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GIS and RS Multi-criteria Analysis of Prospective Groundwater Zones in Undulating Terrain: Wami-Ruvu Basin, Tanzania

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ABSTRACT

Context and background

Groundwater is the most vital and promising natural resource for ecosystems and societies particularly in semi-arid areas. Due to urbanization and various anthropogenic activities the demand of water is hugely increasing. Proper evaluation and demarcation of groundwater potential zones can facilitate proper physical exploration of ground water and hence simplify identification of proper locations for borehole drilling. Sustainable use of groundwater is essential in Tanzania so as to increase long-term agricultural and industrial sustainability as well as to maintain the pace of socio-economic development for poverty reduction and eradication.

Goal and Objectives:

The objective of this research is to delineate prospective zones for groundwater exploration in Wami-Ruvu Basin Water Board (BWB), Tanzania..

Methodology:

A Remote Sensing (RS) and Geographic Information System (GIS) based on Analytical Hierarchical Process (AHP) has been utilized.

Results:

The final groundwater potential map was prepared by assigning appropriate weightage and integration of thematic layers using weighted overlay analysis. The groundwater potential areas have been categorized into five categories very low (0.3%), low (32.0%), moderate (62.8%), high (4.8%) and very high (0.1%). Validation of the identified potential zones indicates a Pearson correlation of 0.6 between yields and GWPZ. This study clearly highlights the efficacy of RS and GIS-based multi-criteria decision technique as useful modern approach for proper groundwater resources evaluation; providing quick prospective guides for groundwater exploration and exploitation. We recommend RS and GIS based identification of Ground potential zones for all Basin Water Boards in Tanzania to support physical groundwater exploration. Future work could test the use of machine learning algorithm particularly random forest and deep learning and incorporation of other parameters for delineating groundwater potential zones.

Keywords

Groundwater prospectivel zones, RS, GIS, Multi-criteria analysis, Wami-Ruvu basin

1. INTRODUCTION

Water covers more than 70% of the Earth's surface, out of that, about 97% is saline and 3% is fresh water and only 0.5% of fresh water is actually suitable for human consumption (Das et al., 2019). The demand for fresh water globally is increasing and the demand is expected to grow much higher over the foreseeable future. The United Nations World Water Development Report (UNWWDR) of 2018 states that about 6 billion peoples will suffer from clean water scarcity by 2050(Boretti & Rosa, 2019). Global change such as urbanization, population growth, socio-economic change, evolving energy needs, and climate change have put unprecedented pressure on water resources systems(Mishra et al., 2021). According to Intergovernmental Panel on Climate Change (IPCC) report of 2018; due to the influence anthropogenic activities, global warming has increased 1°C since pre-industrial times and this rise is likely to reach 1.5°C between 2030 and 2050. Possible effects of climate change are worrying since the climate is a very important factor that control the hydrologic cycle, streamflow rate of rivers and groundwater. Streamflow's in rivers are decreasing at high rates in various parts of the (Bao et al., 2012)due to climate change which alters rainfall patterns, consequently changing the distribution and availability of surface water resources.

The United Republic of Tanzania (URT) has set very ambitious goals to transform the country from low-productivity agricultural country to high-productivity semi-industrialized one. The aim is to enable the country to attain competitive economy and become middle income country by the year 2025. According to National Water Policy (NAWAPO, 2002) water is considered as one of the critical actors to enable Tanzania achieve its 2025 Development Vision objectives including poverty eradication, attaining clean water and food security, and preservation of biodiversity and ecosystems.

Groundwater is considered to be a key supplement for surface water in many parts of the country, and is an essential source of water in semi-arid areas (Godfray & Tembo, 2022; NAWAPO, 2002). It is also ideal for meeting the increasing fresh water in different sectors due to low level contamination. Groundwater is a most vital and valuable natural resource for ecosystems and communities in the drought-prone areas(Godfray & Tembo, 2022). The occurrence of groundwater at any place on the earth is not a matter of chance but a consequence of the interaction of the climatic, geological, hydrological, physiographical and ecological factors. Groundwater exploration operation is essentially a hydrogeological and geophysical inference operation and is dependent on the correct interpretation of the hydrological indicators and evidences. Over-exploitation of groundwater and marked changes in climate over the years have imposed immense pressure on the global groundwater resources. As demand of potable water increases across the globe for human consumption, agriculture and industrial uses, the need to evaluate the groundwater potential and productivity of aquifers also increases (Arulbalaji et al., 2019).

