Structural Controls on Groundwater Potential and Vulnerability to Contamination in Suleja and Environs, North-Central Nigeria: Insights from Aeromagnetic, SRTM and in Situ Water-Quality Data

A. O Jegede*[1], N.N Abdulsalam [1,] T.O Adeeko[1], O. Olasehinde[2]
[1]Department of Physics, University of Abuja
[2]Nigerian Geological Survey Agency
*Corresponding author: Ayotunde Oluwafemi Jegede
Email: jegedeayo49@gmail.com

https://doi.org/10.56201/ijaes.vol.12.no11.2026.pg63.76

Abstract
Groundwater in crystalline basement terrains is held in thin weathered and fractured rock, so geological structure controls both where water occurs and how readily contaminants reach it. This study maps the structural controls on groundwater in part of Sheet 186 (Abuja), around Suleja in North-Central Nigeria (about 22 × 24 km), and rates the vulnerability of the resulting zones to contamination. Aeromagnetic data were reduced to the equator and enhanced with first and second vertical derivatives, the analytic signal and the tilt derivative, then combined with a 30 m SRTM elevation model (209 to 554 m). The basement is densely fractured in the west, north-west and south-west, and five lineament sets were identified (N–S to NNE–SSW, NNW–SSE, WNW–ESE, ENE–WSW and E–W). Six groundwater potential zones were ranked from this framework. In situ measurements at four hand-dug wells (2.6 to 5.7 m deep), one borehole and four river points show a median well TDS of 951 mg/L, a median well conductivity of 1,562 µS/cm and a median well turbidity of 35.5 NTU, against guideline values of 500 mg/L, 1,000 µS/cm and 5 NTU. All redox potentials are positive (174 to 268 mV), indicating oxidizing conditions. The south-western basin, the west-central fracture corridor and the south-eastern lowland combine high yield potential with high vulnerability. The central corridor and the margins of the magnetic highlands are moderately vulnerable, and the northeastern high ground is a recharge area of low to moderate vulnerability. Borehole sites should meet at least three of four structural indicators and be paired with casing, well protection and seasonal monitoring.

Keywords: *groundwater vulnerability; structural control; aeromagnetic data; lineaments; Basement Complex; SRTM; in situ water quality; Suleja; Nigeria*

1. Introduction

Groundwater is the main source of water for domestic, agricultural and industrial use across Nigeria and much of West Africa. In the Basement Complex, which underlies roughly half of Nigeria, it is the only dependable source in many towns. The crystalline rocks have almost no primary porosity. Usable water sits in the weathered regolith and in fractured bedrock, so well yield depends on weathering depth, fracture density and connectivity, and overburden thickness (Wright, 1992; Olorunfemi and Fasuyi, 1993; Dewandel et al., 2006; Akano et al., 2016).

The same features that store water also carry pollutants. Leachate from dumpsites moves down through the unsaturated zone under gravity and reaches the water table in the saturated zone (Igboama et al., 2022), and fractures, shear zones and thin regolith shorten and speed that path. Suleja, a fast-growing satellite town on the Abuja–Kaduna corridor, combines high groundwater demand, unlined hand-dug wells, open refuse dumps, an abattoir, timber sheds and recurrent flooding.

Faults, joints, shear zones and lithological contacts control where weathering penetrates deeply and where permeability is enhanced. Aeromagnetic surveys map such structures at regional scale because they respond to contrasts in magnetization and can reveal features buried beneath soil and regolith (Blakely, 1995; Kearey et al., 2002). Derivative filters, the analytic signal and the tilt derivative sharpen these responses and locate source edges (Nabighian, 1972; Roest et al., 1992; Miller and Singh, 1994; Verduzco et al., 2004). Digital elevation models add a surface view, because linear valleys, scarps and drainage convergence often follow fracture zones. Regional structural information to guide borehole siting and protection around Suleja is scarce, and the available water-quality data are point measurements.

This paper combines aeromagnetic and SRTM data with in situ water-quality measurements to explain how structure controls groundwater occurrence and vulnerability to contamination in Suleja and its environs.

1.1 Aim and objectives

The aim is to explain how geological structure controls groundwater occurrence and its vulnerability to contamination in Suleja and its environs. The objectives are to:

- describe the terrain, drainage and lineament framework of the area;
- rank zones by groundwater potential from that framework;
- characterize the in situ physical and redox quality of well, borehole and river water;
- identify probable geogenic and anthropogenic influences on that quality; and
- rate the vulnerability of each structural zone to contamination and propose siting and protection measures.

2. Study Area

The study area is part of Sheet 186 (Abuja) in Niger State, on the northern border of the Federal Capital Territory (Figure 1). It includes Suleja and Madalla, which together held about 215,000 people at the 2006 census. The structural survey covers about 22 × 24 km between 7°04′ and 7°16′E and 9°05′ and 9°18′N (UTM zone 32N, WGS 84). The hydrogeochemical survey is concentrated on the Suleja metropolis.

Terrain. The ground is undulating, with gentle slopes, small inselbergs and lowlands, most clearly in the centre. SRTM elevation runs from 209 to 554 m (Figure 2). Three terrain units were recognized: a south-western lowland basin (209 to 260 m), north-eastern and eastern highlands (450 to 554 m), and a west-central belt of NW–SE and NNW–SSE ridges and valleys with a linear scarp at about 7°08′ to 7°10′E.

