.6926	11.1458	104	4.26	2.97703E-05	0.000126821	10.95736967
15	7.6926	11.145	15.6	3.16	2.47725E-05	7.82811E-05	6.763482998
16	7.693	11.1439	21.4	2.96	2.30303E-05	6.81697E-05	5.889861454
17	7.693	11.144	115	8.95	6.16575E-05	0.000551835	47.678521
18	7.6927	11.1437	98.2	5.9	4.15432E-05	0.000245105	21.17706254
19	7.6914	11.1445	74.8	3.11	2.25746E-05	7.02069E-05	6.06587857
20	7.6899	11.14644	135	1.87	1.2552E-05	2.34722E-05	2.028001449
21	7.6898	11.1445	248	6.27	3.63363E-05	0.000227829	19.68440401
22	7.6889	11.1436	129	1.45	9.80905E-06	1.42231E-05	1.228877377
23	7.6896	11.14547	125	28.6	0.000194484	0.005562233	480.5769562
24	7.6879	11.1448	53	2.43	1.81457E-05	4.4094E-05	3.809722886

Table 1: Transmissivity Values and VES coordinate for Angwan Fulani (Palladan)

VES Points	Y-coord (Lat.)	X-coord (Long.)	Thickness of Aquifer	Aquifer Resistivity	Hydraulic Conductivity (m/s)	Transmissivity (m2/s)	Transmissivity (m2/day)
1	11.17730556	7.675138889	6.07	31.4	4.66177E-05	4.66177E-05	4.027768673
2	11.17775	7.674805556	2.48	212	1.50609E-05	1.50609E-05	1.301259314
3	11.17754167	7.674411111	6.41	129	4.33628E-05	4.33628E-05	3.746541731
4	11.176825	7.675533333	7.37	106	5.13703E-05	5.13703E-05	4.438389763
5	11.17783333	7.676	6.75	23.5	5.23752E-05	5.23752E-05	4.525221125
6	11.17833333	7.675472222	3.49	14.1	2.74129E-05	2.74129E-05	2.368473547
7	11.17838889	7.677111111	1.5	74.8	1.08881E-05	1.08881E-05	0.940728265
8	11.17936111	7.677777778	2.25	172	1.43934E-05	1.43934E-05	1.243592234
9	11.18083333	7.678333333	7.7	92.2	5.46419E-05	5.46419E-05	4.721064328
10	11.18	7.680277778	9.07	130	6.12776E-05	6.12776E-05	5.294381705
11	11.17888889	7.679722222	8.69	115	5.98663E-05	5.98663E-05	5.17245214
12	11.17833333	7.678333333	9.66	106	6.7332E-05	6.7332E-05	5.817482376
13	11.17777778	7.677777778	8.93	155	5.84025E-05	5.84025E-05	5.045972162
14	11.17722222	7.676666667	6.7	111	4.63977E-05	4.63977E-05	4.008757989
15	11.17666667	7.675833333	4.3	70.9	3.13711E-05	3.13711E-05	2.710461624
16	11.17611111	7.674722222	3.04	390	1.46479E-05	1.46479E-05	1.265581188
17	11.17722222	7.673888889	4.66	111	3.22706E-05	3.22706E-05	2.78818093
18	11.17861111	7.673333333	4.8	64.7	3.53023E-05	3.53023E-05	3.050116713
19	11.18019444	7.674583333	11	39	8.36496E-05	8.36496E-05	7.227326661
20	11.17916667	7.675833333	1.69	31.9	1.29708E-05	1.29708E-05	1.12067644
21	11.17972222	7.676666667	3.42	54	2.55052E-05	2.55052E-05	2.203648707

Table 2: Transmissivity Values and VES coordinate for Angwan Rimi (Basawa)

