International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 10, Issue 8, pp 79-94, August-2026

https://doi.org/10.47001/IRJIET/2026.108009

Spatial Mapping and Proximity Assessment of Groundwater Sources and Dumpsites within FUTA and Its Environs

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***Abstract* - Groundwater is an essential source of freshwater for domestic, agricultural and institutional activities, particularly in rapidly developing environments. However, close occurrences of open dumpsites and groundwater sources can increase the potential risk of contamination. This study mapped dumpsites/septic tanks, boreholes and hand-dug wells spatial proximity within the Federal University of Technology, Akure (FUTA) and surrounding communities. GPS receiver and Mobile Topographer application were used in data collection, resulting to identification of 89 dumpsites, 76 boreholes, 100 hand-dug wells, 100 septic tanks and 121 water reservoirs. Database were organized and analyzed in QGIS-Geo-Package, using the Universal Transverse Mercator (UTM) Zone 31N coordinate system. Buffer zones of 100, 250 and 500 m were generated around dumpsites, while Euclidean distance analysis was used to determine the distance of each groundwater source from its nearest dumpsite. The results revealed that distances ranged from 2.18 to 427.18 m; with Mean nearest-dumpsite distances of 87.92 m for boreholes and 74.56 m for hand-dug wells. Out of the 176 groundwater sources analyzed, 131 (74.4%) were located within 100 m of a dumpsite, 36 (20.5%) occurred between 100 and 250 m, and 9 (5.1%) between 250 and 500 m respectively. However, none was located beyond 500 m. Given the recommended minimum separation distance of 100 m, most groundwater sources require closer environmental attention. Therefore this study is hereby recommended for adoption, with the view to supporting buffer zones enforcement, prioritizing water-quality testing at high-risk locations, and using the geospatial database to guide future groundwater and waste-management planning.**

Keywords: Groundwater Sources; Dumpsites; Spatial Proximity; Geographic Information System (GIS); Environmental Risk Assessment.

I. INTRODUCTION

Groundwater is an important source of water for domestic and institutional activities in many developing urban environments [15]. Where groundwater sources occur within the same environment as uncontrolled waste-disposal facilities, their spatial relationship becomes an important consideration for environmental protection and water-resource management. GIS provides an effective framework for mapping existing groundwater sources and waste-disposal facilities and evaluating their spatial relationships ([2]; [10]; [15]).

Dumpsites can generate leachate capable of migrating through soil and subsurface materials and potentially affecting groundwater. Geophysical and physicochemical investigations have demonstrated the usefulness of electrical resistivity, geochemical analysis, and integrated approaches for identifying and evaluating leachate-related impacts ([1]; [6]; [7]; [12]).

Spatial proximity is particularly useful as an initial screening criterion because groundwater sources located close to dumpsites may warrant priority investigation. However, proximity alone does not demonstrate contamination, since contaminant migration is also controlled by geological, soil, terrain, and hydrogeological conditions ([14]; [8]).

Evidence from Nigeria further demonstrates the relevance of the groundwater–dumpsite relationship. [9]Examined the effects of major solid-waste dumpsites on water sources in Mubi, while [15] demonstrated the importance of

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incorporating groundwater geopollution considerations into waste-dump siting.

In Akure, [13]) investigated the Ijemikin waste dump using integrated geophysical and hydrochemical techniques and reported evidence of groundwater and subsurface conditions associated with waste-derived contamination. This local evidence establishes the relevance of dumpsite–groundwater interactions but does not provide a comprehensive spatial inventory of existing groundwater sources and dumpsites across FUTA and its environs.

1.1 Literature Review

Previous research on groundwater-related spatial assessment has largely concentrated on groundwater quality, vulnerability, or potential rather than on comprehensive inventories of existing groundwater sources. [2] Demonstrated the application of GIS and remote sensing to the spatial distribution of groundwater-quality indices, while [3] used geostatistical modelling to investigate the spatial distribution of groundwater-quality parameters. [8] Similarly applied spatial analysis and GIS to identify groundwater-quality hotspots and potential health risks. These studies demonstrate that groundwater-related information can be effectively analyzed as spatial data.

Although these studies demonstrate the value of spatial techniques for groundwater assessment, their emphasis is primarily on the spatial behaviour of groundwater-quality variables. They do not directly address the question of how existing groundwater abstraction sources are spatially distributed relative to dumpsites. This distinction is important because the present study does not seek to predict groundwater potential or interpolate water-quality parameters; rather, it evaluates the proximity of mapped groundwater sources to mapped dumpsites.

However, these investigations primarily addressed groundwater quality or risk characteristics rather than establishing a comprehensive inventory of existing groundwater abstraction sources and their distances from dumpsites. The present study therefore shifts the emphasis from groundwater-quality interpolation to the spatial relationship between existing water sources and waste-disposal facilities.

[10] Examined the spatial distribution and landscape impacts of waste dumpsites, while [15] incorporated groundwater geo-pollution considerations into GIS-based waste-dump/landfill siting. [7] Further demonstrated the value of spatial analysis for assessing leachate penetration around a dumpsite.

[1] Investigated leachate pathways using geoelectrical methods, whereas [6] reviewed geophysical and physicochemical approaches to dumpsite-related groundwater contamination. [12] Combined chemical and geophysical evidence to investigate contamination behaviour in water and soil. These studies collectively demonstrate that spatial proximity provides an important screening basis, but detailed confirmation of contamination requires additional environmental evidence.

[14] Specifically investigated groundwater vulnerability to open dumpsites using electrical resistivity and water analysis. Their approach demonstrates the value of combining spatial relationships with geophysical and physicochemical evidence rather than relying on proximity alone.

[9] Provided further Nigerian evidence by examining the relationship between major solid-waste dumpsites and water sources in Mubi. Together, these studies demonstrate the environmental relevance of groundwater–dumpsite proximity while also revealing the need for spatially explicit inventories of existing groundwater sources.

The Nigerian and Akure contexts are particularly relevant to the present study. [9] Reported environmental effects associated with major solid-waste dumpsites and water sources in Mubi, Nigeria. In Akure, [13] used integrated geophysical and hydro chemical investigations to assess the influence of the Ijemikin waste dump on groundwater quality. While these studies provide valuable evidence of groundwater–dumpsite interactions, the available literature does not provide a comparable comprehensive spatial inventory of existing boreholes and hand-dug wells against the distribution of dumpsites across FUTA and its adjoining communities.

The literature therefore establishes three important points. First, dumpsites can represent potential sources of groundwater degradation. Second, GIS provides an effective means of documenting and analyzing their spatial distribution. Third, actual contamination cannot be inferred from proximity alone and requires field-based environmental investigation. These observations provide the basis for the present spatial mapping and proximity assessment.

1.2 Problem Definition

Previous studies have established the potential relationship between waste-disposal facilities and groundwater resources and have demonstrated the value of GIS, geophysical and hydro-chemical techniques for investigating such relationships ([6]; [15]; [14]). However, most existing investigations have focused on individual dumpsites,

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Volume 10, Issue 8, pp 79-94, August-2026

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groundwater-quality assessment, geophysical characterization, or the suitability of waste-disposal locations.

Consequently, a spatial information gap remains concerning the combined distribution of existing groundwater sources and dumpsites at the campus–community scale. This is particularly relevant within FUTA and its environs, where the expansion of residential and institutional activities has resulted in the coexistence of groundwater abstraction points and informal waste-disposal locations.

The problem addressed by this study is therefore not the prediction of groundwater occurrence or potential zones, but the lack of a spatially explicit baseline showing the locations of existing groundwater sources, the locations of existing dumpsites, and the distances separating them.