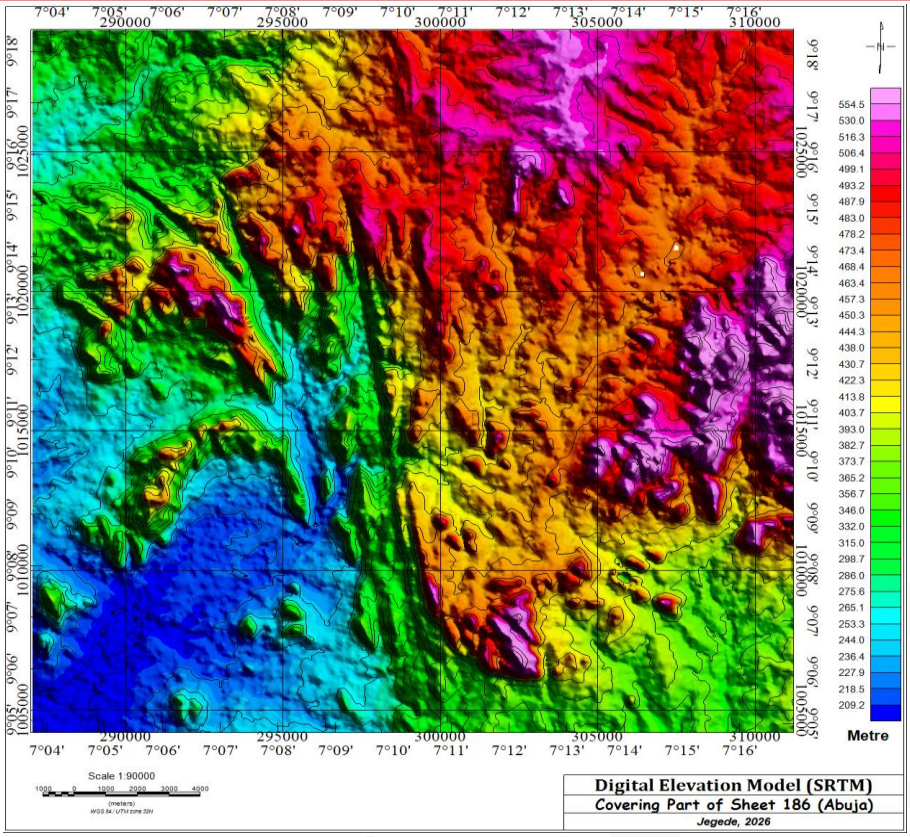

Figure 2: Digital Elevation Model (SRTM) Covering part of Sheet 186 (Abuja)

Drainage. The Gurara River is the main perennial channel and flows north-west to south-east. Most other channels are first-order streams or perennial tributaries of the Kwamba River, forming a dendritic pattern that is in places visibly structure-controlled. The Kwakoshe River also feeds the area from upstream.

Climate and vegetation. The climate is tropical savanna. Rain falls from April to September or October, peaks between July and September, and totals about 1,100 to 1,600 mm a year. Temperatures range from about 24 to 35 °C (Ayoade, 2004). The vegetation is Southern Guinea Savanna, now heavily modified by farming, urban growth, fuelwood cutting and quarrying, with raffia palms and tall grasses along streams.

Access. The area is reached by the Abuja–Kaduna expressway and the Madalla–Suleja–Minna highway and their connecting roads.

3. Geological and Hydrogeological Setting

3.1 Regional geology

Nigeria lies in the Benin–Nigeria Shield of the Dahomeyan (Trans-Saharan) mobile belt, between the West African and Congo cratons (Obaje, 2009). The shield records Neo-Proterozoic and older Precambrian rocks reworked in the Pan-African orogeny (600 ± 150 Ma), which imposed a N–S structural trend and emplaced the Older Granites (Grant, 1969; Ajibade and Wright, 1989; Key and Pitfield, 2009). Rahaman (1988) divides the basement into migmatite–gneiss–quartzite complexes, schist belts, charnockitic and dioritic rocks, Older Granites, calc-alkaline volcanics and late dolerite and syenite dykes. Cretaceous to Recent sediments overlie it elsewhere in the country.

3.2 Geology of the study area

Suleja falls within Abuja Sheet 186 in the western Nigerian Terrane. The terrain consists of migmatitic gneisses with infolded low- to medium-grade schist belts, Pan-African Older Granite intrusions, and smaller meta-basic bodies (Ogezi, 1977). Foliation trends N–S and NE–SW. Field mapping identified four units:

- **Porphyritic granite**, the dominant unit, in massive outcrops, boulder fields and low exposures. It is coarse, light-coloured, fractured and well jointed, with feldspar phenocrysts about 1.5 to 3 cm by 5 to 8 cm set in a quartz–biotite matrix.
- **Granite gneiss**, fine to medium grained, with foliation defined by biotite and a mineralogy of quartz, biotite, plagioclase, K-feldspar and hornblende.
- **Mylonites**, which mark zones of ductile shear.
- **Quartz veins**, which commonly fill or follow fractures.

The mylonites and veins are field evidence of the shear zones and fractures that the aeromagnetic data map at regional scale.

3.3 Hydrogeology

The aquifers are the weathered regolith and the fractured bedrock beneath it (Akano et al., 2016). Yields are generally low, and wells and boreholes can dry up in prolonged drought. The sampled hand-dug wells were 2.6 to 5.7 m deep (mean 3.95 m), so these wells tap only the uppermost regolith, where there is least protection from the surface.

