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GEOSPATIAL ANALYSIS AND MODELING OF BOREHOLE DATA FOR GROUNDWATER RESOURCE MANAGEMENT IN DAMATURU METROPOLIS

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Keywords: *Geospatial Analysis, Modeling, Borehole, Groundwater and Static Water Level*

Abstract: *The study focused on the geospatial analysis and modeling of borehole data for groundwater resource management in Damaturu Metropolis, Yobe State. Borehole data, including depth, static water level, and coordinates, were collected from Rural Water Supply and Sanitation Agency (RUWASA) Yobe State and processed using ArcGIS 10.8. Additionally, Digital Elevation Model (DEM) data from ASTER Global DEM (30m resolution) was utilized to derive surface elevation, slope, contour lines, and hydrological parameters. The borehole data were interpolated using the Inverse Distance Weighting (IDW) algorithm to generate continuous surfaces for groundwater flow analysis, while the ArcGIS Hydrology Toolset was employed to model groundwater movement. The findings revealed that Damaturu Metropolis has an elevation range of 374m to 401m above sea level, influencing both surface water flow and groundwater recharge. Borehole depths varied significantly from 12m to 132m, with deeper boreholes indicating confined aquifers and lower permeability zones. Static water levels ranged between 18m and 96m, in line with variations in topography and recharge conditions. Slope analysis categorized the area into five classes, with nearly flat terrains favoring groundwater storage and infiltration. The groundwater flow direction predominantly moved southward (21.9%) and eastward (19.4%), identifying major discharge zones in the region. Based on the geospatial analysis, it is recommended that boreholes in other parts of the state be geopositioned, with their locations recorded for GIS applications. This will facilitate effective monitoring and modeling of groundwater levels in a GIS environment. Regular measurements of water table elevations at multiple locations will enhance the understanding of groundwater flow patterns, ensuring sustainable water resource management in the State.*

1. Introduction

Water is essential for sustaining life and is one of the most crucial natural resources for any country. However, uneven in water distribution have resulted in acute water shortages in some regions while creating surpluses in others (Radwan *et al.,* 2020). Understanding the spatial patterns of hydrological events is crucial for developing proactive and adaptive water resource management strategies globally.

Sub-Saharan Africa faces significant pressure on its water resources due to rapid urbanization, expanding irrigation projects, and the effects of climate change. The region's highly variable and often insufficient rainfall patterns further exacerbate these challenges (Gebre *et al.,* 2015). As the demand for water continues to rise, many developing countries, including Nigeria, are increasingly relying on groundwater as a sustainable water source for both domestic and agricultural use (Gyamfi *et al.,* 2016).

Groundwater, which refers to all subsurface water stored within soil and rock formations, which plays a critical role in Nigeria's water supply due to the inadequacy of surface water sources and public water supply systems. Currently, over 70% of potable water in Nigeria is sourced from groundwater, with some urban areas, such as Abuja, relying on it for over 80% of their municipal water supply (Akinwumiju & Olorunfemi, 2016). However, groundwater is not static; it moves through subsurface materials depending on hydraulic gradients and permeability conditions. The ease with which water flows through rock formations depends on the size and interconnectivity of pore spaces (Amah & Agbebia, 2015).

Understanding groundwater movement is crucial, as it influences water availability and quality. The depth to the water table varies with local topography, geological conditions, and recharge rates, and is typically balanced between recharge and discharge processes despite seasonal fluctuations (Amah & Agbebia, 2015). Groundwater flow patterns do not always align with surface water flow, as water moves from areas of higher hydraulic head to lower hydraulic head. Knowledge of these flow dynamics is essential for effective groundwater resource management (Ige *et al.,* 2018).

Given the increasing depending on groundwater, it is critically important to monitor its availability and quality, particularly in arid and semi-arid regions. Determining groundwater flow directions and recharge zones is crucial to ensuring sustainable use and preventing contamination from land use activities in recharge areas. Extracting underground water resources in water-scarce areas requires efficient and cost-effective methods (Jawad & Yahya, 2013). In this regard, Geographic Information Systems (GIS) and Remote Sensing (RS) are opowerful tools for analyzing hydrological data. GIS enables the integration of large datasets, facilitating the spatial analysis of groundwater potential, aquifer characteristics, and water availability (Nyaberi *et al.*, 2019).

Recent advancements in GIS and Remote Sensing have improved the efficiency of groundwater exploration by enabling the delineation of drainage basins, hydrological modeling, and the identification of groundwater potential zones (Magesh *et al*., 2012; Sreedevi *et al.,* 2013). Digital Elevation Models (DEMs) further enhance hydrological analysis by providing crucial topographical information with minimal fieldwork (Aziz, 2020).

This study applies an integrated approach using remote sensing and GIS to model groundwater levels and flow directions in Damaturu Metropolis, Yobe State. The findings of this research will contribute to the identification of groundwater potential zones, enhance water resource management, and support sustainable groundwater utilization in the region.

2. The Study Area

This study covers Damaturu Metropolis, the administrative capital of Yobe State in Northeastern Nigeria. Damaturu is located along the famous Kano – Maiduguri highway (Usman & Ngurnoma, 2024). it is located between latitude 11° 42’ to 11° 50’ North of the and longitude 11° 50’ to 12° 02’ East, WGS 84 UTM Zone 32N (Shown in Figure 1). It is bounded to the north by Tarmuwa Local Government, to the south by Gujba Local Government Area, and to the west by Fune Local Government’s Area of Yobe State, while to the East it is bounded by Kaga Local Government Area of Borno State. The climate area can be described under Sahel Savannah which often characterized with short wet season that last for four months and long dry season of about eight months. The wet season occurs between August and September, with mean annual rainfall of 350-500mm (Rabiu *et al.* 2020). The temperature is fairly consistent, and the hottest months are March, April, and May with temperature ranges from 39^{o}c-40^{o}c. The vegetation cover in Damaturu is directly related to environmental factors such as soil, rainfall, and human intervention. The entire area falls within the Sahel Savannah; short grasses, thorny shrubs and trees are found dotted around (Rabiu *et al.* 2020)