To address this problem, the study employs field-based spatial inventory, GNSS positioning, GIS database development, spatial overlay, nearest-dumpsite distance analysis, and buffer-based proximity assessment. The resulting spatial framework is used to identify groundwater sources that warrant prioritizing environmental investigation.

Essentially, the approach treats proximity as a potential-risk screening indicator rather than as direct evidence of groundwater contamination. This distinction is consistent with previous studies showing that contaminant migration is influenced by subsurface and hydrogeological conditions in addition to horizontal distance ([1]; [14]).

II. METHODOLOGY / APPROACH

The study adopted a GIS-based approach to map groundwater sources and dumpsites and assess their spatial relationship within FUTA and its surrounding communities. The field observations provided the primary spatial data, which were subsequently organized, analyzed and visualized using GIS.

A reconnaissance survey was conducted to identify and locate groundwater sources, dumpsites and other relevant environmental features. Boreholes and hand-dug wells were surveyed using GNSS equipment, while dumpsites and septic-tank locations were also recorded. Each feature was assigned a unique identification code for effective data management. In total, 297 groundwater sources and 189 dumpsite/septic-tank locations were documented.

The field coordinates were compiled into a GIS database and processed in QGIS Pro using the UTM Zone 31N coordinate system. Distribution maps were produced for the groundwater sources and waste-disposal sites, and the datasets were overlaid to examine their spatial relationship. A Digital Elevation Model (DEM) was also used to characterize the terrain. It was processed to derive slope, aspect, flow direction and flow accumulation, providing information on terrain conditions and potential surface-water movement.

Euclidean distance analysis was applied to determine the proximity of groundwater sources to dumpsites. The proximity results were assessed together with slope and flow accumulation to identify locations requiring greater environmental attention. A weighted spatial index was subsequently developed, assigning 40% to distance from contamination sources, 35% to flow accumulation and 25% to slope. The resulting index classified areas according to their relative potential for interaction between groundwater sources and dumpsites.

2.1 Study Area

The study was conducted within Akure South Local Government Area, Ondo State, in the South-Western region of Nigeria. It falls within latitudes 7°12'N and 7°25'N and longitudes 5°12'E and 5°40'E. The area lies within the tropical rainforest zone of southwestern Nigeria and is characterized by a gently undulating terrain underlain by Precambian Basement Complex rocks. Topographic elevations in the area range from approximately 260m to 470m above mean sea level [16]. These environmental and geological characteristics significantly influence groundwater flow, contaminant migration, and the vulnerability of boreholes and dug wells in the study area.

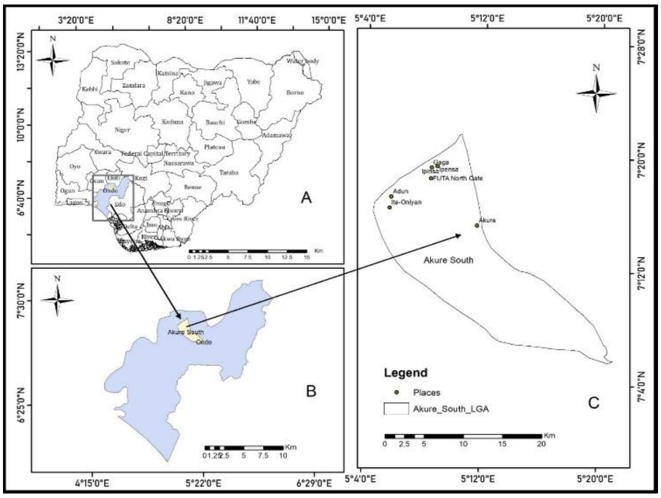

Figure 1: Map of the Study Area: (a). Nigeria (b). Ondo State (c). Akure South LGA. Source: Author's Compilation as modified from [18]

2.2 Data Type and Sources

The study utilized both primary and secondary spatial datasets. These consisted of GPS coordinates of groundwater sources, boreholes, dug-wells, as well as dumpsites.

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Meanwhile, the secondary data comprises of SRTM Digital Elevation Model (DEM), satellite imagery and administrative/base mapping data respectively. These provided the basis of spatial information required for mapping and assessing the distribution of groundwater sources and dumpsites proximity within FUTA and its environs.

Table 2: Data Types and Sources

S/N	Type	Resol.	Year of Acquis.	Source
1	Shuttle Radar Topography Mission (SRTM) DEM	30m	2026	United States Geological Survey (USGS)
2	Satellite Imagery	30m	1995-2025	United States Geological Survey (USGS)
4	Administrative Map	Vector	2026	Open Street Map (OSM)
5	GPS Coordinates (Borehole, Dumpsite and Well		2026	Field Data

2.2.1 Digital Camera

A digital camera was used to capture dumpsites, wells and boreholes within the study area to support visual interpretation during analysis. Figure 2 a, and b provides extract of some photographs of dumpsite, dug-wells and boreholes captured within the study area.

Figure 2: Sample photographs of dumpsite, well and boreholes (a) (b)

2.3 Data Processing

2.3.1 GIS database development

A geospatial database was developed in QGIS 4.0 to organize, manage, and analyze all spatial datasets used in the study. The database integrated GNSS observations with secondary geospatial datasets, allowing groundwater sources, dumpsites, and terrain characteristics to be analyzed within a common coordinate reference system (WGS 84 / UTM Zone 31N).The database was designed as a relational geo-database comprising vector feature classes, raster datasets, and attribute tables. Each mapped feature was assigned a unique identifier to maintain consistency throughout data processing and analysis. Figure 3 provide the conceptual view of this process.

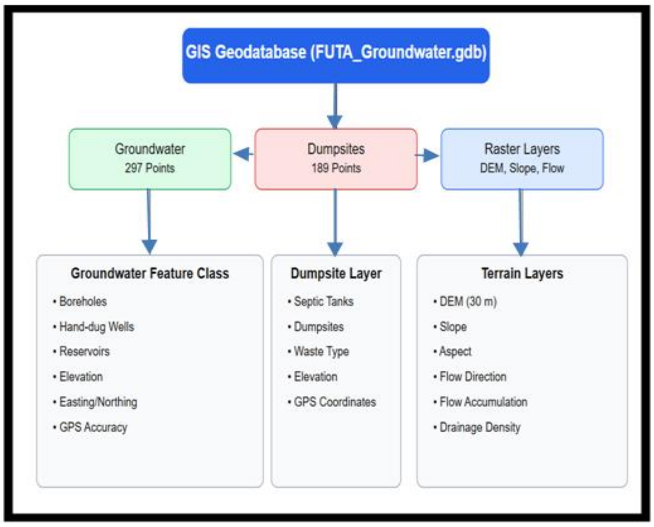

Figure 3: GIS Database Structure

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2.3.1.1 GIS Database Components

Table 1 presents an extract of the spatial database developed for the study. The database contains 297 groundwater-source locations and 189 dumpsite records, together with road, drainage, community, boundary, and terrain datasets. The combination of point, line, polygon, and raster layers provided the spatial framework for mapping, proximity, terrain, drainage, and vulnerability-priority analyses.