4. Materials and Methods

4.1 Aeromagnetic and terrain data

Aeromagnetic data for Sheet 186 were acquired from the Nigerian Geological Survey Agency (NGSA). Magnetic processing used Oasis montaj and mapping used ArcGIS, in UTM zone 32N (WGS 84). Terrain was described from the 30 m SRTM digital elevation model (DEM), displayed as shaded relief with elevation contours. The regional-corrected total magnetic intensity (TMI) grid ranges from −172.7 to +97.5 nT. At this very low magnetic latitude a body gives a negative central anomaly with positive flanks and reduction to the pole is unstable, so the grid was reduced to the equator (RTE; range −116.9 to +128.6 nT), which places anomalies over their sources (Rajagopalan, 2003). Four filters were applied to the RTE grid:

- first and second vertical derivatives (1VD, 2VD), which sharpen shallow sources and contacts;
- the analytic signal (AS), which does not depend on magnetization direction (Nabighian, 1972; Roest et al., 1992);
- the tilt derivative (TDR), whose zero contour approximates source edges (Miller and Singh, 1994; Verduzco et al., 2004).

Lineaments were drawn by eye from linear zero-crossings and breaks of slope on the derivative maps, linear ridges in the analytic signal, and alignment with linear features on the shadedrelief DEM. Only features visible on several maps were kept. Groundwater potential zones were ranked by how many of four indicators coincide: lineament density and intersections, magnetic lows or contact flanks, low topographic position, and low-to-moderate analytic signal. Coordinates quoted in the text were read from the map grids and are approximate.

4.2 Field survey and in situ measurements

Reconnaissance was followed by geological traverses with grab sampling of rock, hydrogeological mapping at 1:25,000 on the Abuja Sheet 186 SW topographic base, and a waste-dump assessment. Water was sampled at 10 points in August 2026, in the rainy season: four hand-dug wells, one borehole, one leachate source and four river points (upstream,

midstream and downstream; Figure 1). Well and stream positions were fixed by GPS and well depths were measured with a dip meter.

Temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured with a Hanna HI 9813-6 multi-parameter meter, dissolved oxygen (DO) with an AZ 8403 meter, turbidity with a portable turbidity meter, and oxidation–reduction potential (ORP) with a portable pH/ORP/temperature meter. Results were summarized by sample type using the minimum, maximum, mean and median. They were compared with the WHO and Nigerian Standard for Drinking Water Quality (NSDWQ) limits, and TDS was classified with the scheme of Hem (1970).

4.3 Vulnerability approach

Vulnerability was rated qualitatively, zone by zone, from four factors drawn from the two data sets: (i) lineament density and intersections, which set how many fast pathways exist; (ii) topographic position and drainage convergence, which set where runoff and leachate collect; (iii) probable regolith thickness and water-table depth, inferred from analytic signal, relief and well depths; and (iv) observed water-quality evidence. Dumpsite coordinates were not available, so distance to source was treated qualitatively.

5. Structural Controls on Groundwater Occurrence

The basement is densely fractured in the west, north-west and south-west and smoother in the centre and south-east, and the best aquifers lie where fracturing coincides with low ground and weakly magnetic, probably weathered, rock.

5.1 Terrain and drainage

- **South-western lowland** (7°04′–7°09′E, 9°05′–9°10′N; 209 to 260 m). A broad basin ringed on the north and east by an arcuate ridge. Runoff and shallow groundwater from the uplands converge here, so it is a zone of accumulation and discharge.
- **North-eastern and eastern highlands** (7°12′–7°16′E, 9°10′–9°18′N; 450 to 554 m). Recharge and runoff ground with a deeper water table.
- **West-central belt** (7°05′–7°10′E). NW–SE and NNW–SSE ridges and valleys with a linear scarp at about 7°08′–7°10′E, probably a fault, fracture or contact zone. Linear valleys of this kind are common sites of deep weathering and water storage.

5.2 Magnetic response

The TMI map (Figure 3) cannot be read directly at this latitude, so interpretation uses the RTE map (Figure 4). A large TMI low at 7°13′–7°15′E, 9°08′–9°10′N becomes a high on the RTE and analytic signal maps, which confirms it is a magnetic body and not a zone of low magnetization.

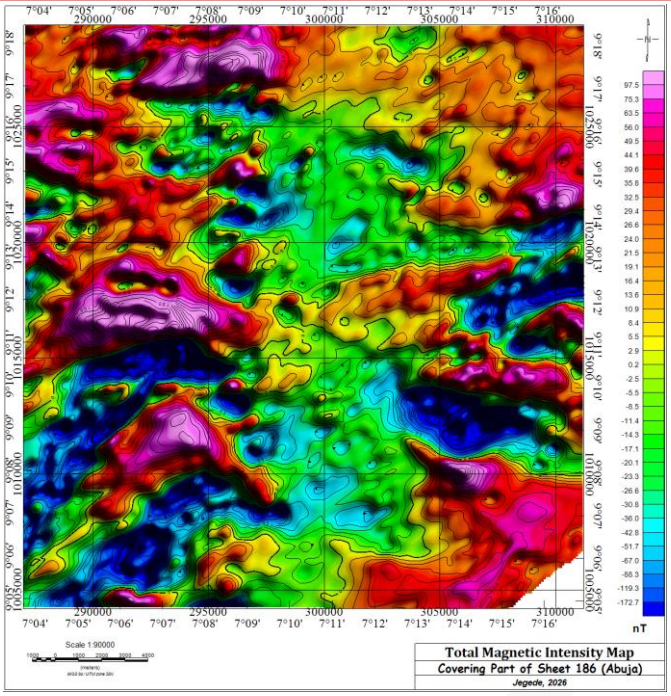

Figure 3: Total Magnetic Intensity Map covering part of sheet 186 (Abuja)

