

Hydrogeochemical And Spatial Distribution of Heavy Metals in Groundwater in Auta Balefi, Northcentral, Nigeria

ABDULMALIK SADIQQ ABDULLAHI-TAHIR¹, IBRAHIM LAPIYA BATAT², PEACE YAKUBU GALADIMA³, EGGA VEREM DAMALU⁴, AMBORE EUNICE IBRAHIM⁵, AUGUSTINA AYIABO MAIYA⁶, AKULAGA TERFA⁷, ISHAYA ESTHER HABU⁸, SAMSON MANDONG PHILIBUS⁹, EDE JOSHUA YAKUBU¹⁰

¹ Geosmart Digital Solutions Ltd, National Centre for Remote Sensing Jos, Plateau state, Nigeria

² Disaster and Environmental Management Department, National Centre for Remote Sensing, Jos

³ Clinic Unit (Directorate), National Centre for Remote Sensing, Jos, Plateau state, Nigeria

⁴ Water Resources and Climate Department, National Centre for Remote Sensing, Jos, Nigeria

^{5,6,7,8,9,10} Department of Geology, Federal University Lafia, Nasarawa state, Nigeria.

Abstract- Water resource pollution is an issue of great concern globally. Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) enter groundwater systems from leaching from rocks, and the activities of man like agriculture, mining, industrial activities, waste disposal, etc. This study is carried out at Auta Balefi, North-Central, Nigeria. A total of 25 water samples were collected (10 from boreholes - BH, and 15 from hand-dug wells – HDW), with the aim of determining the concentration of heavy metals in the water (by geochemical analysis) and their spatial distribution in the area (using remote sensing and GIS). After analysis of heavy metals concentration in groundwater, they are projected in spatial distribution maps for estimating and monitoring the quality of groundwater at study area. Analysis showed most of the heavy metals analysed were within the permissible limit in drinking water by Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organisation (WHO). Arsenic, Lead and Selenium have concentrations in some locations beyond the permissible limit in drinking water by NSDWQ and WHO, with the range of 0.002-0.578, 0.002-0.159 and 0.034-0.765mg/L, respectively. Spatial analysis showed the distribution of the heavy metals in the groundwater of Auta Balefi is of higher concentration in the north-western and south-eastern part of the area.

Keywords: Heavy Metals, Groundwater, Spatial Distribution, Hydrogeochemical, Nigeria

I. INTRODUCTION

Water is one of the essential resources that is very much used all over the world for different purposes such as domestic uses, industrial uses, irrigation in agriculture, fish ponds, etc. As such, it is important to have quality water for domestic use to promote good human health (Ramesh & Elango, 2011).

Water is not pure, in nature, as it gets contaminants from its surrounding and from activities around it (Mendie, 2005). Water is able to dissolve, absorb, adsorb or hold different compounds in suspension, due to its polarity and hydrogen bonds (WHO, 2007).

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) enter groundwater systems from industrial effluents, agricultural runoff, mining activities, and natural geochemical processes (Murariu et al., 2025).

These metals can persist in the subsurface for a very long time, affecting water quality and posing great risks to human health (Narayanan et al., 2025). Some of the landuse/landcover (LULC) types are associated with some human activities having some characteristics that can affect the quality of water ((Mukherjee et al. 2009; Gupta and Srivastava 2010; Srivastava et al. 2010, 2011; Jaiswal et al. 1999; Singh et al. 2010). Groundwater is vulnerable to point and non-point sources of pollution because of

its close connection to the landscape and landuse (Scanlon et al. 2005; Lerner and Harris 2009; Tong and Chen 2002).

The major non-point sources of groundwater pollution from LULC types are agricultural activities and builtup - industrial and domestic activities ((Basnyat et al. 1999, 2000; Behera and Panda 2006).

The existence of heavy metals in water could be of natural origin (mineral dissolution, volcanism products) or from anthropogenic sources (solid wastes disposal). Heavy metals contamination of water resources is of great concern as they could be strongly toxic, even at low concentrations (Marcovecchio et al., 2007).

Remote sensing has spatial, spectral and temporal availability of data, making it useful in evaluating groundwater (Sener et al. 2005; Chowdary et al. 2009; Tweed et al. 2007; Yeh et al. 2009).

