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Suitable Zones for Groundwater Tapping Stations Using Geospatial Techniques in Morogoro Urban, Tanzania

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Abstract

In recent years, Morogoro Urban has experienced significant water scarcity primarily due to rising demand and limited surface water runoff from mountain slopes. Groundwater, therefore, offers a sustainable alternative to the prevailing challenge. This paper uncovers suitable zones for groundwater tapping stations using a GIS-based weighted overlay analysis (WOA), and triangulation of data acquisition methods. Supervised classification and change detection analyses were carried out in thematic layers. The WOA available as a spatial analyst extension in ArcGIS 10.7 was performed to derive final maps depicting groundwater potential zones, and suitable locations for groundwater tapping stations. The results suggest that Morogoro Urban has three groundwater potential zones: high (21.5%), moderate (30.2%), and low (48.3%). Zones highly suitable for groundwater tapping stations occupy 14.4% of the area, while moderate and low suitability zones cover 55.6% and 30%, respectively. The high groundwater potential zones in Morogoro Urban are mainly influenced by land use and geological characteristics. Despite much of the area exhibiting moderate groundwater potential, the studied environment is still conducive for the development of groundwater tapping stations. It is recommended that groundwater development and management in Morogoro Urban be guided by an integrated approach that combines hydrogeological assessment with land-use planning. Town planners and river basin authorities may potentially use the current results as a source of information in planning and designating suitable areas for development of boreholes and wells.

Keywords: *GIS, groundwater, overlay, potential zone, tapping station*

1. Introduction

The earth has about 1.4bn km^3 of water, out of which salt water contained in oceans and seas holds nearly 97%, ice caps and glaciers constitute 2%, while the remaining percent is occupied by rivers, lakes and groundwater (Meran et al., 2021). Despite the available potential sources of water accessible for human consumption, there has been an increase in water demand and use worldwide (Han et al., 2024). This is due to a growing human population, socio-economic development, and changes in patterns of water use (WWAP, 2019), thus posing water accessibility in the future questionable (Auindrila et al., 2025).

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At the global level, many countries are facing acute water stress; while over 2bn people are facing water scarcity (WWAP, 2024). Under such water access challenges, groundwater has become the most preferred source of portable water in many parts of the world; frequently considered as more acceptable, reliable, accessible and sustainable than surface water available in lakes, rivers, dams, and ponds (Guppy et al., 2018).

Africa, like other regions of the world, faces a water crisis. Records show that only 61% of its population has access to safe and clean water (WHO, 2023). Furthermore, one in three Africans has no access to clean water; and about 400m people in Africa have no access to portable water (Holtz & Globus, 2021). Moreover, large populations use more than 30 minutes daily in search of water (Rodriguez & Julian, 2019). With the growing challenge of water scarcity, groundwater is becoming the most preferred source of water to the majority of local populations than surface and rainwater since surface water has high treatment costs before use and, in many areas—especially in dry localities—it is mainly seasonal (Nyika, 2023). Therefore, groundwater harnessing stands as the best optional water source (WaterAid, 2022).

In Sub-Saharan Africa (SSA), harnessing of groundwater from constructed boreholes, wells and natural springs for domestic purposes is inadequately carried out to supply growing populations in the region (Oriol et al., 2020). This is mainly due to low technology for exploring groundwater potential zones, and limited knowledge on spatial distribution of sparse groundwater systems (Castillo et al., 2022; Roy et al., 2024).

Water scarcity is becoming a great challenge in many parts of Tanzania. The main concerns remain on spatial distribution, adequate quantity, sufficient quality, and utilization pattern of available water (Caudally et al., 2024). Diverse competition among users, erratic and inadequate rainfall, growing population, degradation of watersheds and various water sources due to anthropogenic activities: all these are the driving forces of water scarcity (Sigalla et al., 2023). Like in some other parts of Tanzania, Morogoro Urban is facing water shortages partly due to a decline in reservoir water quantity, particularly in the Mindu dam; and the drying-up of rivers originating from the slopes of Uluguru mountains feeding the dam that supplies water in the area (Dutch Water Sector, 2024). Moreover, springs are no longer a reliable source of water as it used to be in the past due to the aforementioned reasons. All this has led to routine water rationing (Kabote, 2024).

The Mindu dam—the main source of water—accounts for 80% of all water supplies in Morogoro Urban. This reservoir currently produces 27m litres per day, and its water has been reported to dry in drought years. The available water sources produce 7m litres per day, while the municipality's daily water demand is over 40m litres per day. Records show that, in March 2017, water demand in the area exceeded the supply by 13m^3; a proportion that suggests the existence of prolonged water shortages in the Morogoro Urban (Melchioly, 2021). It is in this regard that it becomes imperative to explore alternative water sources to enable urban water supply to increase the required volume of water, particularly from groundwater sources that have remained underexploited for many years.

Given the intrinsic challenges of surface water in terms of quality and quantity, if groundwater is properly developed, managed and sustainably exploited, it can become a highly useful, reliable, cost-effective, and an efficient source of water, ultimately addressing the water shortage in Morogoro Urban. The technological development in geographic information systems (GIS) and remote sensing, which have proven to be robust tools in hydrogeology mapping and exploration, can help locate groundwater potential zones when properly used (Chaminé, 2021). At present, the quantity and distribution of groundwater in Morogoro Urban are unclear due to the complex and irregular nature of most groundwater formations in the area. Hence, by using GIS and remote sensing, groundwater potential zones can be determined, and suitable zones for groundwater tapping stations can be identified (Meng et al*.,* 2024). This enables sustainable exploitation of groundwater to ensure supportable water accessibility and availability. This approach is the central focus of this paper.

2. Context and Methods

2.1 Study Area

The study was conducted in Morogoro Urban, Tanzania, located at latitude 6° South and longitude 37° East, covering a land area of 288.25km^2 (Figure 1). According to the 2022 national census, the human population of the Morogoro Urban was 471,409 (URT, 2022). The area has a tropical climate with bimodal rains. Short rain occurs in October to December, while long rains fall in the months of February to May. There are variations of rainfall in the area, ranging between 1800 and 2000mm, depending on elevation. These variations are also notable in temperature, where the minimum average monthly temperature is 16^{o}C, and the maximum temperature is 33^{o}C (Nkya et al*.,* 2017).