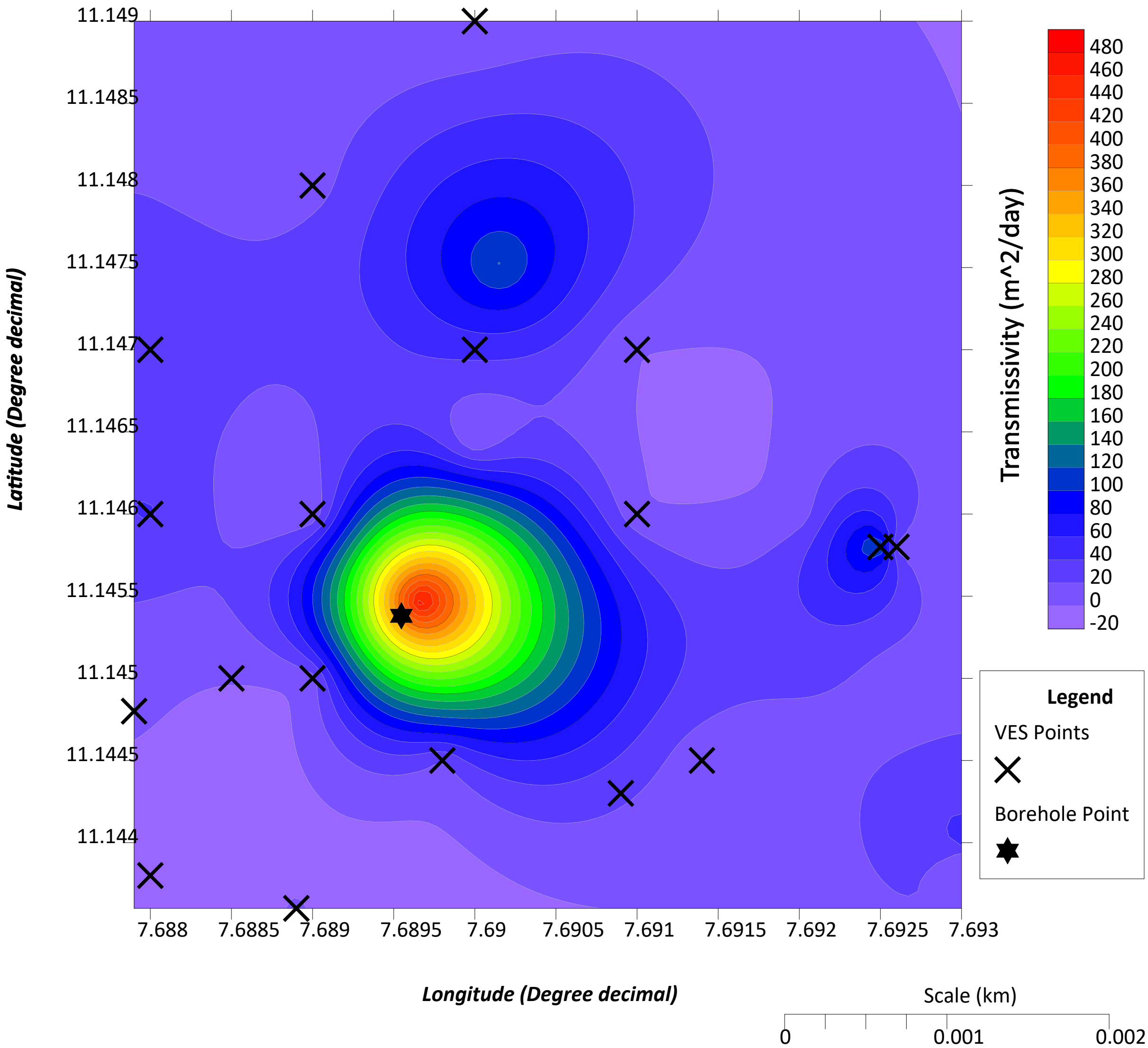

Fig. 3: Transmissivity Map for Angwan Fulani (Palladan)