- **Magnetic highs** lie in the west, south-west, north-west, east-central area and east. They are probably competent, magnetite-bearing rocks. They are poor aquifers in themselves, but their margins and bounding fractures can be good targets.
- **Magnetic lows** lie in the south-east (7°13′–7°16′E, 9°05′–9°08′N), in an elongated E–W zone at 7°05′–7°08′E, 9°11′–9°12′N, in the extreme north-west and in the far southwest. They suggest weakly magnetic granitic gneiss or migmatite, or rock where weathering and fracturing have destroyed magnetite, which favours groundwater.
- A broad N–S corridor of intermediate values (7°10′–7°12′E) probably reflects uniform basement under thicker weathered cover.

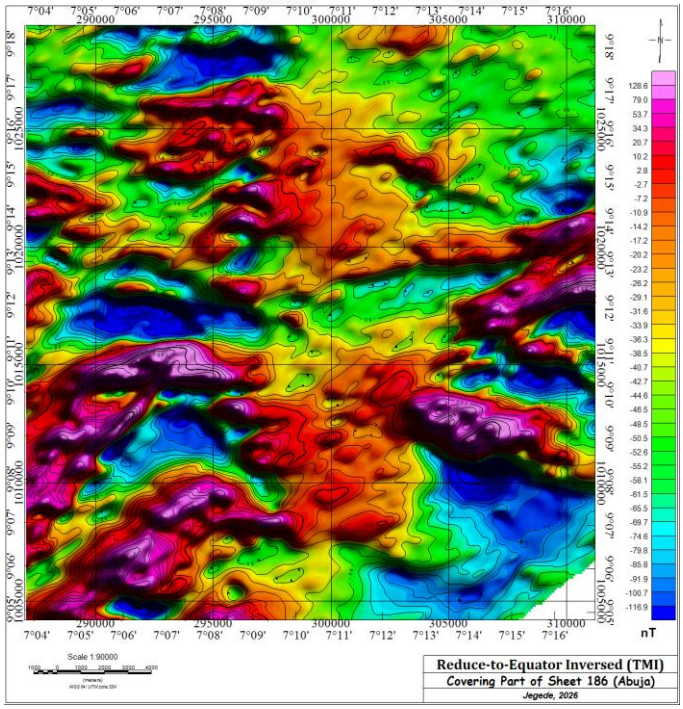

Figure: 4. Reduced – to- Equator Inversed Map

The dominant anomaly elongation is E–W to ENE–WSW with secondary NE–SW trends, consistent with the Pan-African grain.

5.3 Enhanced maps

- **Analytic signal (Figure 5).** Strong highs form an arcuate belt in the west that matches the DEM ridge, a N–S chain of rounded highs in the north-west, and the eastern bloc. These are shallow, strongly magnetic bodies. A broad low-amplitude zone covers the north-central and central area and the south-east, which means deeper or weakly magnetic basement and possibly thicker overburden.

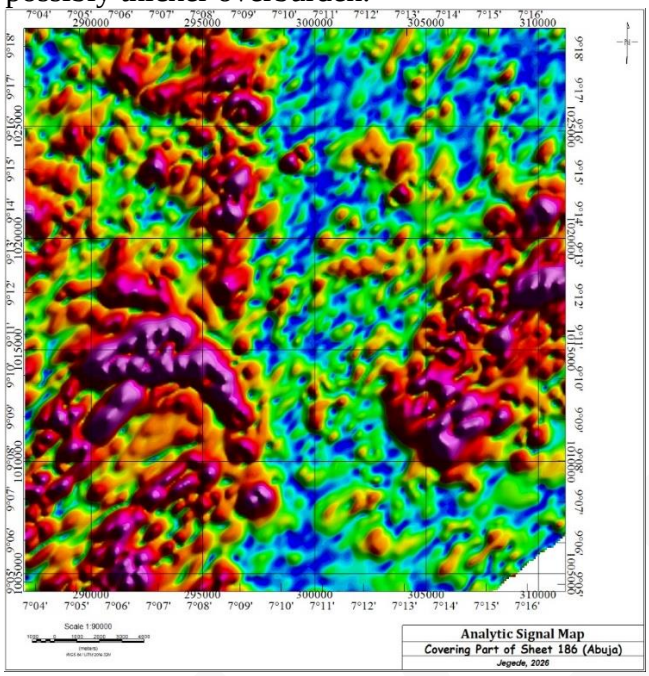

Figure 5: Analytic Signal Map

- **First and second vertical derivatives (Figures 6 and 7).** A dense fabric of narrow alternating highs and lows, mainly NE–SW to ENE–WSW, strongest in the west, southwest and north-west. It represents closely spaced dykes, foliation, fractures or shear zones.