The topography is largely influenced and dominated by the Eastern Arc Mountains, particularly the Uluguru mountains that are characterized by steep slopes, and are responsible for dictating drainage systems and numerous weather patterns (Pori et al*.,* 2022). The main land uses in Morogoro Urban are built-up land, agriculture, vegetation, and water bodies (DWS, 2024). Morogoro Urban was chosen as a study area since it experiences critical water shortage for domestic uses. Nearly 65% of the population in the area lives in unplanned settlements, thereby posing risks of water contamination and increased water-borne diseases (Steven et al*.,* 2015).

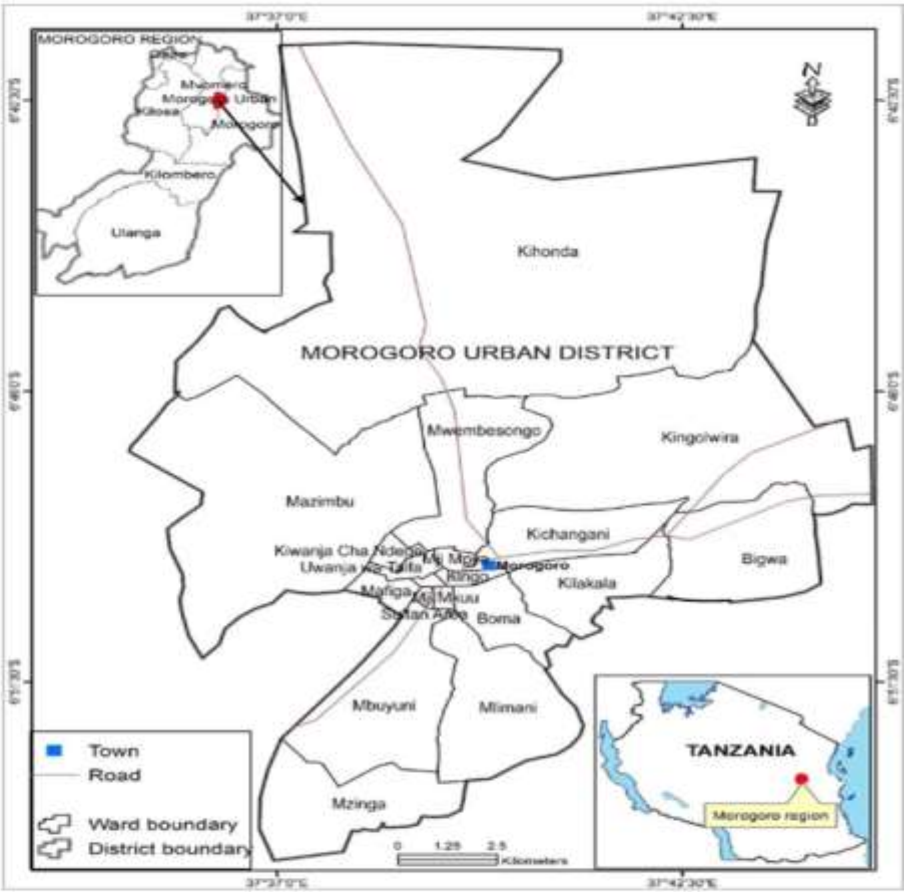


Figure 1: Location of the Study Area
Source: GIS Lab, UDSM (2025).

2.2 Data Collection

The study generated both primary and secondary data. The former were obtained through a triangulation of methods, including participatory observation, reconnaissance and the use of remote-sensed data. Field reconnaissance was conducted to assess the land use, geology, geomorphology, and hydrology of the area (Figure 2). Ground-truthing of satellite imagery and verification of secondary data were conducted to ensure the accuracy of classified land-use information. In addition, a reconnaissance on documented local geological characteristics, presence of lineaments, surface runoff, and drainage features—such as streams and nearby wells—was carried out. These parameters were considered as key indicators for potential identification of aquifer. They are also useful in assessing areas with potential groundwater deposits and sources as vegetation cover absorbs, transmits, and retains significant amounts of water (Pinto et al., 2015).

(a) Hydrology **(b) Geology**

(c)Agricultural land use **(d) Geomorphology**

Figure 2: Hydrogeology, Geomorphology, and Land Use of Morogoro Urban

Source: Author (2025)

The secondary data were obtained through review of available institutional documents and downloading remote-sensed data. The data acquired through remote sensing were digital elevation model (DEM) and satellite images, while the hydrogeology and rainfall data were obtained from relevant institutions. The 30-meter resolution DEM was downloaded from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) site of the United States Geological Survey (USGS). The DEM provided a digital representation of the terrain in Morogoro Urban, which was used to estimate and assess the effects of slope on the area's overall hydrology. Enhanced Thematic Mapper Plus (ETM+) Landsat 7 images covered by Landsat World Reference System-2 (WRS-2)—with a spatial resolution of 30m × 30m, path 166 and row 65 for the years 2000, 2010 and 2020 (Table 1)—were downloaded online from the USGS official website portal available at earthexplorer.usgs.gov.

Table 1: Characteristics of the satellite images used in this study

S/N	Image ID	Acquisition date	Resolution	Path/ Row	Sensor
1.	LE07L1TP16706520000707	07-07-2000	30 m	166/65	ETM+
2.	LE07L1TP16706220100628	28-06-2010	30 m	166/65	ETM+
3.	LC07L1TP16806220200922	22-09-2020	30 m	166/65	ETM+

Source: USGS (2025).

The hydrogeological data—which include the geology, lineament, and drainage density—were extracted from a pre-existing geological toposheet of the Morogoro Quarter Degree Sheets (QDS), No. 183, which had a ratio scale of 1: 125,000. The QDS sheet was acquired from the Tanzania Geological Survey (TGS). The monthly rainfall data covering a duration of 20 years (2000–2020) were obtained from the Tanzania Meteorological Agency (TMA).