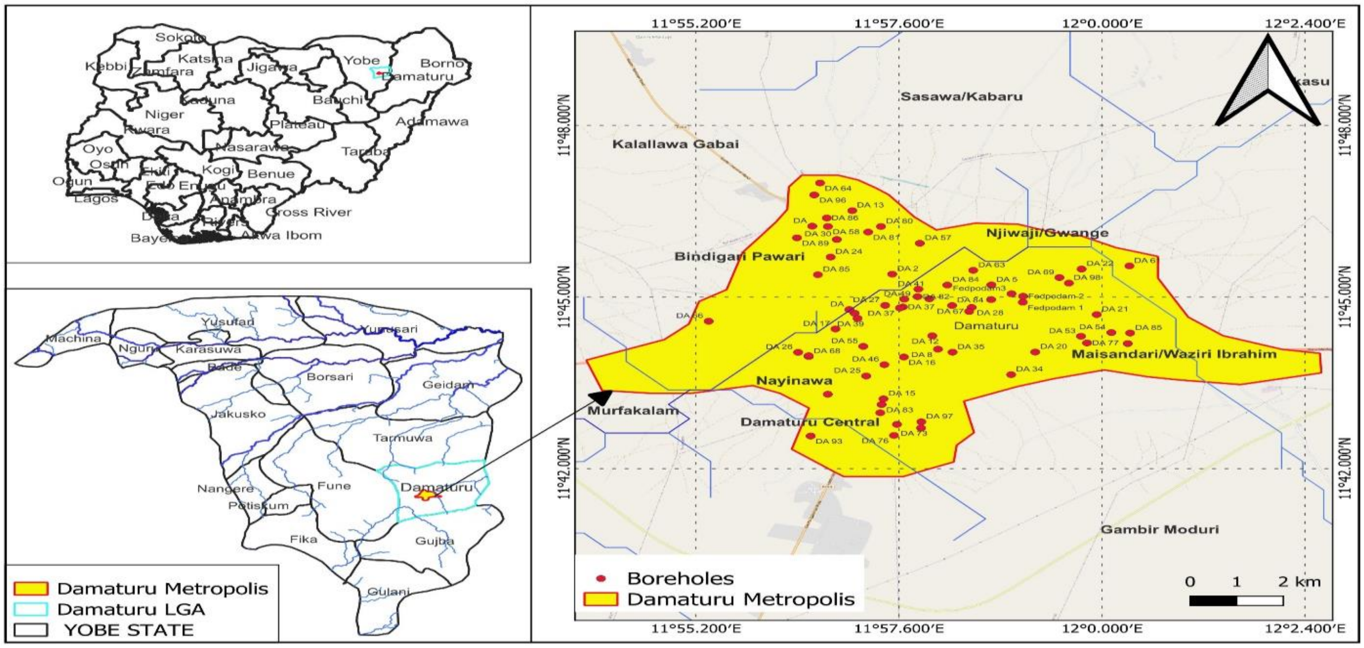

Figure 1: Study Area
Source: Authors, (2025)

2.1 Materials and Method of Data Collection

This study involved the collection and processing of borehole data and Digital Elevation Model (DEM) data to analyze groundwater characteristics and hydrological processes of Damaturu Metropolis. A total of 68 Borehole data, including depth, static water level, and coordinates, were sourced from RUWASA Yobe State and processed in ArcGIS 10.8 for spatial analysis. The ASTER Global DEM (30m resolution), downloaded from USGS (https://lpdaac.usgs.gov/products/astgtmv003/), was used to derive surface elevation, slope, contour lines, and hydrological parameters.

The borehole data were cleaned, formatted into GIS-compatible shapefiles, and projected into the WGS 84 UTM Zone 32N to ensure spatial accuracy. Meanwhile, the DEM was preprocessed by clipping it to the study area and deriving slope and contour maps. Inverse Distance Weighting (IDW) interpolation Algorithm in Spatial Analyst tool was applied in ArcGIS 10.8 to create continuous surfaces for borehole depth, static water level, and groundwater flow direction. These were then integrated with DEM-derived flow direction, accumulation, and watershed delineation to model groundwater movement. The hydrological analysis used the ArcGIS Hydrology Toolset to determine groundwater flow patterns.