The technique of integration of remote sensing (RS) and GIS has proved to be extremely useful for groundwater studies (Abrams et al., 2018; Allafta et al., 2021; Das et al., 2018; Faye et al., 2021; Ganapuram et al., 2009; Hilal et al., 2024; Hussein et al., 2017; Makonyo & Msabi, 2021; Tolche, 2021). Satellite RS provides an opportunity for better observation and more systematic analysis of various geomorphic units/landforms/lineaments due to synoptic and multi-spectral coverage of a terrain. Investigation of remotely sensed data for drainage map, geological, geomorphological and lineament characteristics of terrain in an integrated way facilities effective evaluation of groundwater potential zones. Similar attempts have been made in the generation of different thematic maps for the delineation of groundwater potential zones in different parts of the world (Allafta et al., 2021; Arulbalaji et al., 2019; Das et al., 2018; Faye et al., 2021; Makonyo & Msabi, 2021; Sangana et al., 2019; Senapati & Das, 2021; Tolche, 2021). Analysis of remotely sensed data along with Tanzania topographical and collateral information with necessary ground check helps in generating the base line information for groundwater targeting. GIS and AHP techniques have been utilized extensively in determination and mapping of groundwater potential zones (Arulbalaji et al., 2019; Faye et al., 2021; Hilal et al., 2024; Senapati & Das, 2021).

Generally, groundwater exploration surveys and projects are implemented without sufficient knowledge of the potential areas for ground water resources abstraction. Lack of preliminary hydro geological and spatial information accounting distribution and variation in groundwater potential zones in country has a negative implication on groundwater management as the area will be explored with higher uncertainties. This results in the increase of borehole drilling cost for the groundwater resources abstraction. Considering many semi-arid areas suffer with chronic water shortages in Tanzania, decision on where to successfully and timely explore groundwater is largely a function of how well groundwater potential and suitable zones have been delineated. Furthermore, the currently hydro geological understanding in Tanzania puts little emphasis on geological fault systems and suitability for artificial groundwater recharge areas and hasn't considered constraints restricting groundwater availability. Moreover, little attempts have linked groundwater potentiality in semi-arid regions of developing world, particularly in Tanzania(Godfray & Tembo, 2022; Makonyo & Msabi, 2021). Thus, an alternative method combining both influencing factors and restricting constraints to delineate groundwater potential zones is needed for effective and timely decision making and poverty alleviation processes. Remote sensing and GIS based ground water exploration techniques provide large area coverage information regarding potential area for ground water availability at a relatively short time period. Such that the process requires less amount of subsistence allowance for field work during identification of locations suitable for borehole drilling. The GIS and RS based ground water potential zones identification is considered to be faster and cost-effective.

However, the guideline utilized for ground water exploration directs on the use of convectional ground water exploration surveys techniques only. This indicates the dire urgent need for integration of the GIS and RS techniques in the procedural guideline for ground water explorations. The effort to support groundwater exploration is generally linked to safeguarding the achievement of sustainable development goals (SDGs) and Tanzania Development Vision (TDV), 2025 on management of water resource and sanitation for all (SDG 6), poverty reduction and eradication (SDG 1), food security (SDG 2), gender equality (SDG 5), cities sustainability and human settlement (SDG 11), climate change adaptation and mitigation (SDG13) and terrestrial ecosystems protection (SDG 15). The current paper presents result for a GIS and RS based groundwater potential zone identification and demarcation to support groundwater exploration and quick identification of borehole drilling locations in Wami-Ruvu BWB.

1.1 Description of the Study Area

The Wami-Ruvu BWB lies between latitude 5o and 8o South of the equator and between Longitude 35.5o and 40o East of the Greenwich meridian, covering a total area of 66,360 km2 (Figure 1). The river catchment consists of two main rivers namely Wami and Ruvu; is comprised of the Wami, Ruvu and Coast Rivers. The Wami river originates in the Eastern Arc Mountain ranges of Tanzania and flows southeast, passing through dense forests and savannah grasslands before reaching the Indian Ocean. Wami river sub-catchment spreads Dodoma region semi-arid areas to the humid inland swamps in the Morogoro region to Bagamoyo district. The Ruvu river sub-cathment ranges from Morogoro through Coast region to Dar es Salaam. The Ruvu sub-catchment consists of the most lowlying areas, excluding the Uluguru Mountains in the West. Population of Wami-Ruvu basin is around 5.4 million. The basin's climate varies featuring semi-arid conditions in the western part and a humid climate with high rainfall in the eastern areas near the Indian Ocean.