2.3 Data Analysis

The satellite images were processed, and scenes selected for geometrically and radiometrically corrections and calibration to make them dropouts free using ArcGIS 10.7 image analyst extensions. With the Landsat 7 ETM+ for the year 2020, a line removing process was done so as to fill gaps on areas of the image scenes that had no data. The process involved identifying the missing or corrupted scan lines caused by the Scan Line Corrector (SLC) failure. The pixels affected by the SLC failure were detected using the quality assessment information and the characteristic wedge-shaped pattern of data loss. This was achieved by applying a spatial interpolation approach, in which the values of neighbouring valid pixels were used to reconstruct the missing data. In areas where sufficient neighbouring information was available, local averaging and focal statistics were employed to generate replacement values that preserved the spatial continuity of the images. After gap filling, the corrected images were visually inspected to assess the effectiveness of the line removing process using statistical comparisons between original valid pixels and the filled areas to ensure that no significant radiometric distortions were introduced. Thereafter, all images were stratified into separate zones considering similarities of spectral properties of land cover types within a zone. The main analytical techniques were supervised classification, change detection analysis, and overlay analysis using ArcGIS 10.7 spatial analyst extensions. A combination of thematic geologic layers, drainage density, lineament density, slope, land use and rainfall data were used in the analysis.

In performing land use/cover analysis, three land use maps from the images of 2000, 2010 and 2020 were created and superimposed to detect land use changes. Thereafter, a supervised classification analysis was employed to classify the images into respective land use classes, which included forests, built-up areas, wetlands, and water bodies. Some land use classes—such as grassland, barren land, and shrubland—were excluded in the analysis because they are highly seasonal, especially during the dry period. These classes are also temporally unstable and frequently transitional; shifting between farmlands and sparse forests due to grazing, burning, or farming cycles; which make them less distinct and persistent. In addition, they usually occur as small, fragmented patches mixed with dominant classes such as farmland, forest, or built-up areas; hence these were assigned to the surrounding dominant land cover. In areas where cloud contamination persisted, the affected pixels were classified as cloud or no-data class, and excluded from land use/cover change detection due to the lack of reliable surface information. This reduced the risk of misclassification and prevented cloud-related noise from biasing change detection results to ensure transparency and enhance the reliability of the LULC change results.

The geological maps were digitized and updated with satellite images to generate drainage and lineament density layers. Monthly rainfall data were prepared for different rainfall stations located in Morogoro Urban for the period 2000–2020. For each year, twelve (12) thematic maps—consisting of twelve (12) monthly rainfall data—were generated. For each year, all thematic maps were combined using a raster calculator to produce a single thematic map. Subsequently, the thematic maps for the entire study period were aggregated, summed, and divided by 20 to obtain the average values across all study years. Finally, the resulting map was classified to illustrate the spatial distribution of rainfall in Morogoro Urban.

After the preparation of geological, rainfall, land use, drainage, and lineament density thematic maps, weights were assigned to them with a consideration of their relative importance in groundwater recharge and discharge (Table 2). Rainfall was given 25% as it is the main source of groundwater, drainage density and geology were assigned 20% each because they control infiltration, storage capacity, and runoff. Land use was given 15% because of its role in regulating infiltration through vegetation cover and human activities, while slope and lineament density were given lower weights of 10% each as they influence recharge indirectly, mainly by affecting runoff velocity and localized groundwater movement through fractures (Kabeto et al., 2022; Arumugam et al., 2023; Mustapha et al., 2023; Alharbi, 2024). Rainfall received more weight than all other criteria because it is the primary and direct source of groundwater recharge, determining the total amount of water available for infiltration in Morogoro Urban. Without sufficient rainfall, recharge cannot occur regardless of hydrogeology and land cover types. Therefore, rainfall exerts a stronger and more fundamental control on groundwater availability than all criteria, which plays supportive and secondary role in the recharge process.

Thereafter, each thematic layer was apportioned into several classes according to their hydrogeological characteristics. All classes were weighted based on how they are relatively important in yielding groundwater; and percentage weights were normalized to ensure their sum equalled 100%. As such, ranks 1 to 3 were assigned to each layer based on their influence on groundwater occurrences. For example, in the rainfall thematic layers, the first rank was assigned to areas receiving high annual rainfall, the second rank to areas with moderate rainfall, and the third rank to areas with low annual rainfall. The classification and ranking systems for each factor were guided by expert judgment considering them as primary factors that represent and control groundwater potential in Morogoro Urban and in the document review (Arulbalaji et al., 2019; Godif & Manjunatha, 2023).

Table 2: Criteria, Classes, Ranks and Weights of Thematic Layers

Criteria	Classes	Rank	Weight (%)
Geology	Sedimentary rocks, friable, porous rocks	1	20
	Faulted basement rocks	2	
	Basement rocks	3	
Drainage	Low drainage density	1	20
	High drainage density in porous/ fractured terrains	2	
	High drainage density	3	
Lineament	Present	1	
	Non-present	3	10
Slope	<20	1	10
	20-50	2	
	>50	3	
Rainfall	Heavy	1	25
	Medium	2	
	Low	3	
Land use	Forest, agricultural plantation and cropland.	1	.
	Fallow harvested land, and degraded forest	2	
	Hills/barren rocks/stones/ sheet rocks, mining and built-up land, and salt affected land.	3	15

Source: Author (2025).

Furthermore, for geologic thematic maps, favourable geological settings like those containing alluvial and sedimentary deposits were given a 1st rank, while a 2nd and 3rd ranks were given to jointed basement terrains and impenetrable un-jointed settings, respectively. In the case of lineament density layer, areas containing high lineament density were given a 1st rank, while areas with no lineament density were given a 3rd rank. Again, in the drainage density layer, areas with low drainage density—exemplified by surface runoff—were given a 1st rank as they allow less runoff and have a significant percolation of groundwater. However, areas with dense surface runoff were given a 3rd rank for reason that they allow more runoff, and thus less percolation.

Concerning slope, the 1st rank was given to gentle slope with elevation less than 20m since these areas had slower surface runoff and allow more water percolation per unit time. The 2nd rank was assigned to areas with elevation between 20–50m, while the 3rd rank was given to steep slopes with elevation above 50m. With land use thematic map, the 1st rank was assigned to crop plantations and agricultural fields; the 2nd rank was given to fallow harvested lands and degraded forest; while the 3rd rank was assigned to settlements or built-up land. Thereafter, a spatial analyst tool was used to analyse all layers to produce a groundwater potential map. Finally, a weighted overlay analysis (WOA) was performed by multiplying each reclassified thematic layer by its corresponding weight, and summing the results on a pixel-by-pixel basis to generate a groundwater suitability map. The WOA generated an overall final map showing groundwater categorised into high, medium and low potential zones using the natural breaks classification method. The WOA computation for groundwater suitability index (GSI) was presented as:

$$GSI = \sum_{i=1}^{n} (W_i \times R_i)$$

Where; W_i represents the normalized weight of the i^{th} thematic layer; and R_i represents the reclassified suitability score of that layer.