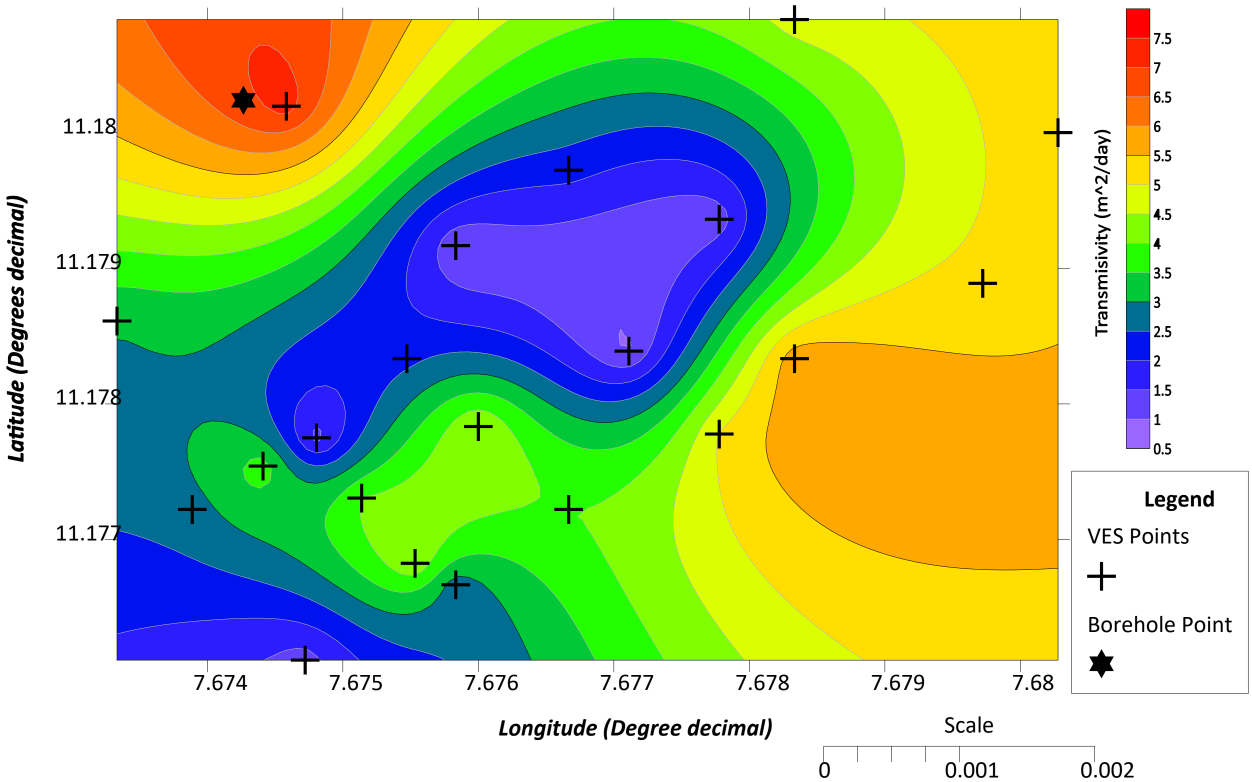

Fig. 4: Transmissivity Map for Angwan Rimi (Basawa)

Water Quality Test and Analysis for both borehole water located at Angwan Fulani (Palladan) and Angwan Rimi (Basawa)

IAR Physio-Chemical Parameters Tests of Water Sample

After the drilling at Angwan Fulani (Palladan) on the 15th of March 2023, a water sample from the well was taken to the Multi-User Laboratory, Ahmadu Bello University, Zaria for detailed analysis. The water was subjected to Physical, Chemical and Biological test to a certain the quality and standard of the water for domestic and public use.

The Table below shows the parameters that were measured in the laboratory.