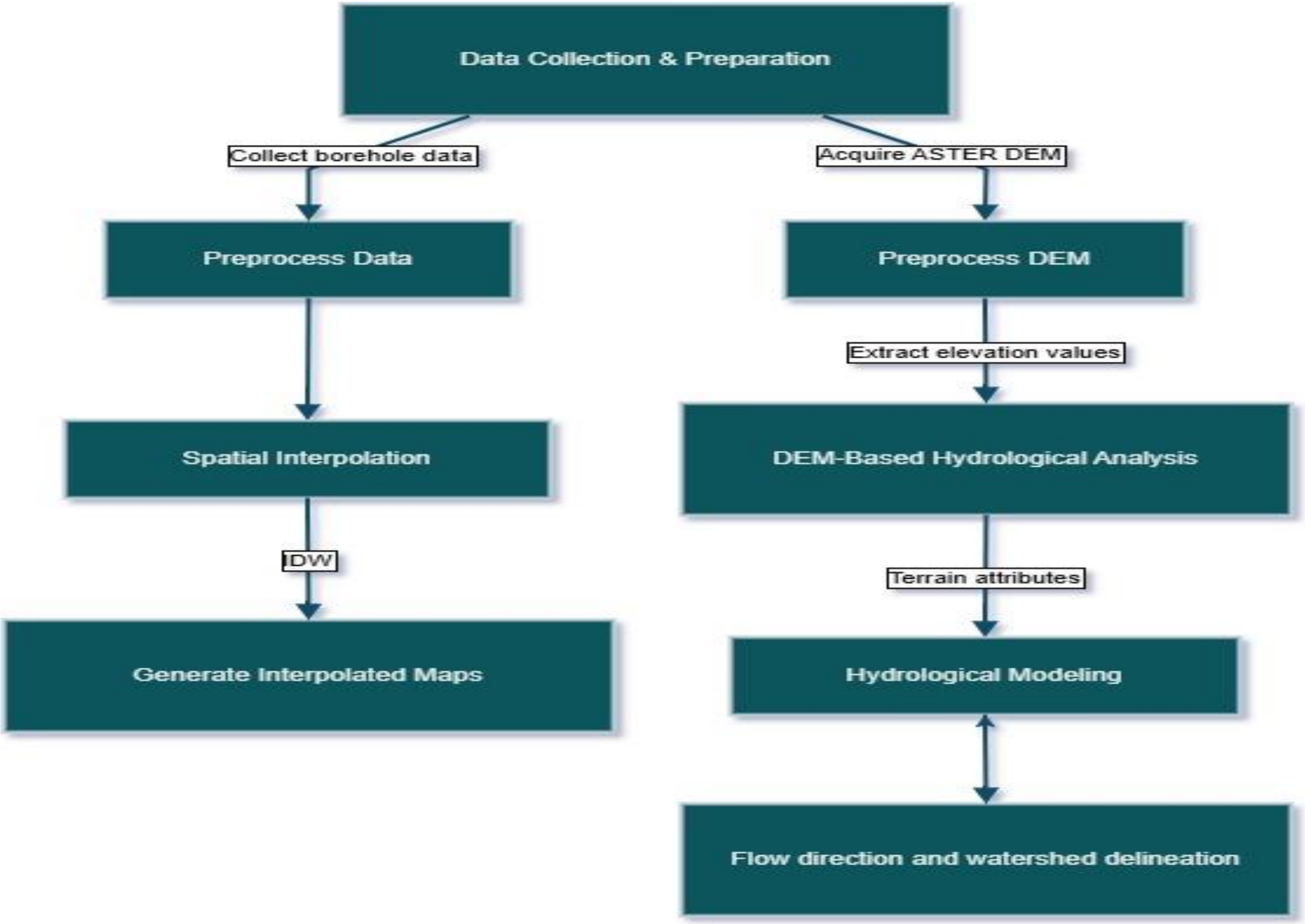

Figure 2. Methodological Flow Chart

The hydraulic Head (HH) of the study area was determined from the differences between surface elevation and SWL, as in Equation 1. The hydraulic heads of the different locations were obtained by subtracting the depth of the water table in the boreholes from the ground elevation concerning the mean sea level which provides insight into groundwater potential and flow dynamics (Table 3).

$$HH = SE - SWL \qquad \text{Eq}^{\underline{n}} \quad 1$$

Where: SE = Surface Elevation or DEM values; SWL = Static Water Level;

3. Results and Discussion

3.1 Topography and Hydrology

Figure 3 presents the topographical and hydrological map of the study area. It indicates that the elevation in Damaturu Metropolis ranges from 374 m to 401 m above sea level, influencing both surface water flow and groundwater recharge. The stream ordering analysis reveals that the highest stream order in the area is the third order, terminating in the northeastern corner. According to Mephors *et al.* (2021), high elevation poses challenges for groundwater utilization. In areas with higher elevations, residents may need to travel long distances to access water, or advanced technology will be required to extract the limited and distant groundwater resources effectively.