The GSI values were subsequently reclassified into high, medium, and low groundwater potential zones (Mehmet et al., 2024; Chalachew & Demeke, 2025). The GSI was normalized to a 0–100 scale, with areas scoring 70–100 classified as high potential, representing locations with highly favourable recharge conditions such as permeable geology, gentle slopes, and high rainfall. Areas scoring 40–69 were considered medium potential, indicating moderate suitability where certain factors may limit groundwater availability. Areas scoring 0–39 were classified as low potential, typically associated with unfavourable conditions such as steep slopes, impermeable rocks, low rainfall, high drainage density, or urban and industrial land where groundwater recharge is limited.

Thereafter, a suitability analysis for groundwater tapping stations was conducted using rasterized groundwater potential zone maps generated at an earlier stage, supported by thematic layers representing the key factors used in the groundwater potential analysis. Criteria, buffer distances, and rankings for groundwater tapping station suitability analysis were created and treated as constraint or exclusion/buffer criteria particularly for protecting water quality, ensuring safety, avoiding land-use conflict, and complying with national planning and legal restriction, while supporting safe and sustainable groundwater development. After generating the finalized master plan map, the

RECLASS tool was applied to reclassify all the parameters into three suitability classes (Table 3), which were finally subjected to WOA. On the master plan map, the 1st rank was assigned to areas that are not yet developed; the 2nd rank was assigned to the buffer zones located in, and near, the linear features such as rivers, railways and roads; and the 3rd rank was assigned to the already developed and conserved areas in which tapping stations in consideration cannot be developed.

Table 3: Groundwater Tapping Station Suitability Analysis Scheme

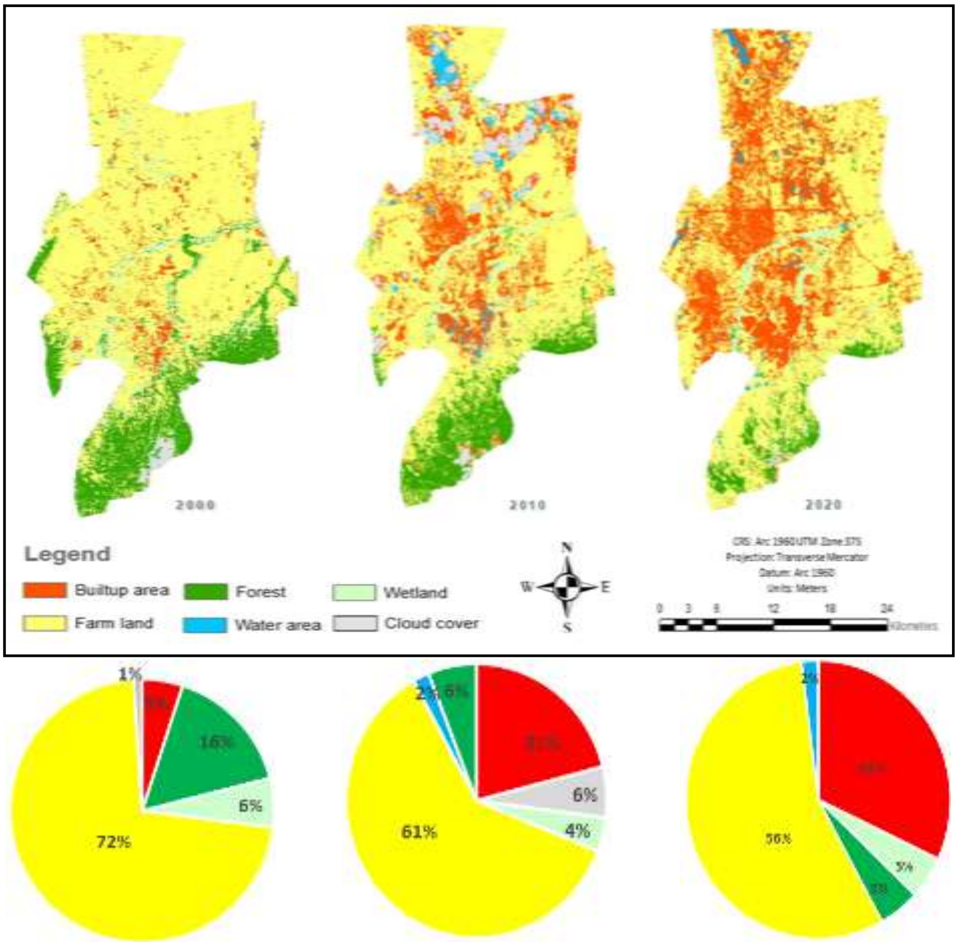
Criteria	Buffer distance (m)	Suitability Class	Rank
Settlements, education and commercial centres	< 500 500–1000 > 1000	Low suitable Moderate suitable Highly suitable	1 2 3
Water bodies and rivers/ streams buffer zones	< 300 300–500 > 500	Low suitable Moderate suitable Highly suitable	1 2 3
Airport and military areas	< 1000 > 1000	Excluded Low suitable	0 1
Cemeteries	< 250 250–500 > 500	Low suitable Moderate suitable Highly suitable	1 2 3
Conserved and tourism areas	Inside protected area ≤ 1000 buffer > 1000	Excluded Low suitable Moderate suitable	0 1 2
Roads, pipelines and railway networks	< 150 150–300 > 300	Low suitable Moderate suitable Highly suitable	1 2 3

Source: Author (2025).

3. Results and Discussion

3.1 Parameters Influencing Groundwater Potentiality

The type and distribution of land use significantly influence groundwater recharge and discharge. Land use affects infiltration, soil moisture, and surface water retention, which are key indicators of groundwater availability. Understanding these relationships is particularly important in urban areas, where rapid changes in land use can impact groundwater resources. Morogoro Urban has five primary land use and land cover classes, namely farmland, built-up areas, forests, wetlands, and water bodies (Figure 3). Among these, vegetative grounds—which include agricultural plantations and croplands—cover the largest portion of the study area. These vegetative areas exhibit high water retention due to their soil structure, vegetation density, and root systems: all of which enhance infiltration and reduce surface runoff.