GIS has become an effective tool in the analysis and integration of spatial and non-spatial data to get important outputs (Gupta and Srivastava 2010; Srivastava et al. 2012; Patel et al. in press). Integrating remote sensing data with GIS can help in delineating contamination pathways and simulating pollutant transport in aquifers (Murariu et al., 2025).

II. MATERIALS AND METHODS

Groundwater samples used for the analysis were collected from twenty-five different sites (10 boreholes and 15 hand-dug wells). The samples collection was done in the month of April, between 8:00 A.M – 2:00 P.M, ensuring that all the samples were collected and treated in accordance with the (ASTM, 2004; APHA, 2005).

Water from the boreholes were allowed to flow freely for about 3 minutes before it was being collected. The concentrations of Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Selenium and Zinc were determined using Microwave Plasma Atomic Emission Spectroscopy (MP-AES) at the Multipurpose Laboratory, Ahmadu Bello University, Zaria, Nigeria.

The drainage of the area was extracted from Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) of the area, using ArcGIS software, and the 3D model of the topography was generated from the DEM using ESRI ArcScene software (figure 1).

III. RESULTS AND DISCUSSION

The values, in milligrams per litre (mg/L), of the concentrations of the heavy metals in the groundwater from the study area is presented in table 1.

Arsenic (As)

Arsenic is used in semiconductor electronic devices. It is also used in the production of pesticides, herbicides and insecticides. Improper disposal of such materials may lead to groundwater getting contaminated with arsenic (<https://ww2.health.wa.gov.au/Articles>; <https://www.h2odistributors.com/pages>).

The concentration of arsenic in groundwater in the study area ranges from 0.002 mg/L to 0.578 mg/L. Several of the locations have concentrations greater than the WHO and NSDWQ limit of 0.01 mg/L. These locations include BH1, BH5, BH6, BH9, BH10, HDW1, HDW6, HDW7, HDW9, HDW13, and HDW15.

Cadmium (Cd)

Cadmium can get into groundwater from mining operations, use of phosphate fertilizers, improper disposal of paint pigments, etc. Prolonged exposure or high intake of cadmium can cause lung damage, kidney disease, bone weakening, etc. (www.idph.state.il.us/factsheets; <https://lenntech.com/elements>).

The WHO and NSDWQ limit for cadmium in drinking water is 0.003 mg/L. Cadmium concentration in groundwater of the area ranges from 0.001 mg/L to 0.033 mg/L.

Chromium (Cr)

Groundwater contamination may occur as a result of improper disposal of mining tools and supplies. High intake of Chromium VI may cause ulcers, nose

bleeding, weakened immune system, alteration of genetic materials, and damage to liver and kidney, formation of tumours, birth defects, infertility, etc (<https://www.lenntech.com/periodic/ch...>;

https://serc.carleton.edu/case_studies). The WHO and NSDWQ limit for chromium in drinking water is 0.05 mg/L. The concentration of chromium in the area ranges from 0.001 mg/L to 0.007 mg/L.

Copper (Cu)

Water may be contaminated with copper through mining operations, pesticides used on farms, municipal or industrial waste water released into rivers, etc. When copper is consumed in high levels, it can lead to nausea, vomiting, diarrhea, and headaches. (<https://www.health.state.mn.us/water>; <https://ww2.health.wa.gov.au/Articles>). The WHO limit for copper in drinking water is 1.0 mg/L while the NSDWQ limit is 2.0 mg/L. The concentration of copper in the area ranges from 0.001 mg/L to 0.008 mg/L.

Iron (Fe)

Iron is considered a secondary or aesthetic contaminant. High ferrous iron in water gives it a metallic taste. When such water is used in making beverages, it turns black and has a bad taste.

Vegetables cooked with this kind of water turns dark (<https://www.pbwatersoftening.com/5-h...>). The concentration of iron in the area ranges from 0.016 mg/L to 4.107 mg/L. Locations with concentration of iron greater than the WHO and NSDWQ limit of 0.3 mg/L include BH6, BH7, HDW7, HDW8, HDW9, HDW10, and HDW11.

Lead (Pb)

The sources of lead in groundwater include poorly disposed paint, gasoline, batteries, building materials, etc. When children are exposed to lead (even at low levels), they can experience several adverse effects.