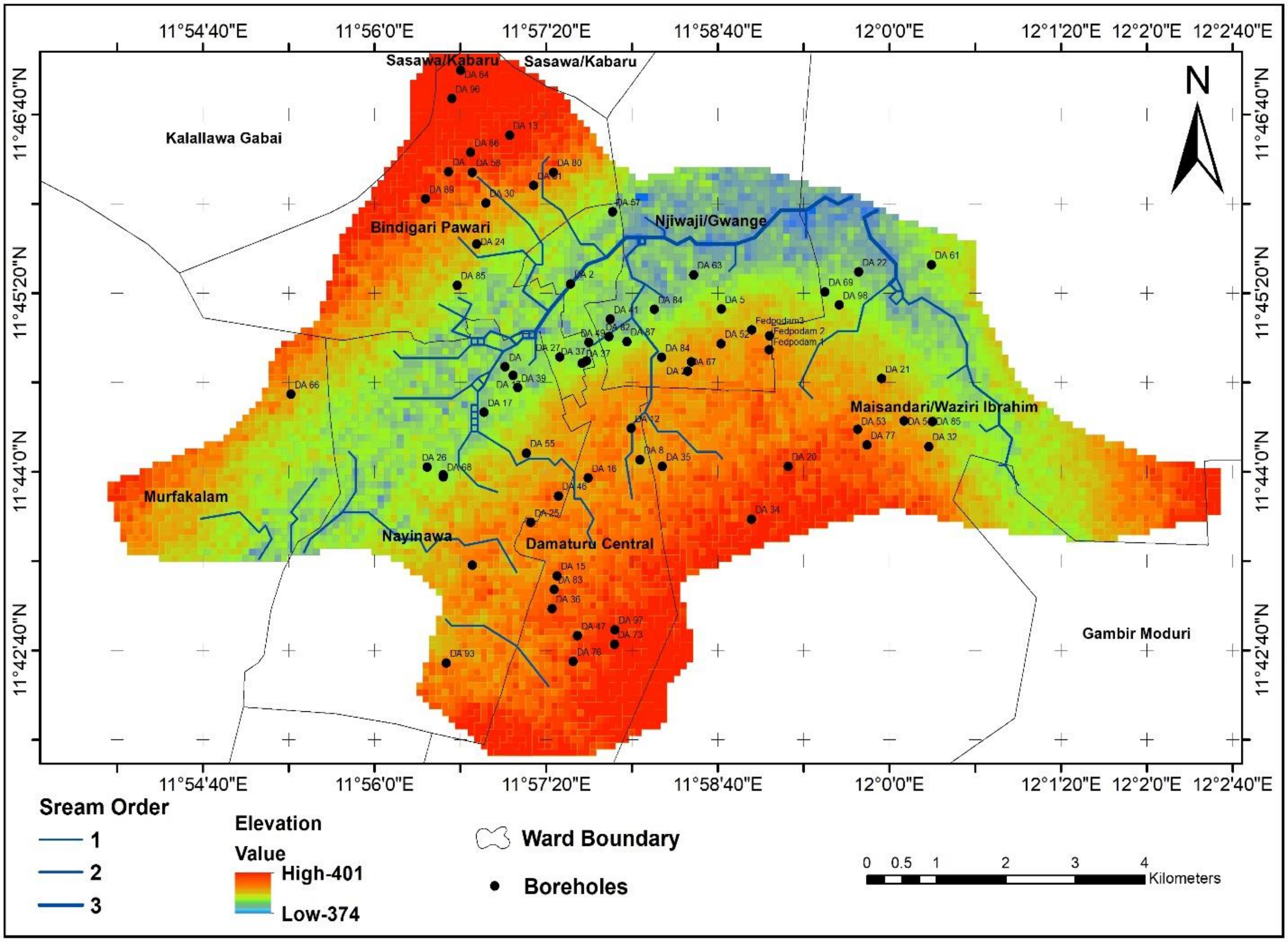

Figure: 3: Topographical and Hydrological Map

3.2 Slope

Slope is one of the most significant parameters for groundwater exploration. The slope of any area affects the runoff and recharge of surface water. In terms of groundwater recharge, an area with flat terrain topography falls into the Very Good category and has a relatively higher infiltration rate (Barik et al., 2019). Figure 4 shows the slope map of the study area. Topographically, the area is categorized from plains to steeply sloping. The slope varies from 0° to 3°. Based on the degree of slope, the study area has been classified into five slope classes. The area having 0° – 0.41° falls into the High category for groundwater storage due to its nearly flat terrain and relatively high infiltration rate. Areas with slopes between 0.42° and 0.73° are considered Good due to slightly undulating topography. The area with a slope of 0.74° to 1° experiences relatively high runoff and low infiltration, hence categorized as Poor. Areas with slopes between 1.6° and 3° are considered Very Poor due to the high slope and significant runoff.