Table 1: Physio-Chemical Parameters borehole 1 at Angwan Fullani (Palldan)

Parameter	pH	Hardness mg/l	Nitrates mg/l	SO_4^{2-} mg/l	PO_4^{3-} mg/l	Na mg/l	K mg/l	N_i mg/l	Z_n mg/l	F_e mg/l	P_b mg/l	C_d mg/l	C_r mg/l	BOD mg/l	COD mg/l	DO mg/l	TSS mg/l	TDS mg/l	EC µS/cm	Tb N.T.U.
Lab. Tests	7.14	3.00	130.86	3.59	9.04	25.50	3.50	0.70	0.04	1.43	0.27	0.04	0.01	0.80	80.00	1.00	2.40	0.20	300.00	159.00

Table 2: Physio-Chemical Parameters Tests' Results v. Standards

Parameter	pH	Hardness mg/l	Nitrates mg/l	SO_4^{2-} mg/l	PO_4^{3-} mg/l	Na mg/l	K mg/l	N_i mg/l	Z_n mg/l	F_e mg/l	P_b mg/l	C_d mg/l	C_r mg/l	BOD mg/l	COD mg/l	DO mg/l	TSS mg/l	TDS mg/l	EC µS/cm	Tb N.T.U.
Lab. Tests	7.14	3.00	130.86	3.59	9.04	25.50	3.50	0.70	0.04	1.43	0.27	0.04	0.01	0.80	80.00	1.00	2.40	0.20	300.00	159.00
Standards	9	180	50	500	40	200	10	0.02	3	0.3	0.01	0.003	0.05	3	100	9.5	75	1200	400	5

Analyses of Physio-Chemical Parameters Tests' Results based on WHO/European/CCME/EPA Standard Limits

The pH value (7.4) obtained from testing the groundwater sample was within the permissible limit (9) of good water quality.

The Total Hardness level (3 mg/l) obtained from testing the groundwater sample was within the permissible limit (180 mg/l) of good water quality.

The Total Nitrates concentration (130.86 mg/l) obtained from testing the groundwater sample was above the permissible limit (50 mg/l) of good water quality by 80.86 mg/l.

The Total Sulphate concentration (3.59 mg/l) obtained from testing the groundwater sample was within the permissible limit (500 mg/l) of good water quality.

The Total Phosphate concentration (9.04 mg/l) obtained from testing the groundwater sample was within the permissible limit (40 mg/l) of good water quality.

The Total Sodium level (25.50 mg/l) obtained from testing the groundwater sample was within the permissible limit (200 mg/l) of good water quality.

The Total Potassium concentration (3.50 mg/l) obtained from testing the groundwater sample was within the permissible limit (10 mg/l) of good water quality.

The Total Nickel level (0.70 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.02 mg/l) of good water quality by 0.68 mg/l.

The Total Zinc concentration (0.04 mg/l) obtained from testing the groundwater sample was within the permissible limit (3 mg/l) of good water quality.

The Total Iron level (1.43 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.3 mg/l) of good water quality by

1.13 mg/l.

The Total Lead level (0.27 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.01 mg/l) of good water quality by 0.26 mg/l.

The Total Cadnium level (0.04 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.003 mg/l) of good water quality by 0.003 mg/l.

The Total chromium level (0.01 mg/l) obtained from testing the groundwater sample was within the permissible limit (0.05 mg/l) of good water quality.

The Biological Oxygen Demand level (0.80 mg/l) obtained from testing the groundwater sample was within the permissible limit (3 mg/l) of good water quality.

The Chemical Oxygen Demand concentration (80 mg/l) obtained from testing the groundwater sample was within the permissible limit (100 mg/l) of good water quality.

The Dissolved Oxygen level (1.00 mg/l) obtained from testing the groundwater sample was within the permissible limit (9.5 mg/l) of good water quality.

The Total Suspeneded Solids level (2.40 mg/l) obtained from testing the groundwater sample was within the permissible limit (75 mg/l) of good water quality.

The Total Dissolved Solid level (0.20 mg/l) obtained from testing the groundwater sample was within the permissible limit (1200 mg/l) of good water quality.

The Electrical Conductivity level (300 µS/cm) obtained from testing the groundwater sample was within the permissible limit (400 µS/cm) of good water quality.

The Turbidity level (159.00 N.T.U.) obtained from testing the groundwater sample was above the permissible limit (5 N.T.U.) of good water quality by 154.00 N.T.U.