These include damage to the central and peripheral nervous system, learning disabilities (lower IQ), shorter stature, impaired hearing, and anemia (poor formation and function of blood cells).

Lead accumulation in pregnant women can cause reduced growth of the foetus and premature birth (<https://www.epa.gov/basic-information-...>). Lead concentration in the area ranges from 0.002 mg/L to 0.159 mg/L. Locations that show high lead concentration (beyond the WHO and NSDWQ limit of 0.01 mg/L) include BH5, BH7, HDW4, HDW6, HDW8, and HDW10.

Selenium (Se)

Exposure to high levels of selenium can cause changes to hair and fingernails or lead to their loss. It can also cause damage to the peripheral nervous system, high case of numbness and circulation problems (<https://www.freedrinkingwater.com/sele...>;

<https://www.h2odistributors.com/pages>). Selenium concentration in the area ranges from 0.034 mg/L to 0.765 mg/L. All the locations except BH2, BH3, HDW1, HDW3, HDW4 and HDW5 have selenium concentration greater than the WHO limit of 0.04 mg/L.

Zinc (Zn)

It can get into groundwater from mining activities and through improper disposal of zinc containing wastes from industries. Zinc is essential for growth and metabolism. Too little zinc can cause loss of appetite, slow wound-healing, decreased sense of taste and smell, etc.

Prolonged intake of high zinc concentration can cause anemia, nervous system disorders, and damage to the pancreas. The WHO limit for zinc in drinking water is 5.0 mg/L while the NSDWQ limit is 3.0 mg/L. Concentration of zinc in the area ranges from 0.013 mg/L to 0.093 mg/L.

Table 1: Groundwater Heavy Metals Concentration values

Sample location no.	As	Cd	Cr	Cu	Fe	Pb	Se	Zn
BH1	0.578	0	0.001	-0.005	0.3	0.033	0.149	-0.013
HDW1	0.265	0.002	0	-0.006	0.083	0.041	0.034	-0.018
HDW2	-0.043	0.002	0	-0.007	0.127	0.079	0.106	-0.023
HDW3	0.014	0.001	0.001	-0.004	0.088	0.04	0.063	-0.026
HDW4	-0.006	0.001	0	-0.002	0.481	0.11	0.067	-0.03
HDW5	-0.049	0.001	0.002	-0.008	0.118	0.002	0.07	-0.025
BH2	-0.016	0	0.002	-0.002	0.09	0.008	0.073	0.093
BH3	-0.014	-0.001	0.001	-0.007	0.047	0.038	0.075	-0.027
BH4	0.032	0.002	0.002	-0.008	-0.019	-0.017	0.106	-0.028
BH5	0.086	-0.001	0.001	-0.004	0.089	0.09	0.136	-0.031
BH6	0.122	-0.002	0.002	-0.003	1.139	0.061	0.136	-0.024
BH7	0.126	-0.002	0.004	-0.001	3.305	0.07	0.177	0.046
HDW6	0.083	-0.002	-0.002	-0.004	0.206	0.05	0.175	-0.03
HDW7	0.141	-0.001	0.002	-0.004	1.334	0.017	0.107	-0.021
HDW8	0.212	-0.003	0.001	-0.005	1.349	0.06	0.2	-0.018
HDW9	0.187	-0.003	0	-0.007	0.714	0.006	0.176	-0.024
HDW10	0.203	-0.004	0.003	-0.006	1.817	0.159	0.765	0.016
HDW11	0.002	0.001	0.007	-0.003	4.107	0.011	0.195	-0.015
BH8	0.008	0.002	0.002	-0.008	0.081	-0.017	0.159	-0.031
HDW12	0.068	-0.001	-0.001	-0.003	0.096	0.028	0.243	-0.025
HDW13	0.198	0	-0.002	0.001	0.364	0.052	0.249	-0.026
BH9	0.207	-0.001	-0.002	-0.004	0.06	0.009	0.33	0.017
HDW14	0.33	-0.033	-0.002	-0.003	0.159	0.044	0.375	-0.033
HDW15	0.447	-0.002	-0.004	-0.003	0.016	0.015	0.362	-0.03
BH10	0.42	-0.004	-0.005	-0.005	0.171	0.042	0.487	-0.031

All measurements in mg/L.