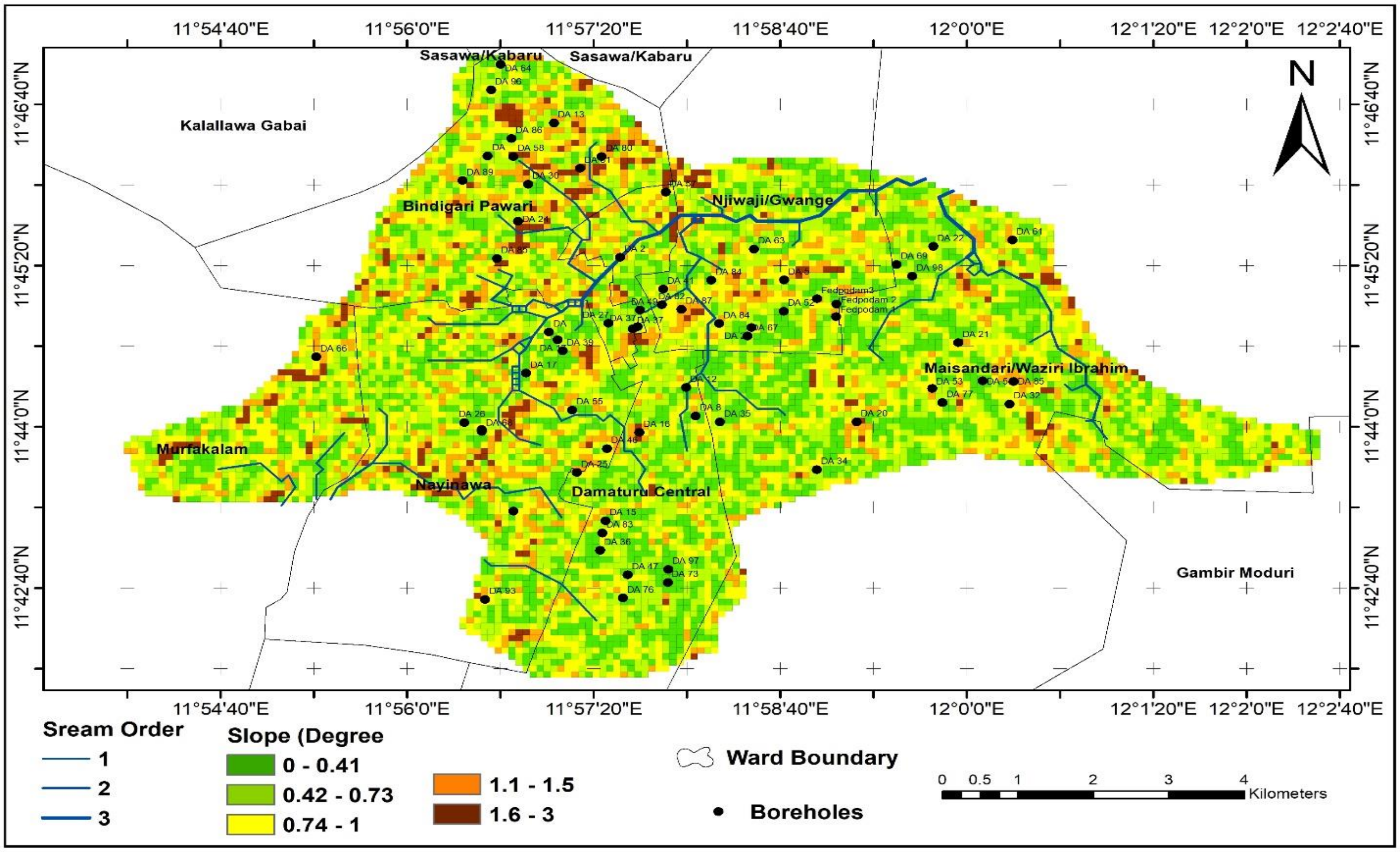

Figure 4: Slope Map of Damaturu Metropolis

3.3 Borehole Depth Distribution

The borehole depth distribution in Damaturu Metropolis varies significantly, ranging from 12m to 132m (Figure 5 and Table 2), indicating diverse subsurface conditions and groundwater availability. This finding contradicts similar studies conducted in southern Nigeria. Agbede *et al.* (2019) reported borehole depths ranging from 24.24m to 70m, while Odipe *et al.* (2020) found that depths to water ranged from 1.6m to 13.3m. Similarly, Damilola and Olumide (2017) revealed a range of 2.06m to 10.3m. Deeper boreholes, exceeding 100 m, indicate areas with deeper aquifers, possibly due to lower permeability or confined groundwater conditions, while shallower boreholes (below 50 m) suggest regions where groundwater is more accessible, likely within unconfined aquifers. According to Akinwumiju and Olorunfemi (2016), high groundwater elevation can be attributed to a thin overburden layer and favorable climatic conditions. The variation in borehole depth across Damaturu is influenced by topography, climatic condition, and recharge rates, with deeper boreholes commonly found in areas with lower hydraulic heads or higher elevations.

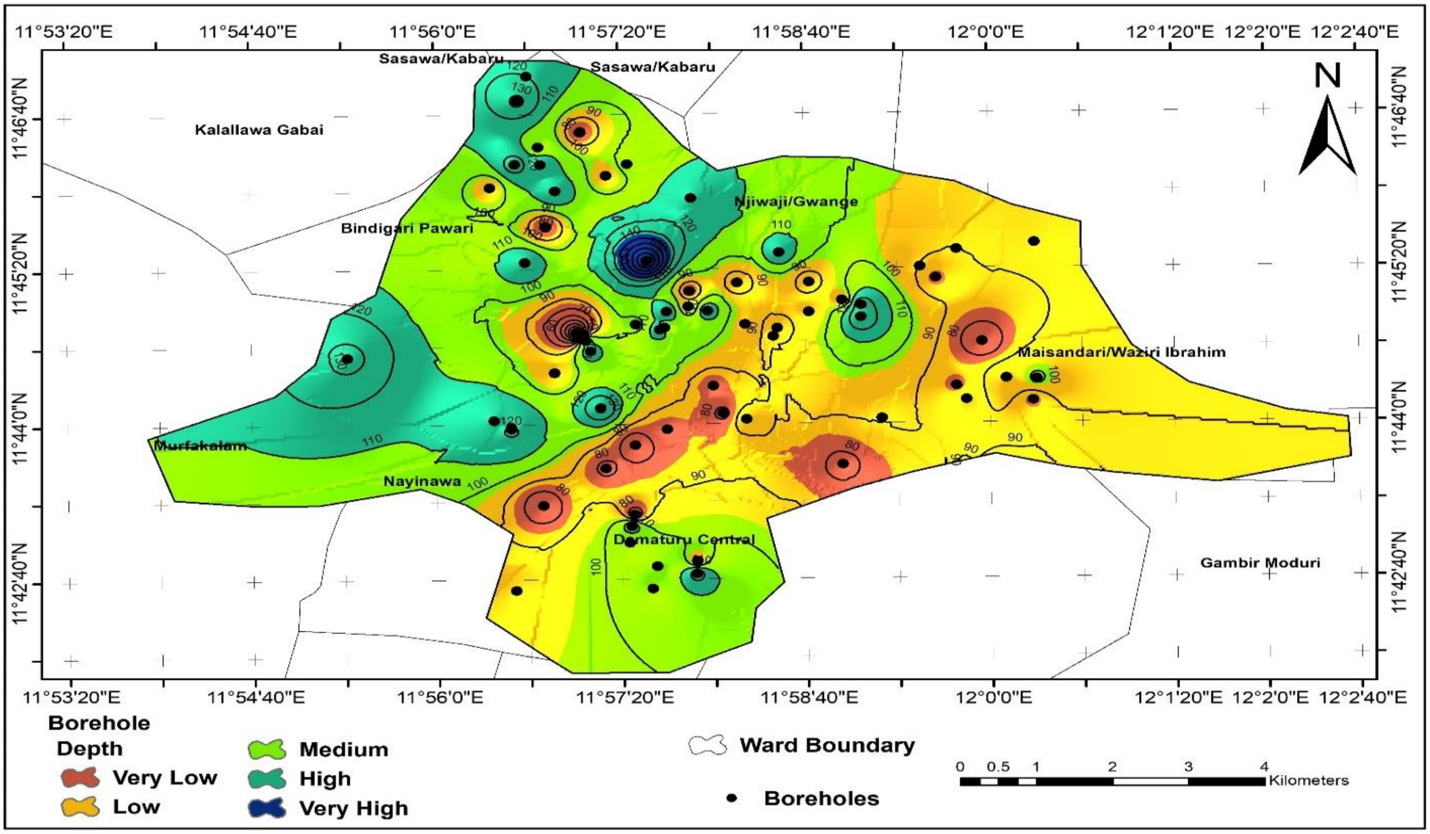

Figure 5: Contour Map of Borehole Depth in Damaturu Metropolis

3.4 Spatial Distribution of Borehole Depth Categories and Extent

Table 1, presents the spatial distribution of borehole depths across different categories within Damaturu Metropolis, covering a total area of 69.6 square kilometers. The depth categories range from Very Low to Very High showing variations in groundwater accessibility or drilling efforts across the region. The largest area, 27.54 sq km (39.6%), falls under the Low depth category revealing that shallow boreholes are common in a significant portion of the metropolis.