Computation of Water Quality Index (WQI) for borehole Source based on Test Results (Table 1)

The WQI is computed using the weighted arithmetic water quality index (WQI_A) method (Horton, 1965; Brown *et al.*, 1972) and it is given as follows:

$$WQI = \sum_{i=1}^{n} w_i q_i \Big/ \sum_{i=1}^{n} w_i \qquad (1)$$

Where,

n = the number of parameters,

w_i = the relative weight of the i^{th} parameter and,

q_i = the water quality rating (sub-index) of the i^{th} parameter.

The unit weight (w_i) (that is, $\sum_{i=1}^{n} w_i = 1$) of the various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters. The value of q_i which relates the value of the parameter in contaminated water to the recommended or standard permissible value is computed as follows:

$$q_i = 100\left[(V_i - V_{id})/(S_i - V_{id})\right] \qquad (2)$$

Where,

V_i = the observed value of the i^{th} parameter,

S_i = the standard permissible value of the i^{th} parameter and,

V_{id} = the ideal value of the i^{th} parameter in pure water.

Most of the time, the ideal value of a parameter for drinking water is taken as zero except for pH (7.0) and DO (14.6 mg/L) according to Tripaty & Sahu (2005).

The unit weight (w_i) which is inversely proportional to the standard permissible values is calculated as:

$$w_i = k/S_i \qquad (3)$$

Where,

$$k = 1\Big/\sum_{i=1}^{n} 1/S_i \qquad (4)$$

The rating of the water quality in this study is based on the index value according to the modified version of Tiwari & Mishra (1985), House & Ellis (1987), CCME (2005), and Youngu *et al*. (2022) designations as shown below in Table 3.

Table 3: WQI ratings (modified after; Tiwari & Mishra, 1985; House & Ellis, 1987; CCME, 2005; Youngu *et al*., 2022)

Designation	**Index value**	**Description**
Excellent	95 and above	Suitable for drinking water
Good	80-94	Slightly polluted water
Fair	65-79	Moderately polluted water
Marginal	45-64	Excessively polluted water

Poor	0-44	Severely polluted water

WQI (20 parameters) = 1756.366 (See Appendix I).

The value of the WQI obtained showed that the groundwater location is within the 'suitable for drinking water' [Excellent] designation based on Table 3.

Borehole Water for Angwan Rimi (Basawa)

After the drilling at Angwan Rimi (Basawa) on the 15th of April 2023, a water sample from the well was taken to the Multi-User Laboratory, Ahmadu Bello University, Zaria for detailed analysis. The water was subjected to Physical, Chemical and Biological tests to a certain the quality and standard of the water for domestic and public use.

Table 4 below shows the parameters that were measured in the laboratory.

Table 4: Physio-Chemical Parameters

Parameter	pH	Hardness mg/l	Nitrates mg/l	SO_4^{2-} mg/l	PO_4^{3-} mg/l	Na mg/l	K mg/l	N_i mg/l	Z_n mg/l	F_e mg/l	P_b mg/l	C_d mg/l	C_r mg/l	BOD mg/l	COD mg/l	DO mg/l	TSS mg/l	Cl^- mg/l	EC µS/cm	Tb N.T.U.
Lab. Tests	6.49	3.30	103.74	15.63	18.78	48.00	9.80	0.45	0.12	1.26	0.52	0.07	0.03	0.50	70.00	2.00	0.01	0.20	1750.00	117.50

Table 5: Physio-Chemical Parameters Tests' Results v. Standards

Parameter	pH	Hardness mg/l	Nitrates mg/l	SO_4^{2-} mg/l	PO_4^{3-} mg/l	Na mg/l	K mg/l	N_i mg/l	Z_n mg/l	F_e mg/l	P_b mg/l	C_d mg/l	C_r mg/l	BOD mg/l	COD mg/l	DO mg/l	TSS mg/l	Cl^- mg/l	EC µS/cm	Tb N.T.U.
Lab. Tests	6.49	3.30	103.74	15.63	18.78	48.00	9.80	0.45	0.12	1.26	0.52	0.07	0.03	0.50	70.00	2.00	0.01	0.20	1750.00	117.50
Standards	9	180	50	500	40	200	10	0.02	3	0.3	0.01	0.003	0.05	3	100	9.5	75	120	400	5

Analyses of Physio-Chemical Parameters Tests' Results based on WHO/European/CCME/EPA Standard Limits

The pH value (6.49) obtained from testing the groundwater sample was within the permissible limit (9) of good water quality.