Table 1: GIS Database Components

Layer Name	Geo.	No. of Records	Purpose
Groundwater Sources	Point	297	Mapping boreholes, wells and reservoirs
Dumpsites	Point	189	Mapping dumpsites and septic tanks
Roads	Line	Existing	Accessibility analysis
Drainage	Line	Derived	Flow-path assessment
FUTA_Boundary	Polygon	1	Study-area boundary
Communities	Polygon	Existing	Settlement mapping
DEM_30m	Raster	—	Terrain analysis
Slope	Raster	—	Slope derivation

2.3.1.2 Groundwater Sources Attribute Structure

Here, Table 2 display the attribute fields used to describe the mapped groundwater sources. Here, the database captures source identification and type, geographic and projected coordinates, elevation, community, operational condition, and survey date. These attributes enabled the groundwater sources to be accurately located, classified, and analyzed spatially.

Table 2: Groundwater Sources Attribute Structure

S/N	Field Name	Data Type	Sample
1)	GW_ID	Text	BHP001
2)	Source_Type	Text	Borehole
3)	Latitude	Double	7.300133
4)	Longitude	Double	5.137625
5)	Easting	Double	737198
6)	Northing	Double	807916
7)	Elevation_m	Double	376.16
8)	Community	Text	FUTA North Gate
9)	Condition	Text	Functional
10)	Date_Surveyed	Date	18-06-26

2.3.1.3 Dumpsites Attribute Structure

Also, Table 3 presents the attribute structure used for the mapped dumpsites. Here, each record contains information on the dumpsite identification, location, elevation, community, waste type, and operational status. These attributes provided the required information for mapping dumpsite distribution and assessing their spatial relationship with groundwater sources.

Table 3: Dumpsites Attribute Structure

S/N	Field Name	Data Type	Sample
1)	DSP_ID	Text	DSP001
2)	Type	Text	Dumpsite
3)	Latitude	Double	7.2999
4)	Longitude	Double	5.136289
5)	Elevation_m	Double	376.16
6)	Community	Text	WESCO
7)	Waste_Type	Text	Municipal
8)	Status	Text	Active

2.3.1.4 Raster Database Structure

Table 4 presents the characteristics of the raster datasets used for terrain and drainage analysis. A 30-metre SRTM DEM was download to serve as the primary elevation dataset from which slope, aspect, flow direction, flow accumulation, and drainage density were derived. These raster products provided the basis for evaluating terrain characteristics, surface-water movement, and their relationships with groundwater sources and dumpsites.

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Table 4: Raster Database Structure

S/N	Raster	Source	Resolution	Derived Product
1)	DEM	SRTM	30 m	Elevation
2)	Slope	DEM	30 m	Terrain steepness
3)	Aspect	DEM	30 m	Surface orientation
4)	Flow Direction	DEM	30 m	Water-flow direction
5)	Flow Accumu.	DEM	30 m	Drainage concentration
6)	Drainage Density	DEM	30 m	Hydrological intensity

2.4.1 Spatial Distribution Analysis

Spatial distribution analysis was used to determine the density and pattern of groundwater sources and dumpsites within the study area. Feature density was calculated as the number of mapped features per unit area ([5]):

$$D = \frac{N}{A} \quad (1)$$

Where: D is feature density, N is the number of mapped features, and A is the area of the corresponding analysis unit.

The spatial distribution pattern was further evaluated using Global Moran's I ([11]), following the formulation implemented in ArcGIS Pro ([3]):

$$I = \frac{n}{S_O}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (2)$$

Where: n is the number of feature, $z_i = x_i - \bar{x}$, w_{ij} represent the spatial relationship between features I and j, and S_O is the sum of all spatial weights. The Moran's I , z-score, p-value were used to determine whether the observed distribution was significantly clustered, dispersed, or random. This follows the Global Moran's I formulation documented in ArcGIS Pro.

2.4.2 Proximity Analysis

The proximity between groundwater sources and dumpsites was determined using Euclidean distance as follows ([3]):

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (3)$$

Where: d_{ij} is the distance between groundwater source I and dumpsite j, while x and y represent their projected coordinates.

GIS distance analysis was used to identify the nearest dumpsite to each groundwater sources and classify them into specified proximity zone.

The proportion of groundwater source within each proximity zone was calculated as ([3]):

$$P_z = \frac{N_z}{N_{gw}} \times 100 \quad (4)$$

Where: P_z is the percentage of groundwater source within zone z, N_z is the number of groundwater sources in that zone, and N_{gw} is the total number of mapped groundwater sources.

2.4.3 Terrain and Drainage Analysis

Terrain and drainage characteristics were derived from the 30-m DEM. Slope was calculated from the rate of elevation change ([3]):

$$S = \tan^{-1}\left[\sqrt{\left(\frac{\partial Z}{\partial x}\right)^2 + \left(\frac{\partial Z}{\partial y}\right)^2}\right] \quad (5)$$

Where: S represents terrain slope and z represents elevation. Flow direction and flow accumulation were subsequently derived from the processed DEM to identify potential surface-water pathways. DEM-based hydrological processing, including flow direction and accumulation, is an established approach for extracting drainage-related information from elevation data ([3]):

Drainage density was calculated as:

$$D_d = \frac{L}{A} \quad (6)$$

Where: D_d is drainage density, L is the total length of drainage channels, and A is the corresponding area

2.4.4 Groundwater Vulnerability-Priority Modelling

A GIS-based weighted-overlay model was used to integrate the selected vulnerability criteria. Each criterion was reclassified to a common evaluation scale before being assigned a relative percentage influence. The vulnerability-priority index was expressed as ([3]):

$$VPI = \sum_{i=1}^{n} w_i r_i \quad (7)$$

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Where: VPI is the groundwater vulnerability-priority index, w_i is the percentage influence assigned to criterion i, r_i is its reclassified rating, and n is the number of criteria.

For this study, the model was represented as ([3]):

$$VPI = E_{wE} + S_{wS} + D_{wD} + L_{wL} + P_{wP} \quad (8)$$

The criteria were standardized and reclassified before overlay, and their relative influences were assigned according to their anticipated contribution to groundwater contamination risk. The Weighted Overlay approach multiplies the reclassified raster values by their assigned percentage influences and sums the resulting values to generate the composite output. ArcGIS requires the percentage influences in Weighted Overlay to sum to 100%. The five criteria used ([3]):

$$wE + wS + wD + wL + wP = 100\% \quad (9)$$

The resulting VPI values were subsequently classified into low, moderate, high, and very high vulnerability-priority zones.

2.4.5 Statistical Analysis

Descriptive statistics were used to summarize the groundwater-source, dumpsite, proximity, and environmental datasets. The percentage distribution was calculated as([3]):

$$P = \frac{f}{N} \times 100 \quad (10)$$

Where: f is the frequency of an observation or category and N is the total number of observations.

The arithmetic mean was calculated as([3]):

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (11)$$

And the sample standard deviation is given as([3]):

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}} \quad (12)$$

Minimum and maximum values were obtained directly from the observed dataset.

Where relationships between continuous variables were examined, Pearson's correlation coefficient was calculated as ([3]):

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^{n} (X_i - \bar{X})^2 (Y_i - \bar{Y})^2} \quad (13)$$

The coefficient was used to determine the direction and strength of relationships among variables such as dumpsite proximity, terrain characteristics, drainage characteristics, and groundwater vulnerability-priority.

III. RESULTS AND DISCUSSIONS

Table 5 and Table 6 provides extract sample of coordinates used in the creation of maps. Figure 4.2 shows a distribution map of all surveyed Groundwater sources across FUTA and its immediate environs.

3.1.1 Spatial Distribution of Groundwater-Sources

Table 5 present an extract sample of the coordinates used to map the groundwater sources, while Figure 4 show how boreholes and hand-dug wells are Spatially distributed across FUTA and its environs. This spatial pattern provides an indication of areas with higher concentrations of groundwater sources and areas where such sources are relatively sparse.