2000 2010 2020

Figure 3: Land Use Change in Morogoro Urban from 2000 to 2020

Source: Author (2025)

Uplands, fallow harvested land, and degraded forests retain moderate amounts of water; but are less effective than fully vegetated lands due to sparse vegetation and soil degradation. Restoration of vegetation and implementation of soil conservation practices could enhance their ability to contribute to groundwater recharge. Hills, industrial sites, and built-up areas demonstrate low water retention capacity due to impervious surfaces, and poor soil conditions. As a result, they contribute minimally to groundwater recharge while increasing surface runoff, which may exacerbate erosion and reduce groundwater availability. Overall, the findings indicate that vegetative land uses, particularly farmland, are critical for sustaining groundwater resources in Morogoro Urban. Effective land management strategies—including preservation of vegetative cover, rehabilitation of degraded uplands, and careful urban planning—are essential to maintain groundwater recharge.

Slope is an important parameter influencing groundwater occurrence as it directly affects surface water and groundwater recharge through infiltration and percolation. Gentle slopes are characterized by slow surface runoff, which allows more time for water to infiltrate and percolate from the surface into the groundwater system. In contrast, steeper slopes result in rapid surface runoff, thereby reducing the residence time of water on the surface, and limiting the amount of water that can infiltrate into subsurface reserves. Figure 4(a) indicate that areas with gentle slopes—ranging from 0 to 20m (green)—are the most favourable for groundwater prospecting. Such areas allow for higher infiltration rates and enhance recharge potential; and usually have thicker and more uniform soil cover, experience lower soil erosion thereby preserving soil structure and porosity, which in turn enhances infiltration capacity and provide better conditions for the storage and movement of groundwater, making such areas optimal for groundwater development. Areas with moderate slopes—between 20 and 50m (yellow)—are moderately favourable, offering limited but still significant opportunities for groundwater recharge. Conversely, areas with steep slopes exceeding 50m (red) are the least favourable for groundwater accumulation due to rapid runoff and minimal infiltration.

Geology is a critical factor influencing the occurrence and movement of groundwater as it determines how water infiltrates, moves through, and is stored within subsurface and ground formations. Morogoro Urban lies predominantly on basement rocks composed of metamorphosed migmatites and gneisses. The geological formations of the area include high-grade metamorphic rocks of the Precambrian age and part of the Mozambique belt, which include hornblende-pyroxene granulites, muscovite-biotite gneisses, quartzites, banded pyroxene granulites, migmatites, and tonalite-trondhjemite-granodiorite (TTGs) of various origins and compositions. These rocks have undergone folding and faulting. Additionally, younger superficial Neogene deposits are present, including limestone, colluvium, alluvium, sands, Karoo sediments, and red to reddish-brown soils.

As indicated in Figure 4(b), large portion of the study area—extending from the western side towards the central and northern parts (green)—are covered by sedimentary, friable and porous geological formations, including superficial sedimentary deposits as well as colluvial and alluvial materials. These formations contain significant pore spaces between grains, facilitating rapid and efficient infiltration of water into the subsurface and underlying groundwater systems. Areas with high porosity are highly advantageous as they are more permeable, retain larger amounts of water, and allow easier movement of water through pore spaces, making them richer in groundwater resources.

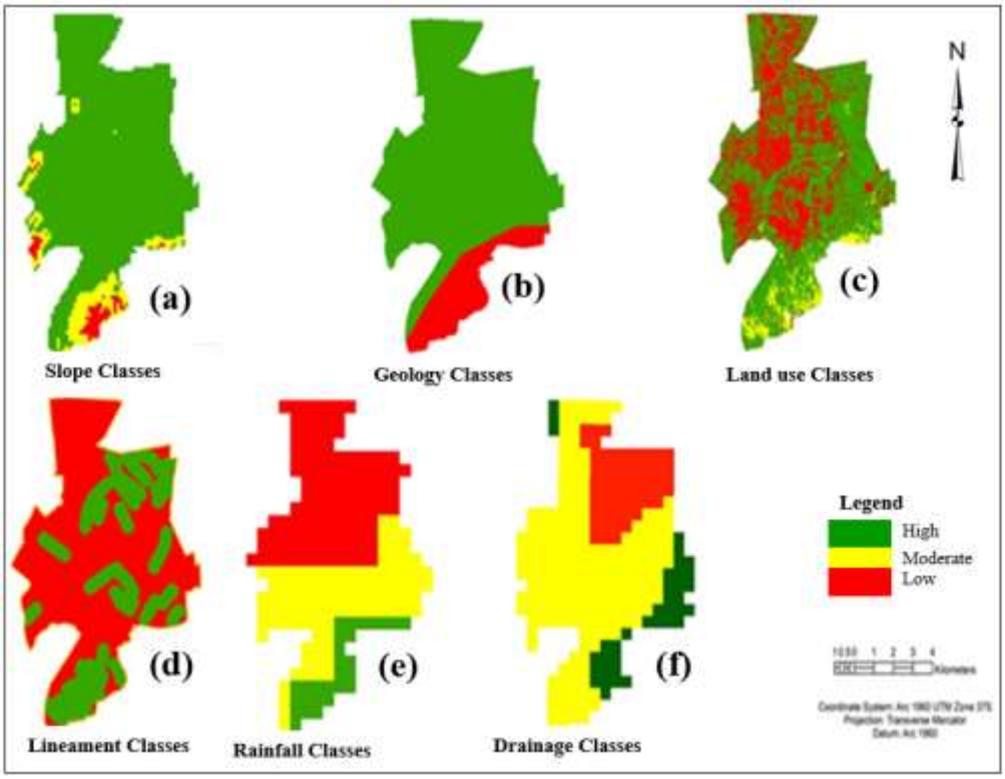


Figure 4: Parameters influencing groundwater potentiality in Morogoro Urban
Source: Author (2025)

Conversely, a smaller proportion of the study area (red) is dominated by aquifuge geological formations unsuitable for groundwater abstraction. These areas are underlain by basement rocks of igneous and metamorphic origin that are neither porous nor permeable, and therefore lack the capacity to store or transmit groundwater. The distribution of permeable versus impermeable geological formations highlights the spatial variability of groundwater potential across Morogoro Urban, and underscores the importance of geology in guiding water resource management. The current results concur with Zeabraha et al. (2020) and Kubingwa et al. (2023), who found groundwater recharge dynamics to depend much on the geology and hydrogeological conditions of an area, as well as existing land use and soil textures.