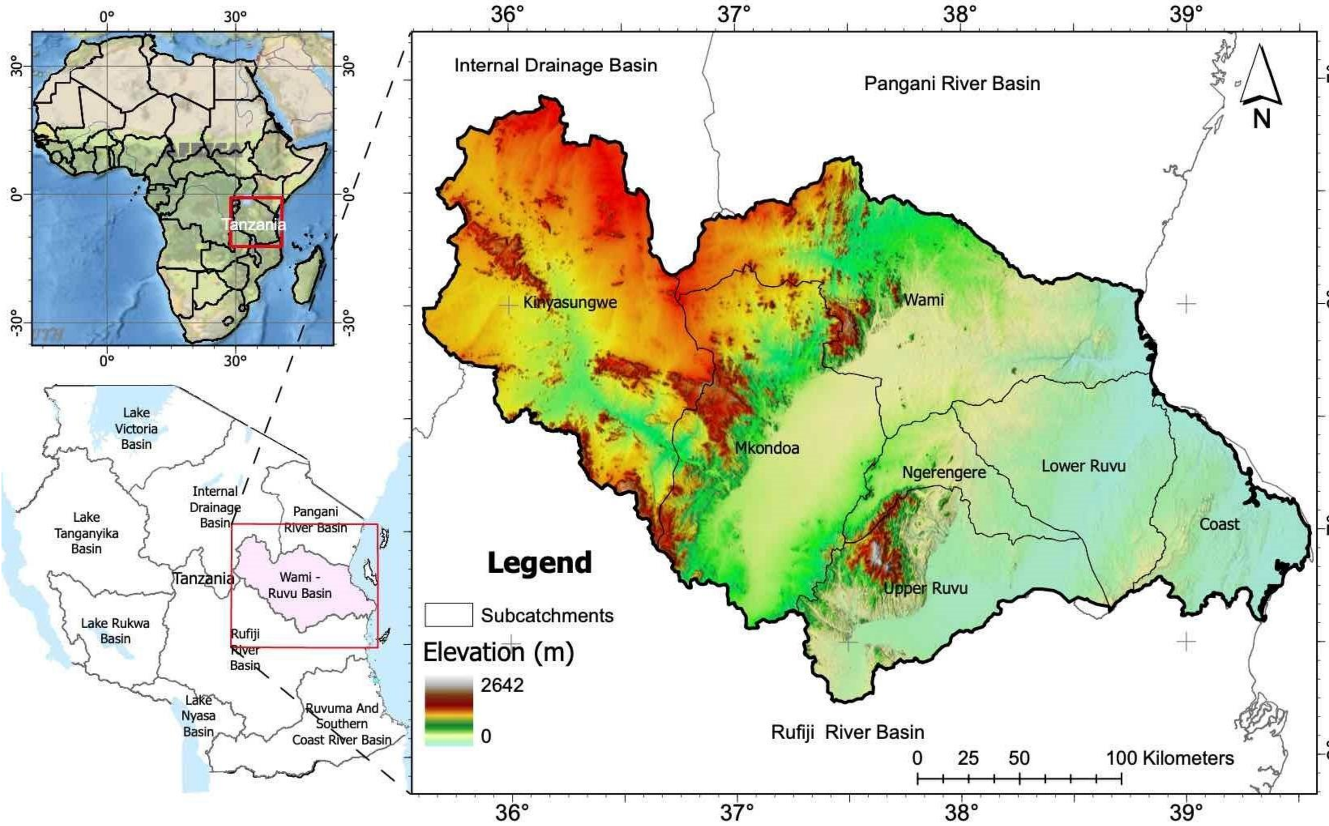

Figure 1: Location of Wami/Ruvu Basin Water Board.

2. DATASETS AND METHODS

2.1 Dataset

The success of groundwater potential area mapping largely depends on the choice of criteria used as input data. For criteria derivation and generation various dataset have been obtained from different sources. This include SRTM` Digital Elevation Model (DEM), soil data, land cover, geomorphology, geology and rainfall.

2.1.1 Digital elevation model (DEM) and Rainfall

The 30m resolution DEM was downloaded from United States Geological Survey (USGS) using the Quantum GIS (GIS) SRTM Tile downloader plugin(USGS, 2014). About fourteen (14) SRTM DEM Tiles covering Wami-Ruvu BWB were downloaded and mosaicked. The DEM was pre-processed to fill voids and clipped based on Wami-Ruvu basin boundary so as to remain with a DEM covering the research area only (Figure 2a). The clipped DEM contributed directly or indirectly to the preparation of the groundwater potential zone mapping criteria layers like Slope and Topographical Wetness Index (TWI).