Table 5: Sample extract of Groundwater Sources

S/N	Point ID	Name	Latitude	Longitude
1	BH 1	Borehole	7.300133	5.137625
2	BH 2	Borehole	7.299372	5.133594
3	BH 3	Borehole	7.301542	5.133836
4	DW 1	Dug Well	7.299628	5.136647

3.1.2 Spatial Distribution of Dumpsite sources

The identified dumpsites were mapped to show their locations and spatial pattern across the study area. Their distribution provides a basis for examining the extent to which dumpsites occur near residential areas, drainage features, and groundwater sources.

Table 6: Sample extract of Dumpsite/Septic tanks Sources

S/N	Point ID	Name	Latitude	Longitude
1	ST 1	Septic Tank	7.299772	5.137597
2	ST 2	Septic Tank	7.300211	5.137758

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S/N	Point ID	Name	Latitude	Longitude
3	ST 3	Septic Tank	7.300186	5.137803
4	DP 1	Dumpsite	7.299900	5.136289

Figure 4.4 shows a combined distribution map of all surveyed Groundwater and dumpsite/septic tank sources across FUTA and its immediate environs.

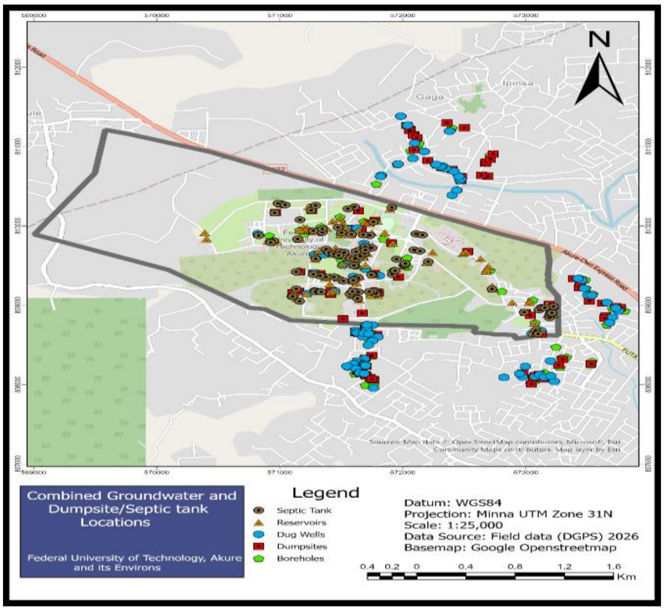

Figure 4: Combined Spatial Distribution of Groundwater Sources and Dumpsites within FUTA and Environs

3.1.3 Groundwater Dumpsite Proximity

The proximity analysis shows the distances between identified groundwater sources and dumpsites. Groundwater sources falling within the different buffer zones around dumpsites were identified and quantified. This helps to highlight groundwater sources that are located relatively close to potential sources of contamination.

Table 7 presents the Distance to Nearest Hub analysis measured the straight line distance from each of the 176 groundwater sources to its nearest dumpsite, which answers the second objective. For the boreholes the distances run from 2.18 m to 365.97 m with a mean of 87.92 m. For the hand dug wells (DW) they run from 3.39 m to 427.18 m with a mean of 74.56 m. The closest borehole, SP53 at the North Gate, stands only 2.18 m from dumpsite (D)70, and the closest well, SP80 near the Chicken n' Tinz area of the campus, sits 3.39 m from dumpsite D03. At the other end of the scale, no source in the entire study area is farther than 427.18 m from a dumpsite.

Table 8 does the same for the hand dug wells. Figure 5 displays the dissolved 100 m, 250 m and 500 m buffer rings around the dumpsites, and the position of each source within or between those rings.

Table 7: Distance from selected boreholes to the nearest dumpsite

Sample ID	Easting (m)	Northing (m)	Source Type	Nearest Dumpsite	Dist (m)	Zone
SP11	735707.922	807742.268	Borehole	D04	271.47	Low
SP18	735003.505	807929.144	Borehole	D09	288.72	Low
SP22	735885.872	807225.938	Borehole	D17	4.27	High risk
SP26	736786.326	807500.628	Borehole	D26	296.19	Low
SP27	736883.591	807241.429	Borehole	D27	326.95	Low

Source: Author's compilation

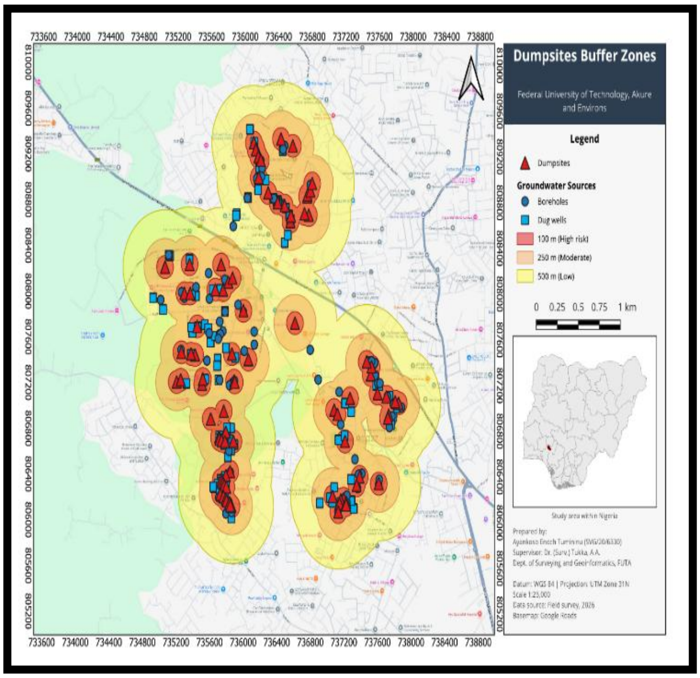

Figure 5: Dumpsite buffer zones at 100 m, 250 m and 500 m. Source: Author's compilation

Of the 76 boreholes, 55 fall inside 100 m of a dumpsite, 16 fall between 100 m and 250 m and 5 fall between 250 m and 500 m. Of the 100 hand dug wells, 76 fall inside 100 m, 20 fall between 100 m and 250 m and 4 fall between 250 m and 500 m. Not a single groundwater source in the study area lies beyond 500 m from a dumpsite.

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Table 8: Distribution of groundwater sources across the buffer zones

Distance Band	Risk Class	Boreholes	Hand Dug Wells	Total	Share of Sources (%)
0 to 100 m	High risk	55	76	131	74.4
100 to 250 m	Moderate	16	20	36	20.5
250 to 500 m	Low	5	4	9	5.1
Beyond 500 m	Negligible	0	0	0	0.0
Total		76	100	176	100.0

Source: Author's compilation

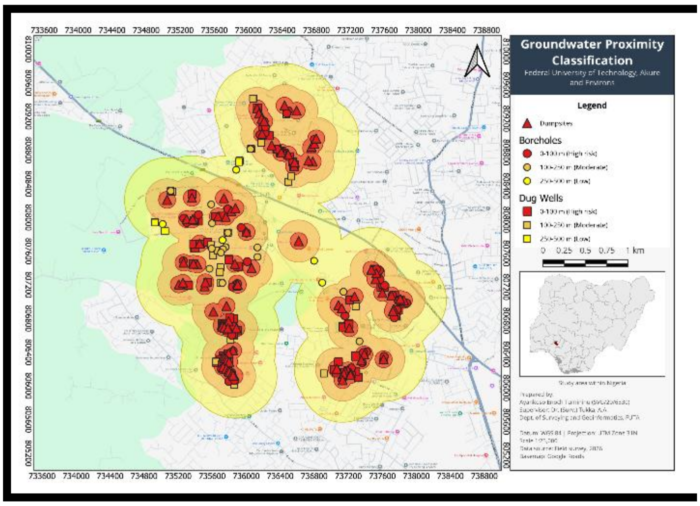

Figure 6: Groundwater proximity classification by risk zone. Source: Author's compilation