The presence of lineaments—such as faults and fractures—significantly influences groundwater recharge by providing secondary porosity and permeability, particularly in basement rock areas. These structural features act as conduits for the infiltration and percolation of surface and subsurface water into groundwater reserves, enhancing recharge potential. Figure 4(d) reveals that areas with faults (green) have the highest groundwater potential. These zones are found to be the most favourable for groundwater tapping due to the increased permeability and connectivity provided by the lineaments. Conversely, areas with no faults (red) are less favourable for groundwater development as the absence of structural conduits limits water infiltration and subsurface flow. Locations with complex lineament density facilitate greater groundwater penetration and recharge, making them highly valuable for sustainable groundwater extraction. These results underscore the importance of incorporating structural lineaments into groundwater assessment, as areas with abundant lineaments can significantly enhance groundwater availability, especially in regions underlain by low-porosity basement rocks.

As pointed out earlier, rainfall is a key factor influencing groundwater recharge as it provides the primary source of water that infiltrates into the subsurface. Areas receiving higher rainfall generally have greater potential for groundwater recharge as rainfall increases soil moisture and surface water availability, thus allowing more water to percolate into underlying aquifers. Conversely, areas with low rainfall receive limited water input, hence reducing infiltration and the overall replenishment of groundwater reserves. As indicated in Figure 4(e), high rainfall zones (green) are most favourable for groundwater development as abundant rainfall promotes efficient recharge of both shallow and deep groundwater systems.

Areas with moderate rainfall (yellow) are moderately suitable for groundwater accumulation, since although recharge is possible, it is limited during dry periods. Areas with low rainfall (red) are least favourable for groundwater, as insufficient rainfall reduces both soil moisture and percolation rates, hence limiting groundwater availability. However, spatial distribution of rainfall across Morogoro Urban interacts with other controlling factors such as land use, geology, and slope to determine the overall groundwater potential. Areas with a combination of high rainfall, permeable geological formations, gentle slopes, and vegetative land cover are expected to have the highest groundwater recharge potential; while zones with low rainfall, impermeable rocks, steep slopes, or built-up areas are likely to be less productive in terms of groundwater resources.

Drainage is a key factor influencing groundwater recharge as it controls the balance between surface runoff and the infiltration and percolation of water into the subsurface. Figure 4(f) shows that drainage density is inversely related to permeability, such that areas with high drainage density (green) generate greater surface runoff, which reduces the time available for water to infiltrate and recharge the groundwater system, thereby rendering these zones less suitable for groundwater development. In contrast, areas with moderate drainage density (yellow) offer some potential for groundwater recharge; while those with low drainage density (red) allow more time for water to percolate into the ground, making them more favourable for groundwater recharge; hence making them have high groundwater potential. These areas provide optimal conditions for infiltration and percolation, thereby making them suitable for developing groundwater tapping stations.

The drainage and lineament characteristics observed in Morogoro Urban are consistent with the findings by Mgelwa et al. (2024) who identified rainfall, topography, lithology, land use, drainage, and lineament density as the key factors influencing groundwater potential in Mpwapwa District, Tanzania. Also, Allafta et al. (2020) had similar findings in the Shatt Al-Arab Basin, Southwest Asia. Minor differences in the ranking of potential zones may reflect variations in soil type, lithology, and aridity across the study sites. Correspondingly in agreement with the current study, Roy et al. (2020) and Adesola et al. (2023) found that areas with poor groundwater potential are generally characterized by low rainfall, steep slopes, high drainage density, and sparse lineaments.

3.2 Groundwater Potential Zones

Morogoro Urban is classified into three groundwater potential zones: high groundwater potential zone covering 62km^2 (21.5% of the total area); moderate groundwater potential zone covering 87.04km^2 (30.2% of the total area); and low groundwater potential zone covering 139.21km^2 (48.3% of the total area). Figure 5 shows a distinct spatial variation in groundwater potential, with most of the southern parts exhibiting low groundwater potential, the central area displaying low to moderate groundwater potential, and the northern part showing moderate to high groundwater potential. Although some parts of southern Morogoro Urban receive relatively higher rainfall compared to the other areas, they still exhibit low groundwater potential. This is mainly attributed to the limited aquifer potential of the basement complex terrain, which is dominated by igneous and metamorphic rocks with low primary porosity. In addition, the spatial distribution of groundwater potential is strongly influenced by slope: whereas the southern part is characterized by steeper slopes, the other parts have gentler slopes. Furthermore, the southern area is largely covered by fallow harvested lands, degraded forests, and uplands without scrubs, which further limit infiltration and groundwater recharge compared to the rest of Morogoro Urban.

Additionally, even though the southern part receives abundant rainfall, it is not in the high groundwater potential zone because recharge depends on how effectively rainwater infiltrates and percolates into the subsurface. However, due to steep slopes in these parts, rainfall rapidly runs off the surface, thereby reducing the time available for infiltration.