Table 1: Spatial Distribution of Borehole Depth Categories and Extent in Damaturu Metropolis

Depth	**Area (Sq km)**
Very Low	4.35
Low	27.54
Medium	25.13
High	12.19
Very High	0.41
Total	69.62

3.5 Static Water Level Depth in Damaturu Metropolis

The static water level (SWL) distribution in Damaturu Metropolis varies between 18 m and 96 m, indicating significant differences in groundwater depth across the region (figure 6). Areas with lower SWL values (18–50 m) indicate shallow water tables, likely found in regions with higher permeable geological formations. Contrarily, higher SWL values (above 70 m) demonstrates deeper groundwater levels, possibly as a result of lower permeability.

This finding contrasts with previous studies. Abolarin and Ibrahim (2015) reported that the static water levels of wells and boreholes in Ilorin ranged between 288.5 m and 357.0 m, while Amah and Agbebia (2015) found that static water levels above sea level, derived from depth-to-water measurements and elevation data, ranged between 270.8 m and 371.4 m.

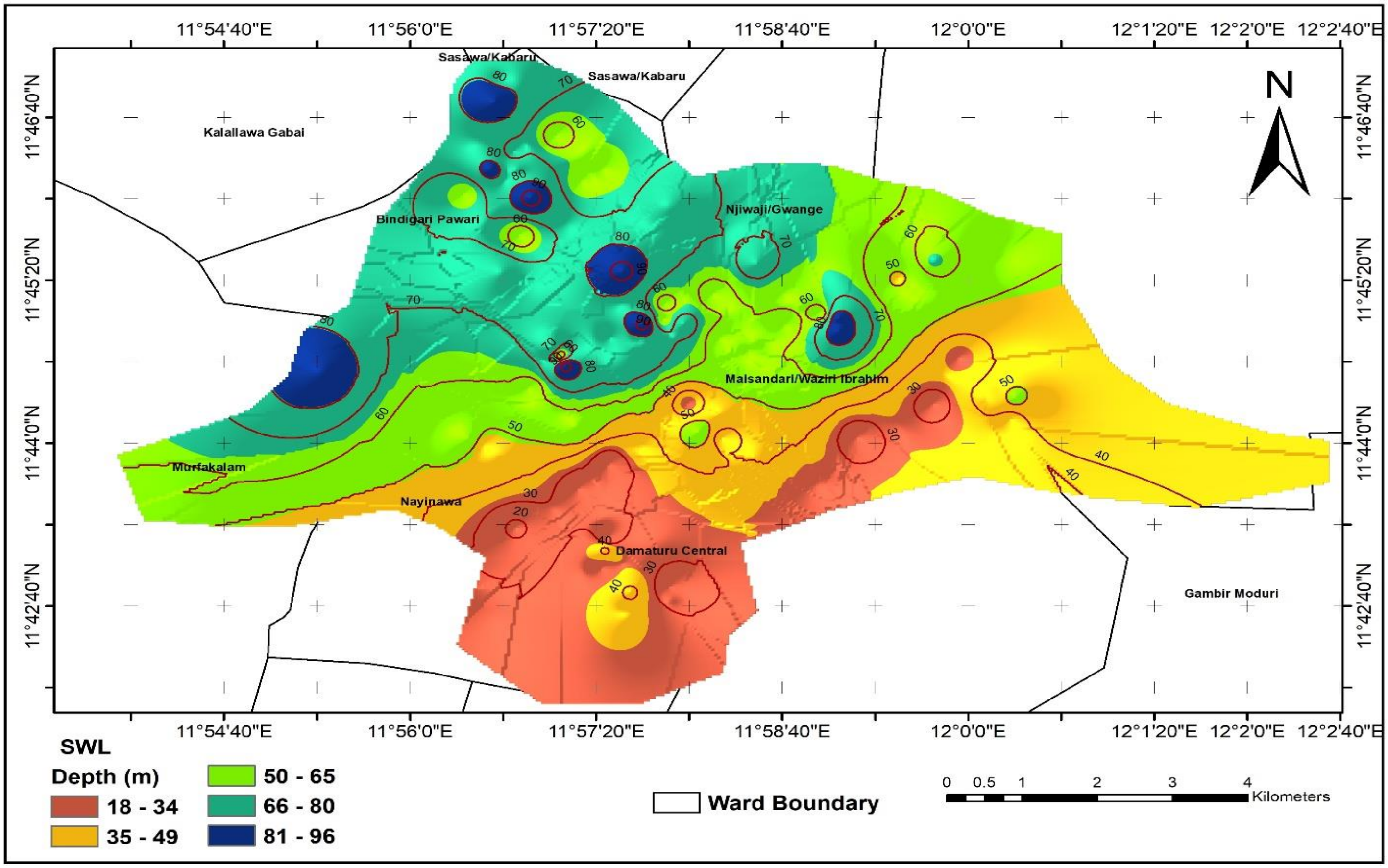

Figure 6: Contour Map of Static Water Level Depth in Damaturu Metropolis

Table 2: Borehole Data, Depths, and Hydraulic Characteristics in Damaturu Metropolis

S/No.	BOREHOLE NAME	BOREHOLE DEPTH	INSTALL DEPTH	STATIC WATER LEVEL	ELEVATION_(m)	Hydraulic Heads	REMARK
1	DA 2	180	126	94	376	282	Functional
2	DA 5	84	64	60	375	315	Functional

3	DA 8	78	68	60	382	322	Functional
4	DA 13	78	68	54	388	334	Functional
5	DA 17	120	100	54	369	315	Functional
6	DA 21	70	60	30	376	346	Functional
7	DA 22	90	70	66	368	302	Functional
8	DA 24	78	60	54	377	323	Functional
9	DA 27	96	68	72	369	297	Functional
10	DA 28	84	60	60	371	311	Functional
11	DA 30	120	100	96	380	284	Functional
12	DA 33	96	66	72	376	304	Functional
13	DA 37	102	90	78	364	286	Functional
14	DA 39	120	90	96	371	275	Functional
15	DA 41	78	60	54	367	313	Functional
16	DA 49	120	102	96	370	274	Functional
17	DA 52	90	72	54	377	323	Functional
18	DA 57	120	102	78	372	294	Functional