Taken together, 131 of the 176 sources, or 74.4%, sit in the high risk band inside 100 m. Another 36 sources, or 20.5%, occupy the moderate band, and only 9 sources, or 5.1%, reach the low band between 250 m and 500 m. Within 250 m the cumulative share climbs to 94.9%. Figure 7 colours every source by its band, and the picture is dominated by the high risk class across the campus and all three gate areas. The proximity problem is therefore not confined to one corner of the study area. It is the ordinary condition of groundwater in FUTA and its environs, a situation comparable studies have described in other Nigerian communities ([17])

Figure7 compares the number of boreholes and hand dug wells falling in each distance band, and the high risk band towers over the rest for both source types. Figure 8 presents the overall shares, with the high risk band taking 74.4% of all 176 sources, the moderate band 20.5% and the low band the remaining 5.1%.

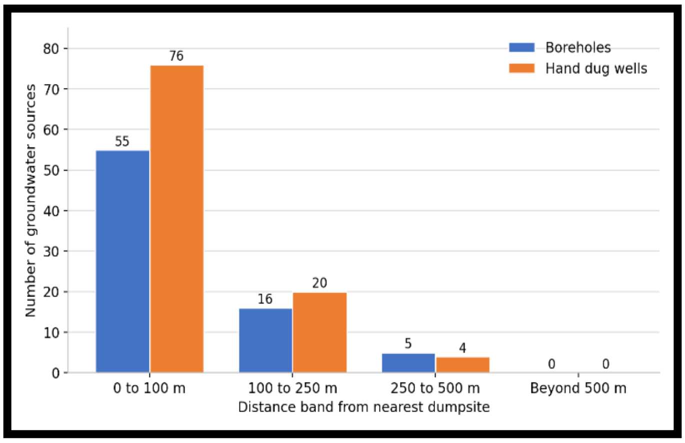

Figure 7: Groundwater sources in each distance band by source type. Source: Author's compilation

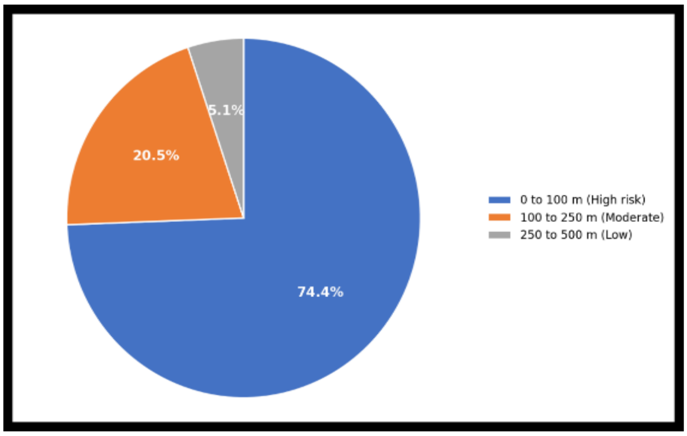

Figure 8: Share of groundwater sources by risk class. Source: Author's compilation

3.1.4 Terrain

Topography and drainage characteristics play a critical role in controlling the movement of surface runoff, leachate migration, groundwater recharge, and contaminant transport from dumpsites into surrounding aquifers. Therefore, the results of the terrain and hydrological analyses derived from the Digital Elevation Model (DEM) and GIS-based hydrological modelling are presented. The findings include: Contour Map, elevation, slope, aspect, drainage density, all of which provide valuable insights into the environmental processes influencing groundwater contamination within the study area.

3.1.4.1 Digital Elevation Model (DEM)

The elevation of the study area was derived from SRTM as presented in Table 9. The elevation was classified based on

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https://doi.org/10.47001/IRJIET/2026.108009

their effect on groundwater. Areas with high elevation were ranked 4, areas with moderate elevation were ranked 3, and areas with low elevation were ranked 2 while areas with the very low elevation were ranked 1. The elevation analysis revealed that the area within the elevation range of 327–351 m had the highest coverage, occupying approximately 9,736.181 units², which represents 31.14% of the total study area and was classified as moderate elevation. This was followed by the 276–327 m elevation range, classified as high elevation, covering about 8,914.627 units² with a percentage coverage of 28.51%. The 351–379 m elevation range, categorized as low elevation, occupied an area of 6,967.535 units², accounting for 22.29% of the total area. Meanwhile, the 379–500 m elevation range had the least coverage, with an area of 5,644.447 units² representing 18.06% of the study area, and was classified as very low elevation. As presented in Figure 9, the Brown color shows elevation between of 276m – 327m, Yellow shows elevation within 327m – 351m, Violet shows elevation within 351m – 379m and Deep blue shows elevation range of 379m – 500m.

Table 9: Elevation Value

S/N	Elevation (m)	Value	Risk Assessment Rank
1	276 – 327	1	High
2	327 – 351	2	Moderate
3	351 – 379	3	Low
4	379 – 500	4	Very Low

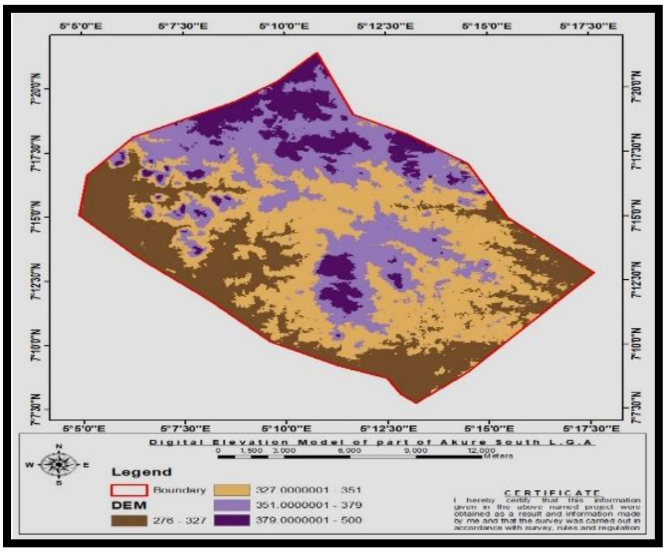

Figure 9: Elevation Map of the Study Area. Source: Author's Compilation

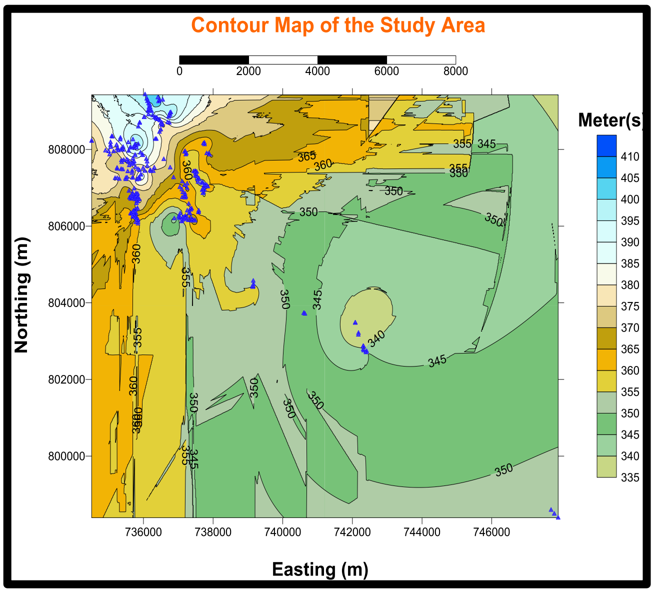

Figure 10: Contour Map of the Study Area. Source: Author's Compilation

3.1.4.2 Slope

Table 10 and side its associated Figure 11 presents the slope value withinthe study. Here, areas with the lowest degree of slope (0 – 2.60) were ranked very low, (2.60 - 5.03) were ranked low, (5.03 - 8.50) were ranked moderate and areas with (8.50 – 14.74) were ranked high and (14.74 - 44.22) were ranked very high. Areas with lower degree of slopes (gentle slope) are at lower risk of groundwater contamination because they promote groundwater recharge while reducing surface runoff. Moderate to steep slopes (higher slope degree) are at higher risk of groundwater contamination due to increased runoff velocity and greater potential for contaminant transport.