The south-eastern part of Auta Balefi and environs (especially HDW15) shows more enrichment in Arsenic (table 1 and figure 2). Areas in the north-western part of the study area show a higher enrichment in lead concentration (figure 3). Parts of the north-west and parts of the south-east of the study area show a higher enrichment in selenium concentration than other parts (figure 4).

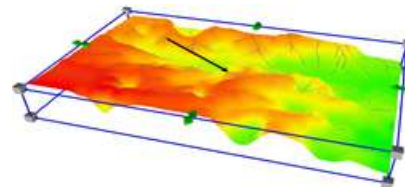


Figure 1: 3D model of Auta Balefi and Environs showing drainage and flow direction (the colours show the topography, with red being the highest, followed by yellow; green is the lowest elevation of the three colours. The blue lines are the drainage lines, and the arrow shows the direction of flow of water in the area, NW-SE direction).

IV. CONCLUSION

Water resource pollution is an issue of great concern globally. Remote sensing and GIS were essential and effective tools for spatial analysis and interpretation of the heavy metals' distribution in the groundwater of Auta Balefi and environs. Geochemical analysis of the groundwater samples showed some locations within the study area showed concentrations in Arsenic, Lead and Selenium higher than the permissible limit for drinking water by the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO).

Remote sensing and GIS showed the locations with the high concentrations of these heavy metals (Arsenic, Lead, and Selenium) to be the north-western and south-eastern parts of Auta Balefi. Continuous monitoring of the areas indicating signs of pollution should be done to re-assess the heavy metals enrichment of the area, and dumpsites should be sited far from settlements to avoid contamination and/or pollution of groundwater resources.

REFERENCES

- [1] APHA (2005). Standard Methods for the examination of water and waste water, 21ST ed. American Public Health Association. APHA: Washingto, D.C.
- [2] American Society for Testing and Material (2004). Annual book of ASTM standards, water and environmental technology, vol.11.01, water (i) ASTM International, West Conshohocken, PA
- [3] Basnyat P, Teeter LD, Flynn KM, Lockaby BG (1999) Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. *Environ Manage* 23(4):539–549
- [4] Basnyat P, Teeter L, Lockaby B, Flynn K (2000). The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *For Ecol Manage* 128(1–2):65–73
- [5] Behera S, Panda R (2006) Evaluation of management alternatives for an agricultural watershed in a sub-humid subtropical region

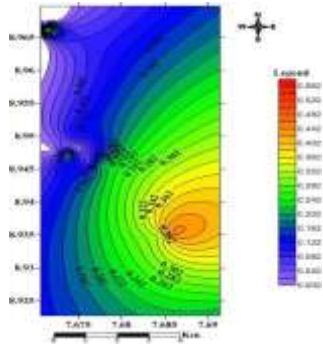


Figure 2: Map of spatial distribution of Arsenic in Auta Balefi and environs

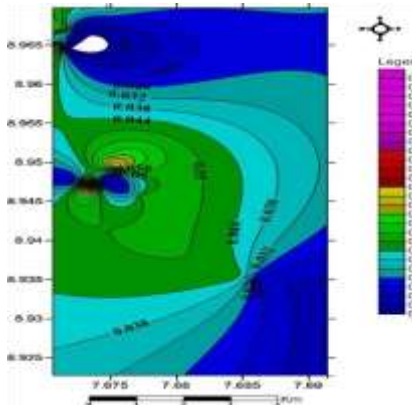


Figure 3: Map of Lead distribution in Auta Balefi and environs.

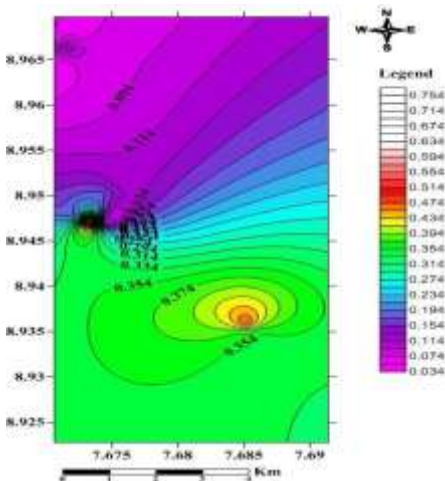


Figure 4: Map of Selenium distribution in Auta Balefi and environs.