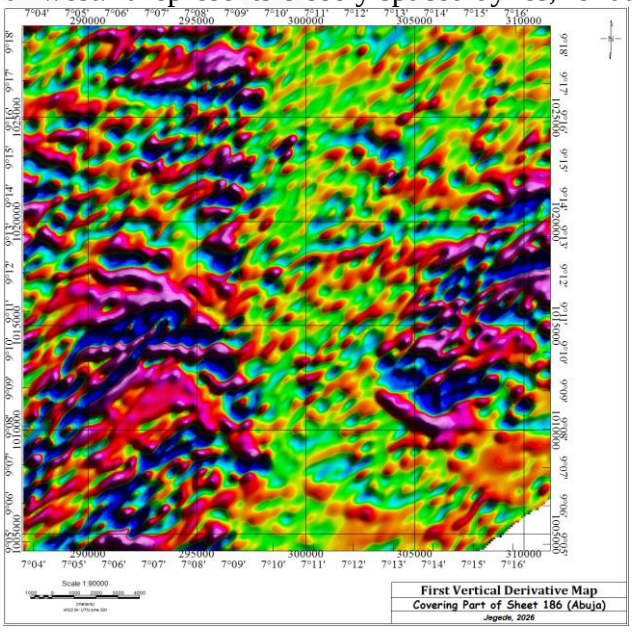

Figure 6: First vertical Derivative Map

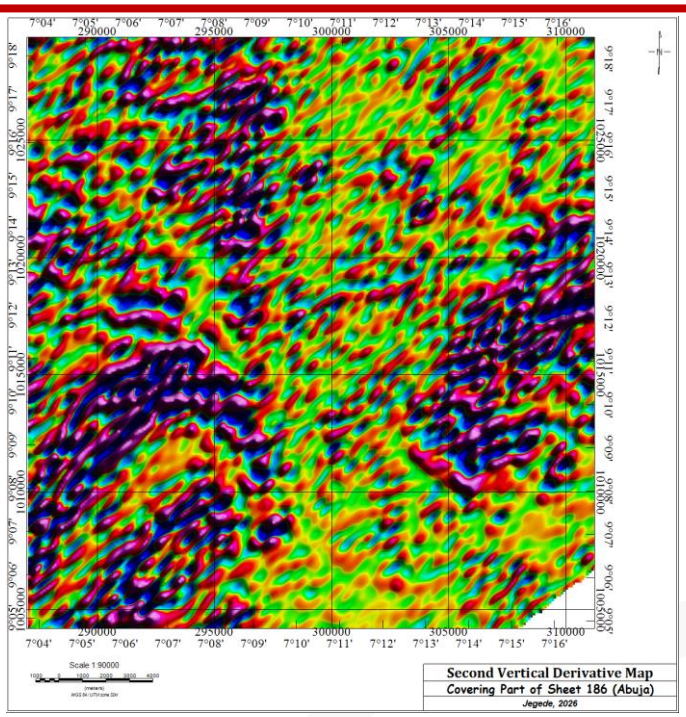

Figure 7: Second Vertical Derivative Map

- **Tilt derivative (Figure 8).** Zero contours show NE–SW and ENE–WSW lineaments dominating, with E–W and NW–SE secondary sets. The densest networks lie in the west, north-west and south-west. A low-tilt N–S to NNE corridor in the centre (about 7°10′–7°11′E, 9°12′–9°15′N) coincides with low analytic signal and may be fault controlled.

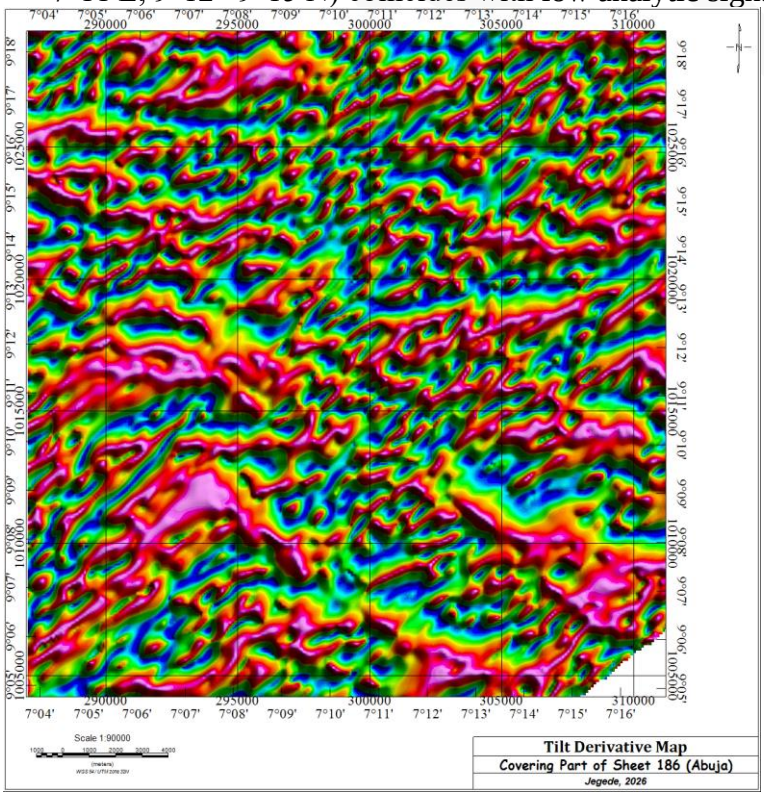

Figure 8: Tilt Derivative Map

5.4 Lineament sets

Lineaments that appear on several enhanced maps were compiled into five sets (Figure 9) Table 1

Table 1. Lineament sets and their hydrogeological role (coordinates approximate).