Table 10: Slope Value

S/N	Slope (degree)	Value	Risk Assessment Rank
1	0 – 2.60	1	Very Low
2	2.60 – 5.03	2	Low
3	5.03 – 8.50	3	Moderate
4	8.50 – 14.74	4	High
5	14.74 - 44.22	5	Very High

International Research Journal of Innovations in Engineering and Technology (IRJIET)

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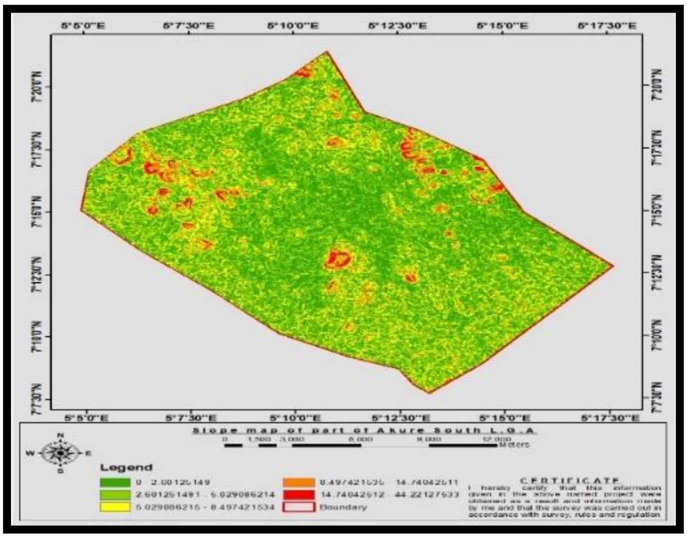

Figure 11: Slope Map of the Study Area. Source: Author's Compilation

3.1.4.3 LULC Distribution in 2025

Table 11 presents the land use/land cover distribution for 2025, built-up covers 11767.100Ha, cultivated land covers 10121.467Ha, vegetation covers 5047.260Ha and bare-land covers 4326.968Ha. Figure 12 illustrates the LULC distribution for the four epochs, while Figure 13 presents the land use land cover map for 2025: built-up covers the largest portion of the landscape, indicating higher waste generation and increased groundwater contamination risk caused by urban expansion. Cultivated land is the second dominant class which causes fertilizer infiltration and chemical contamination, followed by vegetation and bare-land.

Table 11: 2025 Land Use/Land Cover

S/N	Class	Areas (Ha.)	Percentage (%)
1	Vegetation	5047.26	16.14
2	Cultivated land	10121.47	32.375
3	Bare land	4326.968	13.84
4	Built-up	11767.1	37.639
5	TOTAL	31262.79	100

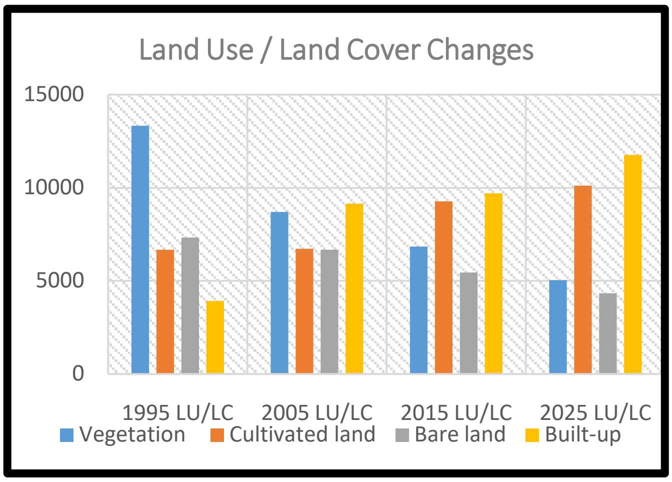

Figure 12: Land Use Land Cover Distribution Chart. Source: Author's Compilation

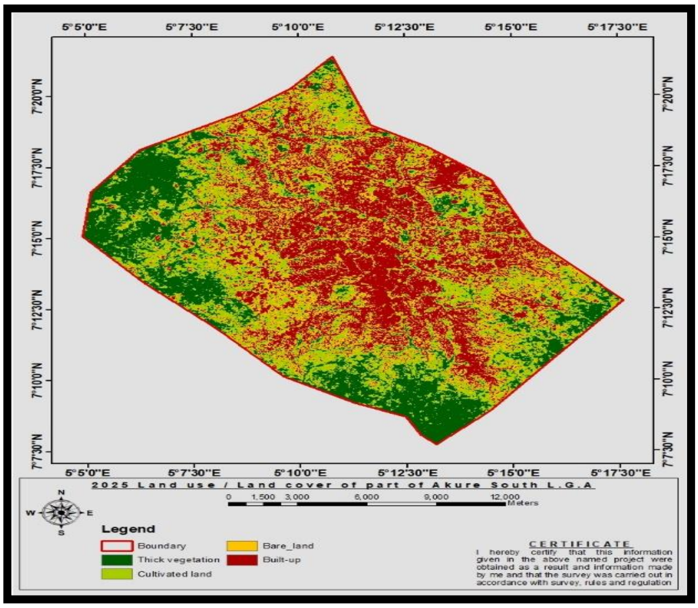

Figure 13: 2025 Land Use Land Cover. Source: Author's Compilation

3.1.4.4 Drainage Density and Relationships

The drainage density map was produced and reclassified into three preference classes for the groundwater contamination risk analysis, as presented in Table 12.The results show how groundwater sources and dumpsites are distributed in relation to the terrain and drainage characteristics of the study area. Elevation, slope, drainage density, flow accumulation, and proximity to drainage channels were examined to determine their spatial relationships with the mapped features.

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Table 12: Risk Category Distribution for all 297 Groundwater Sources

S/N	Risk	Score Range	Count	%	RV	BH	DW
1	Very High	7.01 - 9.00	108	36.40	39	24	45
2	High	5.01 - 7.00	176	59.30	78	49	49
3	Moderate	3.01 - 5.00	13	4.40	4	3	6
4	Low	1.00 - 3.00	0	0.00	0	0	0
	TOTAL	-	297	100	121	76	100

Table 14 presents a selected part of the Extract Multi Values to Points of the slope (in degrees), flow accumulation (cell count) and Euclidean distance (in metres) to the nearest dumpsite or septic tank, from ArcGIS pro.