The Total Hardness level (3.30 mg/l) obtained from testing the groundwater sample was within the permissible limit (180 mg/l) of good water quality.

The Total Nitrates concentration (103.74 mg/l) obtained from testing the groundwater sample was above the permissible limit (50 mg/l) of good water quality by 53.74 mg/l.

The Total Sulphate concentration (15.63 mg/l) obtained from testing the groundwater sample was within the permissible limit (500 mg/l) of good water quality.

The Total Phosphate concentration (18.78 mg/l) obtained from testing the groundwater sample was within the permissible limit (40 mg/l) of good water quality.

The Total Sodium level (48 mg/l) obtained from testing the groundwater sample was within the permissible limit (200 mg/l) of good water quality.

The Total Potassium concentration (9.80 mg/l) obtained from testing the groundwater sample was within the permissible limit (10 mg/l) of good water quality.

The Total Nickel level (0.45 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.02 mg/l) of good water quality by 0.43 mg/l.

The Total Zinc concentration (0.12 mg/l) obtained from testing the groundwater sample was within the permissible limit (3 mg/l) of good water quality.

The Total Iron level (1.26 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.3 mg/l) of good water quality by 0.96 mg/l.

The Total Lead level (0.52 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.01 mg/l) of good water quality by 0.51 mg/l.

The Total Cadnium level (0.07 mg/l) obtained from testing the groundwater sample was above the permissible limit (0.003 mg/l) of good water quality by 0.067 mg/l.

The Total chromium level (0.03 mg/l) obtained from testing the groundwater sample was within the permissible limit (0.05 mg/l) of good water quality.

The Biological Oxygen Demand level (0.50 mg/l) obtained from testing the groundwater sample was within the permissible limit (3 mg/l) of good water quality.

The Chemical Oxygen Demand concentration (70 mg/l) obtained from testing the groundwater sample was within the permissible limit (100 mg/l) of good water quality.

The Dissolved Oxygen level (2.00 mg/l) obtained from testing the groundwater sample was within the permissible limit (9.5 mg/l) of good water quality.

The Total Suspended Solids level (0.01 mg/l) obtained from testing the groundwater sample was within the permissible limit (75 mg/l) of good water quality.

The Total chloride level (426 mg/l) obtained from testing the groundwater sample was above the permissible limit (120 mg/l) of good water quality by 306 mg/l.

The Electrical Conductivity level (1750 µS/cm) obtained from testing the groundwater sample was above the permissible limit (400 µS/cm) of good water quality by 1350 mg/l.

The Turbidity level (117.50 N.T.U.) obtained from testing the groundwater sample was above the permissible limit (5 N.T.U.) of good water quality by 112.50 N.T.U.

Computation of Water Quality Index (WQI) for Borehole Source based on Test Results (Table 4)

The WQI is computed using the weighted arithmetic water quality index (WQI_A) method (Horton, 1965; Brown *et al.*, 1972) and it is given as follows:

$$WQI = \sum_{i=1}^{n} w_i q_i \Big/ \sum_{i=1}^{n} w_i \qquad (1)$$

Where,

n = the number of parameters,

w_i = the relative weight of the i^{th} parameter and,

q_i = the water quality rating (sub-index) of the i^{th} parameter.

The unit weight (w_i) (that is, $\sum_{i=1}^{n} w_i = 1$) of the various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters. The value of q_i which relates the value of the parameter in contaminated water to the recommended or standard permissible value is computed as follows:

$$q_i = 100\left[(V_i - V_{id})/(S_i - V_{id})\right] \quad (2)$$

Where,

V_i = the observed value of the i^{th} parameter,

S_i = the standard permissible value of the i^{th} parameter and,

V_{id} = the ideal value of the i^{th} parameter in pure water.