Set	Where	Notes	Hydrogeological role
N–S to NNE–SSW	West (about 7°05′–7°06′E), centre (about 7°10′E) and east (about 7°15′E), plus a shorter one at about 7°14′E	Longest through-going lineaments; the central one is about 18 km	Likely regional faults or fracture zones; long, connected conduits
NNW–SSE	About 7°12′E, 9°14′N to 7°13′30″E, 9°08′N	About 12 km, parallel to the NNW–SSE valleys of the west-central belt	Likely regional fracture zone
WNW–ESE to NW–SE	North, north-east and south-east	Cut across the older fabric	Link the longer sets and raise connectivity
Set	**Where**	**Notes**	**Hydrogeological role**
ENE–WSW to NE–SW	West, centre-east (7°11′–7°16′E, 9°11′–9°14′N), north-east and south-west	Matches the dominant derivative fabric	Pan-African grain; dense, closely spaced fractures
E–W	West (near 9°10′ and 9°12′N) and southern edge (near 9°06′N)	Shorter sets	Local conduits; bound the west-central E–W magnetic low

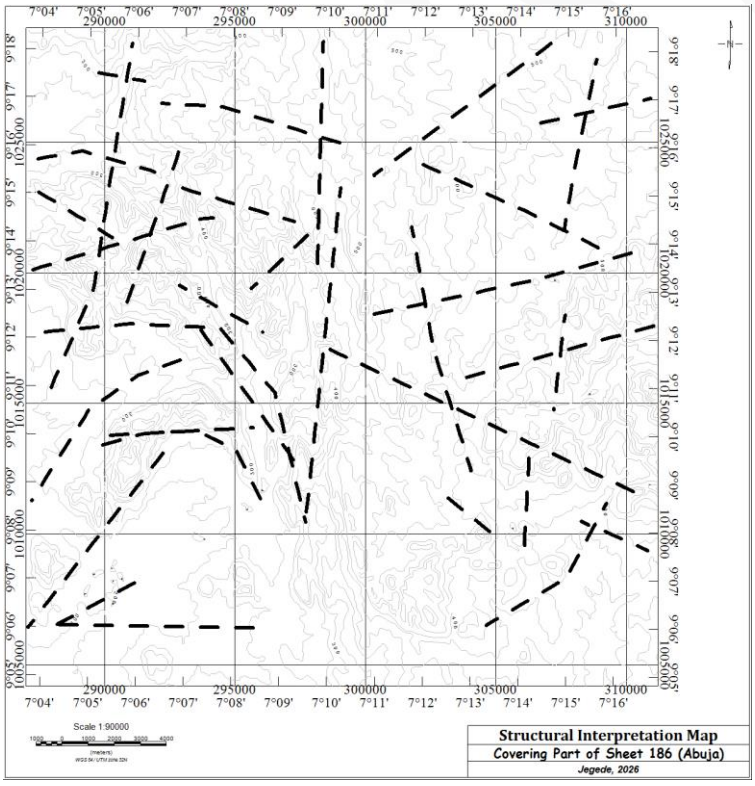

Figure 9: Structural (Lineament) Interpretation Map

Lineaments are most numerous and intersect most often in the west, north-west and south-west. The centre and south-east have fewer, longer ones. Where the long N–S and NNW–SSE features cross the ENE–WSW and WNW–ESE sets, as at about 7°10′E, 9°16′N, intersections favour deeper weathering and storage.

6. Groundwater Potential Zones

Three zones rank high for groundwater potential: the south-western basin, the south-eastern lowland and the west-central fracture corridor (Table 2).

Table 2. Groundwater potential zones (coordinates approximate).

Zone	Location	Supporting evidence	Potential
A. South-western basin	7°04′–7°09′E, 9°05′–9°10′N	Lowest ground, converging drainage, dense NE–SW lineaments, mix of magnetic highs and lows	High. Target flanks of magnetic bodies and the low at 7°07′–7°09′E, 9°08′– 9°10′N
B. South-eastern lowland	7°13′–7°16′E, 9°05′–9°08′N	Moderate relief, strong RTE and analytic signal lows, next to the eastern magnetic body	High to moderate
C. West-central fracture corridor	7°05′–7°10′E, 9°11′–9°13′N	E–W magnetic low between two highs, DEM scarps, many tilt and 2VD zero-crossings	High to moderate. Likely shear or contact zone
D. Central N–S corridor	7°09′–7°12′E, 9°09′–9°16′N	Low analytic signal, NNW–SSE lineaments, elevation about 380 to 470 m	Moderate. Thick regolith likely, water table deeper, so deeper boreholes
E. Strongly magnetic highlands	West arcuate ridge, north-west chain, eastern block	High analytic signal, high relief, massive competent rock	Low on the bodies; margins and bounding fractures are fair targets
F. North-eastern high ground	7°12′–7°16′E, 9°14′–9°18′N	Highest ground (above 480 m), low magnetic response	Low to moderate. Mainly a recharge area

Siting rule. A borehole site should meet at least three of four indicators: a lineament intersection on the tilt and vertical-derivative maps; a magnetic low or contact flank on the RTE map; low-lying or valley-floor topography; and low-to-moderate analytic signal. The strongest analytic signal anomalies lie over massive magnetic rock in the west, north-west and east, which are poor aquifers. The highest-ranked zones are those where fracturing combines with low relief and weakly magnetic rock.

7. In Situ Water Quality

Most in situ parameters sit near or beyond drinking-water limits in at least some samples, and the pattern points to human influence on top of a geogenic salinity signal (Table 3).

Table 3. In situ water-quality measurements, August 2026 (range and mean).