19	DA 58	120	120	78	383	305	Functional
20	DA 61	90	70	50	372	322	Functional
21	DA 63	120	102	78	396	318	Functional
22	DA 64	120	102	78	380	302	Functional
23	DA 66	132	108	90	391	301	Functional
24	DA 69	90	72	48	370	322	Functional
25	DA 84	96	78	54	382	328	Functional
26	DA 85	102	66	54	377	323	Functional
27	DA 80	102	78	60	405	345	Functional
28	DA 81	90	66	60	368	308	Functional
29	DA 82	90	66	60	382	322	Functional
30	DA 84	84	66	54	391	337	Functional
31	DA 85	120	96	78	368	290	Functional
32	DA 86	102	78	66	393	327	Functional
33	DA 87	120	76	78	379	301	Functional
34	DA 89	90	66	60	383	323	Functional

35	DA 96	132	108	90	393	303	Functional
36	DA 98	84	60	54	370	316	Functional
37	DA 67	90	66	54	379	325	Functional
38	DA	126	102	84	387	303	Functional
39	Fedpodam 1	132	108	90	383	293	Functional
40	Fedpodam 2	126	102	87	368	281	Functional
41	Fedpodam3	90	66	54	381	327	Functional
42	DA 17	90	66	54	378	324	Functional
43	DA	12	96	78	371	293	Functional
44	DA 37	120	96	78	373	295	Functional
45	DA 12	82	54	30	387	357	Functional
46	DA 15	72	48	24	395	371	Functional
47	DA 16	84	48	36	381	345	Functional
48	DA 20	90	66	24	387	363	Functional
49	DA 25	78	54	24	394	370	Functional
50	DA 26	120	66	54	377	323	Functional

51	DA 32	84	48	36	382	346	Functional
52	DA 34	78	48	30	393	363	Functional
53	DA 35	96	60	36	389	353	Functional
54	DA 36	102	72	30	393	363	Functional
55	DA 46	72	52	20	381	361	Functional
56	DA 47	108	66	42	388	346	Functional
57	DA 53	84	60	24	394	370	Functional
58	DA 54	96	54	42	391	349	Functional
59	DA 55	132	72	60	388	328	Functional
60	DA 68	126	78	48	382	334	Functional
61	DA 73	126	96	30	390	360	Functional
62	DA 77	90	60	30	376	346	Functional
63	DA 83	120	78	42	383	341	Functional
64	DA 93	90	60	30	385	355	Functional
65	DA 97	90	60	24	389	365	Functional
66	DA 76	102	66	36	379	343	Functional

67		72	54	18	382	364	Functional
68		114	66	48	371	323	Functional

3.6 Groundwater Flow Direction and Proportional Distribution

Table 3 and figure 7 shows the groundwater flow direction analysis in Damaturu Metropolis indicates a predominant movement towards the South (21.9%) and East (19.4%), showing that these areas serve as major discharge zones where groundwater accumulates or flows toward lower elevations. The Southeast (14.0%) and West (11.9%) also exhibit significant groundwater movement, indicating a relatively balanced flow pattern influenced by the region's topography and aquifer characteristics. Less dominant flow directions include the Southwest (8.9%), Northeast (8.1%), North (10.0%), and Northwest (5.7%), revealing localized variations in hydraulic gradients. Odipe, *et al* (2020) and Ashaolu, & Adebayo (2014), opined that groundwater flow pattern based on the principle that water in its normal state flows in a perpendicular direction from zone of higher elevation to lower elevation suggesting that wells dug in zones of lower elevation will possible have high volume of water based on the hydrogeological condition of the aquifer.

Table 3: Groundwater Flow Direction and Proportional Distribution in Damaturu Metropolis

Grid code and Direction	**Count**	**Proportion**
1 (East)	91	19.4
2(SE)	66	14.0
4(South)	103	21.9
8(SW)	42	8.9
16(West)	56	11.9
32(NW)	27	5.7
64(North)	47	10.0
128(NE)	38	8.1
	470	100.0