For most of the times, the ideal value of a parameter for drinking water is taken as zero except for pH (7.0) and DO (14.6 mg/L) according to Tripaty & Sahu (2005).

The unit weight (w_i) which is inversely proportional to the standard permissible values is calculated as:

$$w_i = k/S_i \quad (3)$$

Where,

$$k = 1\bigg/\sum_{i=1}^{n} 1/S_i \quad (4)$$

The rating of the water quality in this study is based on the index value according to the modified version of Tiwari & Mishra (1985), House & Ellis (1987), CCME (2005), and Youngu *et al*. (2022) designations as shown below in Table 6.

Table 6. WQI ratings (modified after; Tiwari & Mishra, 1985; House & Ellis, 1987; CCME, 2005; Youngu *et al*., 2022)

Designation	**Index value**	**Description**
Excellent	95 and above	Suitable for drinking water
Good	80-94	Slightly polluted water

Fair	65-79	Moderately polluted water
Marginal	45-64	Excessively polluted water
Poor	0-44	Severely polluted water

WQI (20 parameters) = 2782.594 (See Appendix II).

The value of the WQI obtained showed that the groundwater location is within the 'suitable for drinking water' [Excellent] designation based on Table 6.

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Appendix I: Computation of WQI for site one Angwan Fulani (Palladan)

Parameter	Sn	1/Sn	K = 1/∑1/Si…n	Wi = K/Sn	Vo	Vid	Vo-Vid	Sn-Vid	Vo-Vid/Sn-Vid	qn = 100*[(Vo - Vid)/(Sn-Vid)]	Wi*qi	WQI = ∑Wi*qi/∑Wi…n
pH	9	0.111111	0.001969	0.000218751	7.14	7	0.14	2	0.07	7	0.001531	1756.366
DO	9.5	0.105263		0.000207238	1	14.6	-13.6	-5.1	2.666667	266.6667	0.055263	
BOD	3	0.333333		0.000656253	0.8	0	0.8	3	0.266667	26.66667	0.0175	
TDS	1200	0.000833		1.64063E-06	0.2	0	0.2	1200	0.000167	0.016667	2.73E-08	
SO_4^{2-}	500	0.002		3.93752E-06	3.59	0	3.59	500	0.00718	0.718	2.83E-06	
Turbidity	5	0.2		0.000393752	159	0	159	5	31.8	3180	1.252131	
EC	400	0.0025		4.9219E-06	300	0	300	400	0.75	75	0.000369	
Na	200	0.005		9.8438E-06	25.5	0	25.5	200	0.1275	12.75	0.000126	
Hardness	180	0.005556		1.09376E-05	3	0	3	180	0.016667	1.666667	1.82E-05	
N_i	0.02	50		0.098438	0.7	0	0.7	0.02	35	3500	344.533	
Nitrates	50	0.02		3.93752E-05	130.86	0	130.86	50	2.6172	261.72	0.010305	
Z_n	3	0.333333		0.000656253	0.04	0	0.04	3	0.013333	1.333333	0.000875	
F_e	0.3	3.333333		0.006562533	1.43	0	1.43	0.3	4.766667	476.6667	3.128141	
P_b	0.01	100		0.196875999	0.27	0	0.27	0.01	27	2700	531.5652	
C_d	0.003	333.3333		0.656253331	0.04	0	0.04	0.003	13.33333	1333.333	875.0044	
C_r	0.05	20		0.0393752	0.01	0	0.01	0.05	0.2	20	0.787504	
PO_4^{3-}	40	0.025		4.9219E-05	9.04	0	9.04	40	0.226	22.6	0.001112	
K	10	0.1		0.000196876	3.5	0	3.5	10	0.35	35	0.006891	
COD	100	0.01		1.96876E-05	80	0	80	100	0.8	80	0.001575	
TSS	75	0.013333		2.62501E-05	2.4	0	2.4	75	0.032	3.2	8.4E-05	
	∑1/Si…n	**507.9339**	**∑Wi..n**	**1**						**∑Wi*qi**	**1756.366**	