Parameter	Wells (n = 4)	River (n = 4)	Borehole (n = 1)	Guideline used
Temperature (°C)	23.5–29.4, mean 27.7	19.7–24.6, mean 22.0	28.1	29 (WHO)
pH	6.7–7.2, mean 6.95	7.4–8.1, mean 7.75	7.5	6.5–8.5
TDS (mg/L)	283–1,327, mean 878	218–603, mean 358	482	500
EC (µS/cm)	596–2,260, mean 1,495	474–1,449, mean 830	934	1,000
Turbidity (NTU)	1.3–100, mean 43.1	3.6–100, mean 19.5	3.6	5
Dissolved oxygen (mg/L)	5.32–8.91, mean 6.83	11–17.7, mean 14.0	12.5	5.0–6.5
ORP (mV)	174–250, mean 209	237–258, mean 249	268	+200 (oxic)

WHO and NSDWQ limits as used by the authors? TDS = total dissolved solids; EC = electrical conductivity; ORP = oxidation– reduction potential. [Maximum well EC of 2,260 µS/cm to be confirmed against the field record.]

Temperature and pH. Well water reaches 29.4 °C, marginally above the 29 °C limit used. Wells are near neutral and river water is mildly alkaline, all within the usual 6.5 to 8.5 range.
TDS and EC. Some wells and river samples exceed 500 mg/L TDS and 1,000 µS/cm EC. Using the Hem (1970) scheme, the median well (951 mg/L) is fresh, but the maximum well (1,327 mg/L) falls in the slightly saline class. The sampling fell in the rainy season, so dilution and heavy runoff from the Kwamba and Kwakoshe rivers probably understate dry-season values. The high conductivity in densely built-up areas points to household waste, effluent and leachate, with a geogenic contribution from weathered rock.

Turbidity. The median well reads 35.5 NTU against a 5 NTU limit. The likely causes are unlined wells, a timber shed near one well, surface runoff entering wells, farmland sediment, flooding of the Kwamba River and abattoir effluent in the Rafin Sanyi area. Turbid water can also carry attached bacteria and other contaminants.

Dissolved oxygen and redox. Well oxygen (5.3 to 8.9 mg/L) is adequate for aerobic life. River oxygen (11 to 17.7 mg/L) is above the roughly 8 to 9 mg/L at which water at 20 to 25 °C is saturated with air, so the river is supersaturated. The likely cause is photosynthesis by algae and aquatic plants in sunlit, shallow, nutrient-enriched stretches, with extra aeration where the flow is turbulent over rocky beds, and daytime readings would catch the oxygen peak. The values show a well-oxygenated river with no sign of oxygen depletion by organic waste at the sampling points at the time of sampling, which agrees with its positive ORP. Every ORP reading is positive (174 to 268 mV), which indicates oxidizing conditions. A full redox classification (McMahon and Chapelle, 2008) needs nitrate, manganese, iron and sulphate, which are not reported here. Oxidizing water gives little reducing capacity to attenuate nitrate along a flow path.

8. Vulnerability of Groundwater to Contamination

Vulnerability is highest where dense fracturing, low relief and shallow regolith wells coincide, which is the same ground that ranks best for yield: the south-western basin and the west-central fracture corridor first, then the south-eastern lowland.

8.1 Vulnerability by structural zone

The ratings in Table 4 rest on structure and terrain, with the in-situ results as general support. They are a screening, not a measured index.

Table 4. Vulnerability of the structural zones to contamination.

Zone	Yield potential	What raises vulnerability	What lowers it	Vulnerability
A. South-western basin	High	Lowest ground, converging runoff, dense NE–SW lineaments, discharge zone for the uplands	Possibly thicker regolith in the basin	Very high
C. West-central fracture corridor	High to moderate	Shear or contact zone, scarps, many open fractures, E–W lineaments	None identified	High to very high
B. South-eastern lowland	High to moderate	Low relief, weakly magnetic and probably well-weathered rock, WNW–ESE lineaments	Fewer lineaments, thicker regolith to attenuate contaminants	Moderate to high
D. Central N–S corridor	Moderate	Long N–S and NNW–SSE lineaments act as conduits over many kilometres	Thick regolith, deeper water table	Moderate
E. Strongly magnetic highlands	Low	Fractured margins and bounding fractures	Massive, low-permeability rock; runoff-dominated	Low on bodies, moderate along margins
F. North-eastern high ground	Low to moderate	Recharge area, so any contamination here moves downgradient	Highest ground, deep water table	Low to moderate

8.2 Protection measures

Siting. In zones A, B and C, case and grout boreholes through the full regolith, site them away from dumps, drains and abattoirs, and set the separation distance by tracer or resistivity survey rather than a rule of thumb. Prefer sites that meet the four-indicator rule in section 6.

Wells. Line and cover hand-dug wells, add an apron and drain, and keep timber sheds, latrines and refuse away from them.

Dumps and effluent. Do not site new dumps on lineaments, in drainage convergence or in zones A and C. Cap or line existing dumps, collect leachate, and treat abattoir effluent before it reaches the stream.

Monitoring. Monitor wells along the central N–S lineament and in each of zones A to C, sampled in both wet and dry seasons for major ions, nitrate, trace elements and microbes.
Interim use. Given the turbidity and conductivity exceedances, treat well, borehole and river water as unfit to drink without treatment until laboratory results confirm potability, and protect recharge ground in zone F.