Table 14: Extract Multi Values to Points

S/N	Field1	Field2	Slope_Deg	FlowAcc	Dist_To_Dump
1	7.29986	5.13630	6.89609	1	0
2	7.29966	5.1362	5.9280319	19	0
3	7.29950	5.13524	4.7718778	0	0.0003928
4	7.29925	5.134753	1.6745193	3	0.0002778

Areas with high drainage density are at lower risk of contamination because higher drainage density promotes surface runoff, reducing infiltration while areas with low drainage density are at higher contamination risk because lower drainage density allows more infiltration of water and leachates into the ground, increasing the potential for groundwater contamination. Figure 14 shows that areas with higher drainage density are less prone to contaminant transport from dumpsites due to increased surface runoff, while low drainage density areas are more vulnerable.

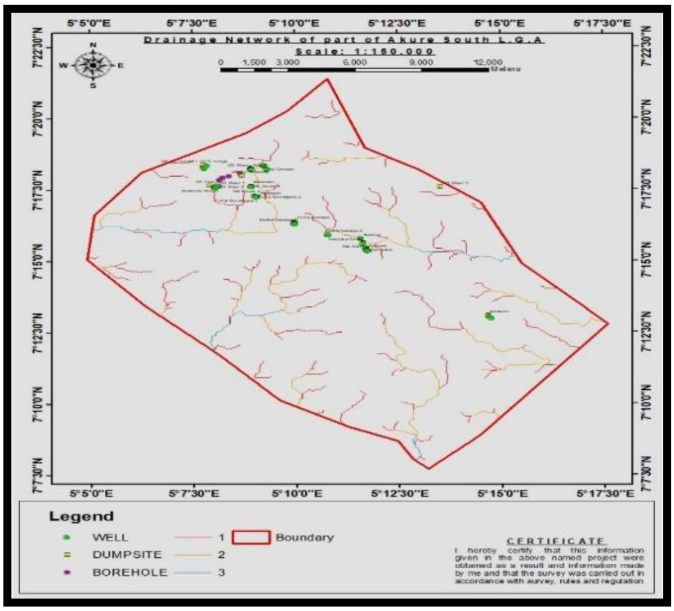

Figure 14: Drainage Density Map of the Study Area. Source: Author's Compilation

3.1.4.5 Vulnerability-Priority Zones

The integrated analysis produced a vulnerability-priority map showing areas with different levels of potential concern. The study area was grouped into low, moderate, high, and very high priority zones based on the combined influence of the selected spatial factors. The distribution of groundwater sources within these zones was then examined to identify locations that may require closer monitoring and further investigation.

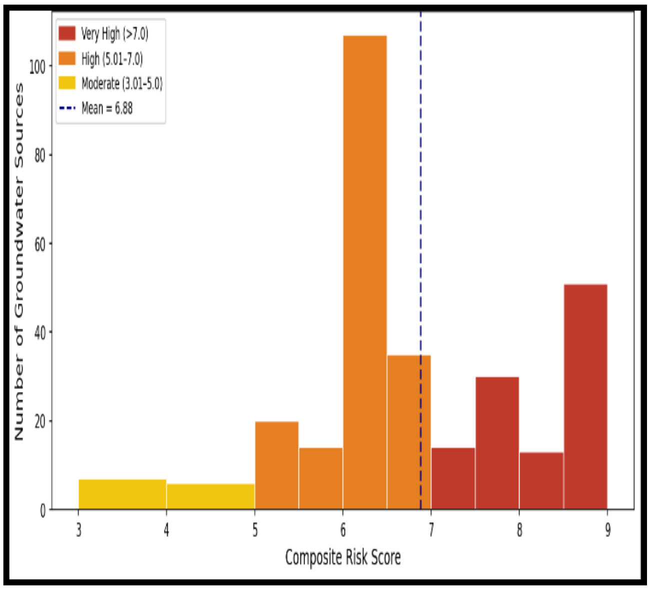

Figure 15: Distribution and Proportion Percentage of Composite Terrain-Based Risk Scores for All 297 Groundwater Sources

ISSN (online): 2581-3048
Volume 10, Issue 8, pp 79-94, August-2026
https://doi.org/10.47001/IRJIET/2026.108009

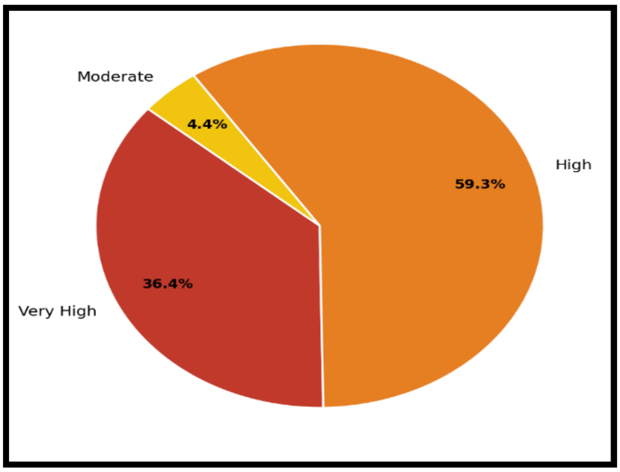

Figure 16: Distribution and Proportion Percentage of Composite Terrain-Based Risk Scores for All 297 Groundwater Sources

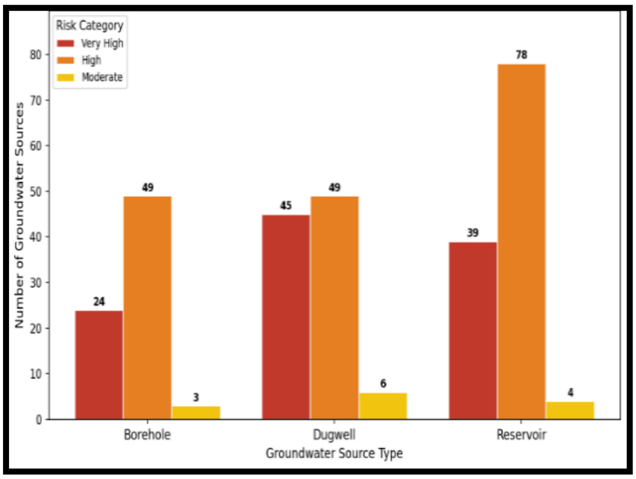

Figure 17: Distribution and Proportion Percentage of Composite Terrain-Based Risk Scores for All 297 Groundwater Sources

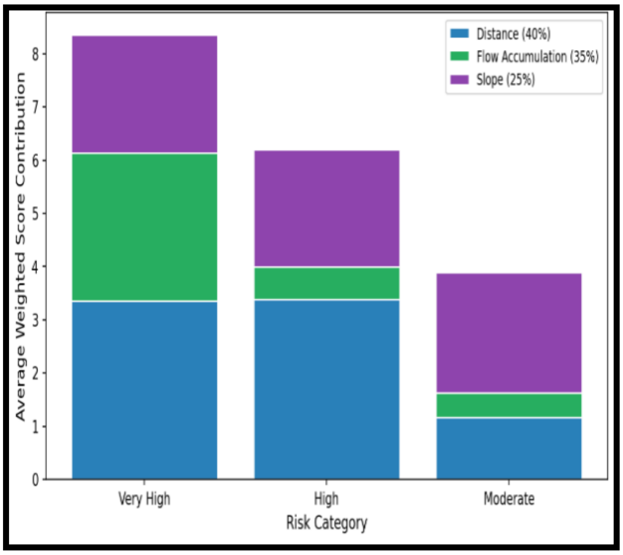

Figure 18: Risk Category Distribution by Groundwater Source Type and Average Weighted Factor Contribution to Composite Risk Score by Risk Category

3.2 Discussion

3.2.1 Distribution of Groundwater Sources and Dumpsites

The spatial distribution shows that dumpsites are concentrated around areas of intense human activity. Within the FUTA campus, they occur mainly around hostel and academic areas, while outside the campus gates they are more common around student residences and densely populated communities along major access routes. This pattern is consistent with previous observations that population growth and inadequate waste-management systems can contribute to the proliferation of informal and open waste-disposal locations ([10]; [15]).