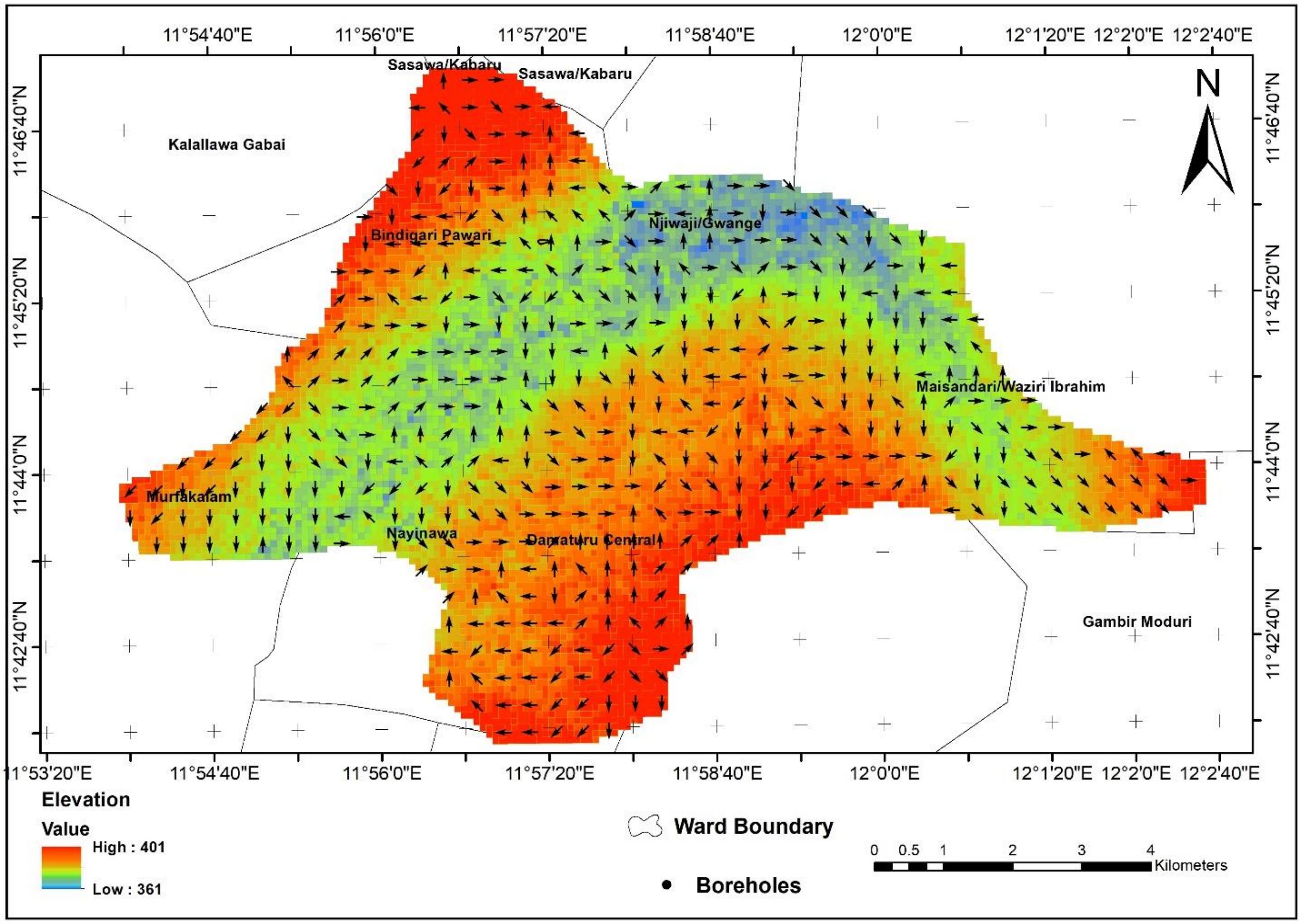

Figure 7: Groundwater Flow Direction in Damaturu Metropolis

Table 4: Geographic Coordinates of Boreholes in Damaturu Metropolis

S/No.	BOREHOLE NAME	LATITUDE_(N)	LONGITUDE_(E)
1	DA 2	11.7567	11.95868
2	DA 5	11.75357	11.97823
3	DA 8	11.73482	11.9677
4	DA 13	11.7752	11.9508
5	DA 17	11.74533	11.95127
6	DA 21	11.74492	11.999

7	DA 22	11.75818	11.996
8	DA 24	11.76168	11.94655
9	DA 27	11.7476	11.9573
10	DA 28	11.747	11.97434
11	DA 30	11.76678	11.94777
12	DA 33	11.73907	12.11967
13	DA 37	11.74713	11.96078
14	DA 39	11.7438	11.95187
15	DA 41	11.75232	11.96385
16	DA 49	11.74942	11.96105
17	DA 52	11.74927	11.97818
18	DA 57	11.76568	11.96412
19	DA 58	11.77058	11.946
20	DA 61	11.75908	12.00543
21	DA 63	11.75782	11.97465
22	DA 64	11.78327	11.94445
23	DA 66	11.74298	11.92252
24	DA 69	11.7557	11.99163
25	DA 84	11.74755	11.97048
26	DA 85	11.73955	12.00557
27	DA 80	11.77058	11.95648
28	DA 81	11.76895	11.95393
29	DA 82	11.75015	11.96368
30	DA 84	11.75352	11.96955
31	DA 85	11.75653	11.94403
32	DA 86	11.77307	11.94578
33	DA 87	11.74952	11.966
34	DA 89	11.76728	11.93992
35	DA 96	11.77977	11.94332
36	DA 98	11.75408	11.9935
37	DA 67	11.74582	11.97385
38	DA	11.77067	11.94292

39	Fedpodam 1	11.7485	11.98443
40	Fedpodam 2	11.75025	11.98448
41	Fedpodam3	11.75098	11.98218
42	DA 17	11.74073	11.9475
43	DA	11.74638	11.95022
44	DA 37	11.74685	11.9602
45	DA 12	11.73873	11.96658
46	DA 15	11.72037	11.95695
47	DA 16	11.73255	11.96098
48	DA 20	11.734	11.98688
49	DA 25	11.72702	11.95355
50	DA 26	11.73392	11.94015
51	DA 32	11.73647	12.0051
52	DA 34	11.72742	11.98212
53	DA 35	11.73397	11.97058
54	DA 36	11.7163	11.95633
55	DA 46	11.73032	11.95713
56	DA 47	11.71293	11.95962
57	DA 53	11.7386	11.99588
58	DA 54	11.73967	12.00188
59	DA 55	11.73565	11.95298
60	DA 68	11.7327	11.94223
61	DA 73	11.71187	11.96438
62	DA 77	11.73665	11.99708
63	DA 83	11.7187	11.95658
64	DA 93	11.70953	11.94262
65	DA 97	11.71367	11.96443
66	DA 76	11.70972	11.95903
67		11.7217	11.94598
68		11.73293	11.94223

4. Conclusion and Recommendation

The findings demonstrate the significant influence of topography and hydrology on

groundwater availability in Damaturu Metropolis. Variations in elevation and slope affect surface runoff, groundwater recharge, and borehole depth distribution. Low-slope areas support groundwater infiltration, whereas higher elevations pose challenges for water accessibility. Borehole depths vary widely, with deeper boreholes indicating confined aquifers and lower permeability zones. Static water levels range from 18 m to 96 m, reflecting variations in topography and recharge conditions. Groundwater flow predominantly moves southward and eastward, marking major discharge zones. These findings are critically important for sustainable water resource management. It is therefore recommended that boreholes in other parts of the State be geopositioned, with their locations recorded for GIS analysis. This will enable effective monitoring and modeling of groundwater levels using geospatial technology. Regular measurement of water table elevations at multiple locations will enhance the understanding of groundwater flow patterns, ensuring better management of water resources in the State.

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