9. Limitations and Further Work

- The groundwater potential zoning is qualitative. No borehole yields or resistivity soundings yet.
- A lineament is an interpreted feature, not proof of an open, water-bearing fracture. A magnetic low may mark weathering or simply weakly magnetic rock, and a low analytic signal may mean deep basement as well as thick regolith. The 30 m SRTM data cannot resolve small valleys.
- The water-quality data are in situ measurements from nine points in one season. Laboratory results for major ions, nutrients, trace elements and microbes are needed to identify contaminant sources.

Further work should test the ranked zones with vertical electrical soundings and electrical resistivity tomography across the main lineaments. Dumpsites, abattoirs, wells and boreholes should be mapped by GPS and overlaid on the zone map. With those data, the qualitative ratings can be replaced by an index method such as DRASTIC or GOD and checked against measured quality.

10. Conclusions

In the Suleja area the structures that store groundwater are the same ones that carry contaminants, so every borehole-siting decision should be paired with a protection decision.

- The basement is densely fractured in the west, north-west and south-west and less so in the centre and south-east. Five lineament sets cut the area, and the long N–S to NNE– SSW and NNW–SSE lineaments are the likely regional fracture zones.
- The south-western basin, the south-eastern lowland and the west-central fracture corridor have the highest groundwater potential. Strongly magnetic highlands are poor aquifers except along their margins.
- Shallow, unlined wells (2.6 to 5.7 m) in a thin regolith aquifer are exposed to runoff, leachate and effluent. Well turbidity (median 35.5 NTU) and conductivity exceed limits, and TDS exceeds 500 mg/L in some samples.
- All redox readings are positive (174 to 268 mV), so the water is oxidizing and has little natural capacity to attenuate nitrate.
- Vulnerability is very high in the south-western basin, high to very high in the west central corridor, moderate to high in the south-eastern lowland, and lower in the central corridor, the highland margins and the north-eastern recharge ground.

References

Ajibade, A. C., & Wright, J. B. (1989). The Togo–Benin–Nigeria Shield: evidence of crustal aggregation in the Pan-African belt. *Tectonophysics*, 165, 125–129.

Akano, O. J., Idris-Nda, A., & Waziri, S. H. (2016). Geology and hydrogeology of part of Suleja, North Central Nigeria. *Journal of Scientific Research and Reports*, 9(5), 1–15.

Ayoade, J. O. (2004). *Introduction to Climatology for the Tropics* (2nd ed.). Spectrum Books, Ibadan.

Blakely, R. J. (1995). *Potential Theory in Gravity and Magnetic Applications*. Cambridge University Press.

Dewandel, B., Lachassagne, P., Wyns, R., Maréchal, J. C., & Krishnamurthy, N. S. (2006). A generalized 3-D geological and hydrogeological conceptual model of granite aquifers controlled by single or multiphase weathering. *Journal of Hydrology*, 330(1–2), 260–284.

Grant, N. K. (1969). The Late Precambrian to Early Paleozoic Pan-African orogeny in Ghana, Togo, Dahomey and Nigeria. *Geological Society of America Bulletin*, 80, 45–56.

Hem, J. D. (1970). *Study and Interpretation of the Chemical Characteristics of Natural Water* (2nd ed.). U.S. Geological Survey Water-Supply Paper 1473.

Igboama, W. N., Hammed, O. S., Fatoba, J. O., et al. (2022). Review article on impact of groundwater contamination due to dumpsites using geophysical and physiochemical methods. *Applied Water Science*, 12, 130. https://doi.org/10.1007/s13201-022-01653-z

Kearey, P., Brooks, M., & Hill, I. (2002). *An Introduction to Geophysical Exploration* (3rd ed.). Blackwell Science.

[Key and Pitfield (2009): full reference to be completed by the authors.]

McMahon, P. B., & Chapelle, F. H. (2008). Redox processes and water quality of selected principal aquifer systems. *Ground Water*, 46(2), 259–271.

Miller, H. G., & Singh, V. (1994). Potential field tilt: a new concept for location of potential field sources. *Journal of Applied Geophysics*, 32(2–3), 213–217.

Nabighian, M. N. (1972). The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation. *Geophysics*, 37, 507–517.

Obaje, N. G. (2009). *Geology and Mineral Resources of Nigeria*. Springer, Berlin.

Ogezi, A. E. O. (1977). *Geochemistry and geochronology of basement rocks from northwestern Nigeria* (Unpublished PhD thesis). University of Leeds.

Olorunfemi, M. O., & Fasuyi, S. A. (1993). Aquifer types and the geoelectric/hydrogeologic characteristics of part of the central basement terrain of Nigeria (Niger State). *Journal of African Earth Sciences*, 16(3), 309–317.

Rahaman, M. A. (1988). Recent advances in the study of the basement complex of Nigeria. In *Precambrian Geology of Nigeria* (pp. 11–43). Geological Survey of Nigeria, Kaduna.

Rajagopalan, S. (2003). Analytic signal vs. reduction to pole: solutions for low magnetic latitudes. *Exploration Geophysics*, 34(4), 257–262.

Roest, W. R., Verhoef, J., & Pilkington, M. (1992). Magnetic interpretation using the 3-D analytic signal. *Geophysics*, 57(1), 116–125.

Verduzco, B., Fairhead, J. D., Green, C. M., & MacKenzie, C. (2004). New insights into magnetic derivatives for structural mapping. *The Leading Edge*, 23(2), 116–119.

Wright, E. P. (1992). The hydrogeology of crystalline basement aquifers in Africa. In E. P. Wright & W. G. Burgess (Eds.), *Hydrogeology of Crystalline Basement Aquifers in Africa* (Geological Society Special Publication 66, pp. 1–27).