- using a physical process-based model. *Agricultural Ecosystems* 113 (1–4):62–72
- [6] Chowdary V, Ramakrishnan D, Srivastava Y, Chandran V, Jeyaram A (2009) Integrated water resource development plan for sustainable management of Mayurakshi watershed, India using remote sensing and GIS. *Water Resources Management* 23(8):1581–1602
- [7] Gupta M, Srivastava PK (2010) Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. *Water International* 35(2):233–245
- [8] Jaiswal RK, Saxena R, Mukherjee S (1999) Application of remote sensing technology for land use/land cover change analysis. *Journal of Indian Society for Remote Sensing* 27(2):123–128
- [9] Lerner DN, Harris B (2009). The relationship between land use and groundwater resources and quality. *Land Use Policy* 26:S265–S273. doi: 10.1016/j.landusepol.2009.09.005
- [10] Marcovecchio, J.E, Botte, S.E, & Freije, R.H (2007). Heavy Metals, Major Metals, Trace Elements, in, *Handbook of Water Analysis*. Nollet, L.M. (Ed.). 2nd Edn. London: CRC Press (2007) pp. 275–311.
- [11] Mendie, U (2005). The Nature of Water, In, *The Theory and Practice of Clean Water Production for Domestic and Industrial Use*, Lagos: Lacto-Medals Publishers (2005) pp. 1–21.
- [12] Mukherjee S, Shashtri S, Singh C, Srivastava PK, Gupta M (2009) Effect of canal on land use/land cover using remote sensing and GIS. *Journal of Indian Society for Remote Sensing* 37(3):527–537
- [13] Murariu, G., Stanciu, S., Dinca, L., & Munteanu, D. (2025). GIS applications in monitoring and managing heavy metal contamination of water resources. *Applied Sciences*, 15(19), 10332. doi.org
- [14] Narayanan, M. S. S., Pitchaimani, V. S., Sivakumar, M., Dinesh Kumar, T., & Abishek, S. R. (2025). Spatial assessment of heavy metal contamination in groundwater in the Kadaladi region, Tamil Nadu, India. *Scientific Reports*, 15, 27704. doi.org
- [15] Ramesh K. & Elango L., (2011): Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. *Environmental monitoring and assessment*. 184: 3887–99.
- [16] Scanlon BR, Reedy RC, Stonestrom DA, Prudic DE, Dennehy KF (2005) Impact of land use and land cover change on groundwater recharge and quality in the southwestern US. *Global Change Biology* 11(10):1577–1593
- [17] Sener E, Davraz A, Ozcelik M (2005). An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. *Hydrogeology Journal* 13(5):826–834
- [18] Singh SK, Singh CK, and Mukherjee S (2010) Impact of land-use and land cover change on groundwater quality in the Lower Shiwalik hills: a remote sensing and GIS based approach. *Central European Journal of Geosciences* 2 (2):124–131.
- [19] Srivastava PK, Mukherjee S, Gupta M (2010) Impact of urbanization on land use/land cover change using remote sensing and GIS: a case study. *International Journal of Ecology and Environmental Statistics* 18(S10):106–117
- [20] Srivastava PK, Mukherjee S, Gupta M, Singh S (2011) Characterizing monsoonal variation on water quality index of river Mahi in India using Geographical Information System. *Water Quality Exposure Health*: 1–11
- [21] Srivastava PK, Kiran G, Gupta M, Sharma N, Prasad K (2012) A study on distribution of heavy metal contamination in the vegetables using GIS and analytical technique. *International Journal of Ecology and Development* 21(1):89–99
- [22] Tong STY, Chen W (2002) Modeling the relationship between land use and surface water quality. *Journal of Environmental Management* 66(4):377–393
- [23] Tweed SO, Leblanc M, Webb JA, Lubczynski MW (2007). Remote sensing and GIS for mapping groundwater recharge and discharge areas in salinity prone catchments, southeastern Australia. *Hydrogeology Journal* 15(1):75–96
- [24] World Health Organisation (2007). *Water for Pharmaceutical Use*, In, *Quality Assurance of Pharmaceuticals: A Compendium of Guidelines and Related Materials*, 2nd Updated Edn.
- [25] Yeh HF, Lee CH, Hsu KC, Chang PH (2009). GIS for the assessment of the groundwater recharge potential zone. *Environmental Geology* 58 (1):185–195.