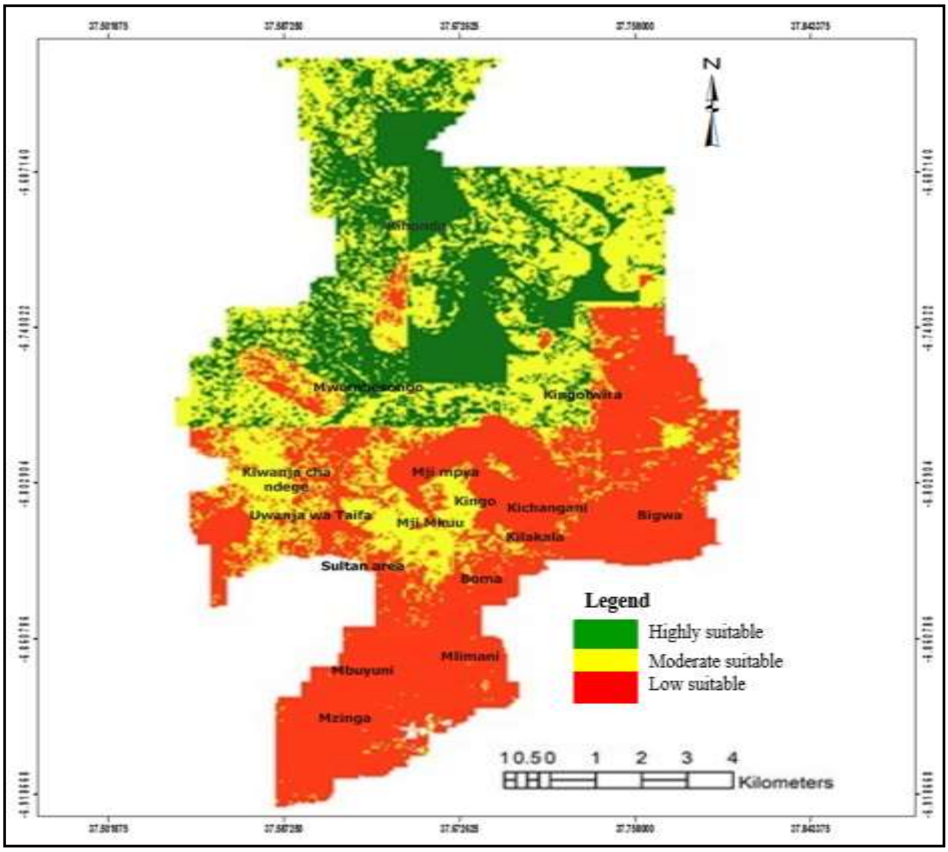


Figure 5: Groundwater potential zones in Morogoro Urban
Source: Author (2025)

Moreover, the area is underlain by low-permeability basement rocks preventing water from percolating into aquifers. It also has high drainage density which further channels water away quickly, thus limiting infiltration. Therefore, despite receiving more rainfall, these areas contribute less to groundwater reserves compared to zones with gentle slopes, permeable soils, lower drainage density, and vegetative land cover in the study area, which allow water to penetrate and recharge the subsurface more efficiently. All these conditions partly contribute to the observed low groundwater potentiality in the southern side of Morogoro Urban.

Furthermore, the expansion of built-up areas in Morogoro Urban at the expenses of forests and agricultural land has had profound implications on groundwater recharge. This has particularly been a threat due to rapid urbanization where land use change has been intense and often poorly regulated. This is due to the fact that as natural forests and agricultural landscapes are replaced by impervious surfaces—such as roads, rooftops, and pavements—the capacity of the land to allow rainfall to infiltrate into the subsurface is significantly reduced. This shift has altered the natural hydrological balance by increasing surface runoff while decreasing infiltration and percolation, which are essential for replenishing aquifers and enriching groundwater reserve. Consequently, groundwater recharge rates in Morogoro Urban have declined.

In the context of urban planning, the challenge is exacerbated by prioritizing the construction of stormwater drainages to capture runoff rather than infiltration, further limiting recharge opportunities. Moreover, the loss of natural recharge zones—such as wetlands, floodplains, and open green spaces—which are replaced by built-up areas and infrastructure, undermines long-term groundwater recharge. Without deliberate planning interventions, a continued expansion of built-up areas may intensify water scarcity and groundwater potentiality. Therefore, integrating groundwater-sensitive urban design through the protection of critical recharge areas is essential to mitigate the adverse impacts of urbanization on future groundwater recharge.

Consistent with the present study, Allafta et al. (2020) applied the analytic hierarchy process (AHP) to map groundwater potential zones in the Shatt Al-Arab River Basin, Southwest Asia, and reported comparable results. The primary distinction between the two studies lies in the classification approach. While the Shatt Al-Arab Basin was classified into five groundwater potential zones (‘very good’, ‘good’, ‘moderate’, ‘poor’, and ‘very poor’), Morogoro Urban was categorized into three zones (‘high’, ‘moderate’, and ‘low’). This difference is largely attributable to the variation in spatial extent, as Morogoro Urban covers a relatively smaller area. Nevertheless, the findings indicate that 21.5% of Morogoro Urban falls within the high groundwater potential zone, whereas 30.2% and 48.3% of the area is classified as moderate and low potential zones, respectively.

Similarly, Tiwari et al. (2019) reported comparable results in their assessment of groundwater availability for domestic use in Bhopal City, India. Bhopal City and Morogoro Urban share similar geological settings, notably the presence of laterites and sandstones, which are favourable for groundwater occurrence. In Bhopal City, 13.51% of the area was classified as very high groundwater potential, 13.77% as high, 12.05% as medium to high, 27.61% as medium, and 33.05% as low potential. These findings indicate that the geological frameworks of both study areas support a substantial proportion of zones with favourable groundwater potentials. Consequently, geology and land use/land cover emerge as key controlling factors of groundwater availability, consistent with the observations by Aju et al. (2021) and Kisiki et al. (2022).

3.3 Suitable Zones for Groundwater Tapping Stations

Figure 6 indicates that the groundwater tapping potential in Morogoro Urban is spatially variable, and strongly influenced by both physical suitability and competing land uses. The highly suitable zones for groundwater tapping cover 35.99km² (14.4% of the study area), reflecting a relatively limited spatial extent where hydrogeological conditions are optimal for groundwater development. Although these areas represent a high suitable class, their effective utilization is constrained by the presence of competing and restricted land uses, including educational institutions, administrative zones, unplanned settlements, and protected areas. This highlights a critical planning challenge where areas with groundwater potential are not always readily available for establishing tapping stations due to existing land-use commitments and regulatory limitations.