Groundwater sources exhibit a broadly similar spatial pattern. Hand-dug wells are particularly common around communities surrounding the campus gates, reflecting their accessibility and relatively simple construction. Their shallow construction and potentially limited sanitary protection may increase their susceptibility to environmental exposure where waste-disposal activities occur nearby ([6]; [14]).

The combined distribution map therefore indicates considerable spatial co-location of groundwater sources and dumpsites within populated parts of the study area. This spatial association does not establish groundwater contamination but identifies locations where the relationship between water abstraction and waste disposal warrants closer environmental investigation.

3.2.2 Proximity of Groundwater Sources to Dumpsites

The proximity analysis indicates a substantial spatial concern. Of the 176 groundwater sources analysed, 131 (74.4%) occur within 100 m of a dumpsite. Thus, approximately three-quarters of the mapped groundwater sources occur within the 100 m screening zone adopted in this study.

The result is consistent with previous research demonstrating the importance of spatial separation between groundwater resources and waste-disposal facilities ([15]; [14]). However, the 100 m criterion used here should be regarded as a screening and precautionary setback criterion, rather than a universal boundary beyond which contamination cannot occur.

Actual contaminant migration depends on geological, soil, topographic and hydrogeological conditions. Geophysical investigations have demonstrated that leachate can migrate through preferential subsurface pathways beyond the immediate waste-disposal footprint, as affirmed by ([1]; [7]).

ISSN (online): 2581-3048
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Therefore, the proximity results identify locations requiring further investigation rather than confirming contamination.

The mean distance of hand-dug wells from dumpsites was 74.56 m, compared with 87.92 m for boreholes. This closer spatial relationship identifies hand-dug wells as an important group for priority environmental monitoring. However, vulnerability cannot be established from distance and source type alone and requires consideration of local hydrogeological conditions.

3.2.3 Groundwater Sources Requiring Priority Investigation

The nearest groundwater sources were located at exceptionally short distances from dumpsites. The nearest borehole, located at Sampling Point (SP) 53 at the North Gate, was located 2.18 m from dumpsite (D) 70. Other closely located boreholes included SP22 (4.27 m), SP35 (4.90 m), SP34 (7.00 m), SP58 (7.07 m), SP59 (7.83 m), and SP44 (8.33 m). Several hand-dug wells were similarly located within 10 m of dumpsites, including SP80 (3.39 m), SP158 (3.71 m), SP125 (5.65 m), SP121 (6.15 m), SP112 (6.42 m), SP138 (6.92 m), and SP151 (7.01 m). In total, 14 groundwater sources were located within approximately 10 m of a dumpsite.

These locations constitute the highest priorities for environmental investigation because their extremely short separation distances establish a strong spatial basis for assessing potential interaction between waste-disposal activities and groundwater recharge or exposure pathways. Previous investigations have demonstrated the usefulness of integrated geophysical and hydro chemical approaches for determining whether such spatial relationships correspond to actual groundwater contamination ([6]; [13]; [14]). The present findings should therefore be interpreted as risk-screening evidence rather than confirmed contamination. The 14 sources cannot be classified as contaminated solely from their mapped distances. Instead, they constitute priority locations for sanitary inspection, microbiological and physicochemical water-quality testing and, where appropriate, geophysical investigation.

IV. CONCLUSION

This study established a spatial inventory of existing groundwater sources and dumpsites within FUTA and its environs and assessed their spatial proximity using GIS-based analysis. Field surveying identified 89 dumpsites, 76 boreholes and 100 hand-dug wells, together with 100 septic tanks and 121 reservoirs used as supporting spatial features.

The nearest-dumpsite distances for the 176 groundwater sources ranged from 2.18 to 427.18 m. Mean distances were 87.92 m for boreholes and 74.56 m for hand-dug wells. Of the groundwater sources assessed, 131 (74.4%) were located within 100 m of a dumpsite, 36 (20.5%) occurred between 100 and 250 m, and 9 (5.1%) occurred between 250 and 500 m. No mapped groundwater source was located beyond 500 m from a dumpsite, while 14 sources were located within approximately 10 m of a dumpsite.

The findings demonstrate substantial spatial overlap between existing groundwater sources and waste-disposal locations within the study area. The 100 m screening zone identifies a large proportion of groundwater sources requiring environmental attention. However, the analysis does not establish contamination because spatial proximity is only an indicator of potential exposure.

The principal contribution of the study is the establishment of a spatial baseline showing where existing groundwater sources occur, where dumpsites are located, and which groundwater sources are closest to potential contamination sources. The resulting database provides a practical foundation for targeted environmental monitoring, subsequent groundwater-quality assessment and improved waste-management planning within FUTA and its surrounding communities.

Recommendations and Implications

The proximity database and associated maps should be incorporated into environmental and infrastructure planning by FUTA Management and relevant local authorities. The 100 m criterion adopted in this study may be used as a precautionary screening and planning threshold, subject to applicable regulatory requirements and site-specific hydrogeological assessment, when evaluating new groundwater sources and waste-disposal locations.

The 14 groundwater sources located within approximately 10 m of dumpsites should receive immediate attention. These sources should undergo sanitary inspection and laboratory water-quality assessment, with emphasis on microbiological, physicochemical and selected heavy-metal parameters. Dry- and wet-season sampling is recommended to assess possible temporal variations in groundwater quality.

Dumpsites located closest to the identified priority groundwater sources, particularly D70, D03, D17 and D71, should be subjected to site-specific environmental assessment. Depending on their condition and operational status, appropriate interventions may include controlled removal or relocation, improved containment, fencing, rehabilitation, or replacement with properly managed waste-collection facilities.

ISSN (online): 2581-3048
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https://doi.org/10.47001/IRJIET/2026.108009

Waste-management practices should also be strengthened within the campus and surrounding communities through regular waste collection and evacuation, properly managed designated collection points, and restrictions on informal dumping near groundwater sources.

The geospatial database developed in this study should be maintained as a dynamic environmental decision-support database. Newly constructed boreholes and wells, emerging dumpsites and other relevant environmental features should be periodically surveyed and incorporated into the database.

Finally, future investigations should progress from spatial proximity assessment to contamination confirmation and process understanding. Priority groundwater sources identified in this study should be investigated through seasonal water-quality sampling, hydro-chemical analysis, groundwater-level measurements and appropriate geophysical surveys. These datasets can subsequently be integrated with terrain, geological and hydrogeological information to establish whether the high-proximity locations exhibit measurable contamination and to determine the factors controlling contaminant movement.

ACKNOWLEDGEMENT

Funding: This research was funded by the Tertiary Education Trust Fund (TETFund) under the 2025–2026 Institution-Based Research (IBR) Projects Intervention of the Federal University of Technology, Akure (FUTA), under reference TETF/DR&D/CE/UNI/AKURE/IBR/2026.

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ISSN (online): 2581-3048
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Citation of this Article:

Tukka A. A., Nzelibe I. U., Adiat K. A., Igejongbo T. F., Fayeun L. S., & Fawole I. D.. (2026). Spatial Mapping and Proximity Assessment of Groundwater Sources and Dumpsites within FUTA and Its Environs. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 10(8), 79-94. Article DOI https://doi.org/10.47001/IRJIET/2026.108009

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