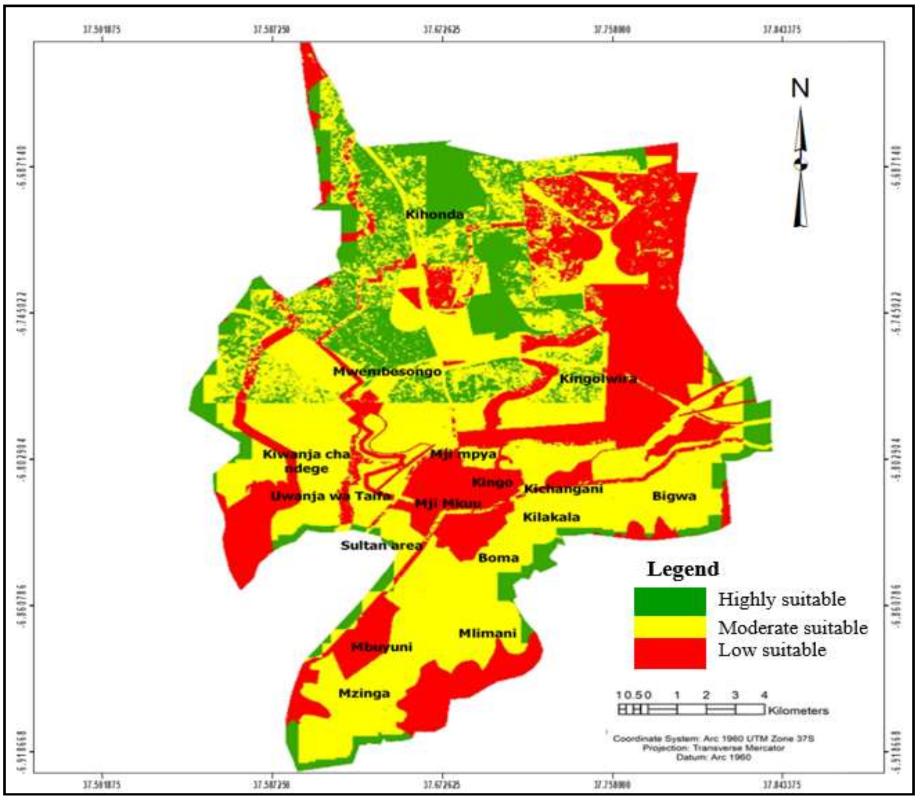


Figure 6: Suitable Zones for Groundwater Tapping Stations in Morogoro Urban

Source: Author (2025)

The moderate suitable zones constitute the largest proportion of the study area, covering 134.93km² (55.6%), indicating that much of Morogoro Urban possesses conditions that can support groundwater tapping with appropriate management and planning interventions. These zones include buffer areas along rivers, roads, pipelines, and the Mindu Dam; all of which are hydrologically important due to their potential for recharge and subsurface water movement. However, the functional use of these areas is restricted in some cases, particularly in road and pipeline reserves, where safety regulations and infrastructure protection limit groundwater development. This suggests that while moderate suitable zones offer a significant potential, careful planning and compliance with land-use regulations are essential to harness groundwater potentiality.

The less suitable zones—covering 73.15km^2 (30% of the study area)—include conserved tourism areas, cemeteries, army zones, industrial areas, commercial centres, bus stands, city parks, and airport. These areas are legally protected, highly secured, and densely developed: all of which restrict drilling and groundwater infrastructure. Using conserved tourism areas may disturb sensitive ecosystems, degrade landscapes, and conflict with conservation objectives. On the other hand, cemeteries pose a high risk of contamination from leachates, and are further restricted by public health regulations, cultural sensitivities, and land-use planning. Similarly, army zones have limited access due to security, and military activities, fuel storage, and hazardous materials that increase contamination risks.

Furthermore, industrial areas are vulnerable to effluents, chemicals, hydrocarbons, and waste; while heavy infrastructure and strict regulations also limit recharge. On their part, commercial centres and bus stands are densely built-up, thereby increasing contamination risk from sewage, waste, and fuel spills, and also limiting maintenance. Likewise, city parks—as recreational spaces—are unsuitable due to potential disturbances and contamination from soil treatments and fertilizers. Similarly, airport areas are highly developed and secured, with extensive pavement restricting recharge and high contamination risks from fuels. Hence, the dominance of such land uses within less suitable zones underscores the importance of integrating groundwater suitability assessments into urban land-use planning to avoid conflicts.

Notably, areas dominated by settlements and social services—including schools and hospitals—fall within the most suitable class despite urban development pressures. Their classification as 'highly suitable' reflects the critical demand for reliable water supply for domestic and institutional uses, emphasizing the socio-economic relevance of groundwater development in Morogoro Urban. Overall, the results demonstrate that while groundwater potential exists across much of Morogoro Urban, the actual feasibility of establishing groundwater tapping stations is heavily shaped by land-use patterns and regulatory constraints. This underscores the need for groundwater-sensitive urban planning that aligns hydrogeological suitability with land-use allocation to ensure sustainable and equitable water supply in Morogoro Urban.

In terms of suitability factors, the findings of this study are consistent with those of Bajpai et al. (2023), who identified suitable zones for groundwater abstraction as areas characterized by low pumping costs, acceptable water quality, and a stable groundwater table. The results of this study are based on similar criteria, with particular emphasis on the availability and accessibility of groundwater resources. With respect to spatial distribution, the findings indicate that suitable areas are less extensive than unsuitable areas, which is consistent with the observations of Aju et al. (2021), who reported that suitable zones for groundwater abstraction in the Vamanapuram River Basin, South India, occupy a smaller proportion of the area compared to unsuitable zones.

However, it should be noted that the omission of accuracy assessment, sensitivity analysis, and field-based validation in this paper is attributed to data and scope limitations. Comprehensive and reliable boreholes inventory data—including spatial locations and productivity records—were not readily available for the study area, hence limiting the possibility of direct validation. In addition, the lack of long-term groundwater monitoring data constrained the implementation of quantitative accuracy assessment techniques. A formal sensitivity analysis was also beyond the scope of the present study as it requires extensive testing of alternative weighting scenarios and detailed field data: limitations similarly reported by Radulović et al. (2022), Ikirri et al. (2023) and Wijesinghe et al. (2023). Consequently, the assessment was designed as an exploratory study intended to provide relative insights into groundwater potential and suitability, rather than site-specific predictions.

4. Conclusion and Recommendations

Overall, the study demonstrates that groundwater potentiality and tapping suitability in Morogoro Urban are highly variable and controlled by a combination of hydrogeological and land-use factors. Rapid urbanization, land-use changes, and replacement of vegetative cover with impervious surfaces: all have reduced infiltration and recharge, further limiting groundwater availability. The assessment of tapping suitability further reveals that while highly suitable zones are limited in spatial extent, moderate suitable zones cover the majority of the area, and can support groundwater development in Morogoro Urban if carefully managed. However, effective utilization of high and moderate suitable zones is often constrained by competing land uses, including educational, administrative, industrial, and protected areas: all these highlighting the socio-economic and regulatory challenges of groundwater development in Morogoro Urban.

Owing to increasing built-up areas, it is recommended that groundwater development and management in Morogoro Urban be guided by an integrated approach that combines hydrogeological assessment with land-use planning.

Conservation priority should be given to areas with high to moderate groundwater potential for tapping, while ensuring the protection of critical recharge zones such as vegetated lands, wetlands, and floodplains. Incorporating geological, slope, drainage, and rainfall considerations into future urban development will be critical for sustaining Morogoro Urban's groundwater resources over the long-term. Town planners should use the results and maps showing groundwater potential zones and suitable tapping stations as useful information in planning for various uses, especially when planning suitable areas for the development of boreholes and wells.

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