Rainfall data were obtained from the Terra Climate (TC) database (Abatzoglou, et al., 2018). The TC database provides high spatial resolution ($^{1}/_{24^{\circ}}$, ~4km) monthly climate and water balance for global terrestrial surfaces from 1958 to 2019. The Long-term Mean (LTM) Monthly rainfall for 32 years (1988-2020) in Wami/Ruvu basin ranged between 42 and 135 mm. The annual LTM of rainfall in Wami/Ruvu for 32 years was found to range from around 503 up to 1550 mm (Figure 2b).

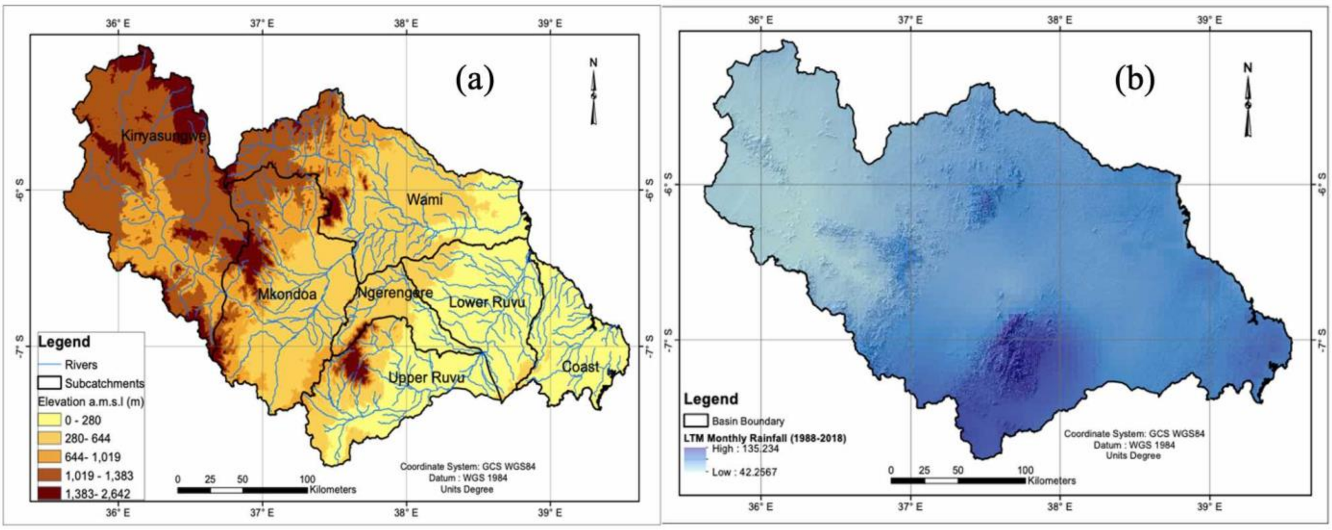

Figure 2: Terrain and Rainfall(mm) distribution.

2.1.2 Soil and Land cover data

The soil dataset was acquired from the International Soil Reference and Information Centre (ISRIC) -World Soil Information. The dataset was then clipped to obtain the Soil data covering Tanzania, and from there the soil data covering Wami-Ruvu basin was extracted (Figure 3a). Land cover refers to the physical material on the earth surface which relates to natural and man-made features including vegetation, surface water bodies, bare soil, rocks and built-up areas (Dar et al., 2021). The landcover data was extracted from a 20 m resolution yearlong Sentinel-2A aggregated data over Africa from December 2015 to December 2016 (https://2016africalandcover20m.esrin.esa.int/). The classification of the utilized landcover data is based on the CORINE classification system. The product is distributed in GeoTIFF format with a size of approximatively 6GB together with the colour legend. The land cover criteria layer was clipped from the downloaded ESA land cover layer covering Tanzania (Figure 3b). The identified land cover types in Wami-Ruvu basin based on ESA 20m landcover map of 2016 are: Trees Cover (TC), Shrub land (SL), Grassland (GL), Cropland (CL), Wetlands (WL), Sparse vegetation (SV), Bare land (BL), Built up areas (BA) and Open water (OW).

2.1.3 Structural and Geological data

The Tanzania structural and geological maps utilized were provided by the Geological Survey of Tanzania (https://www.gst.go.tz/).

2.2 Methods

2.2.1 Preparation of Groundwater Criteria layers

A vital aspect of groundwater prospective area mapping is the criteria thematic layers used. As highlighted earlier, the choice of criteria used in this study was based on the aggregation of expert knowledge gleaned from several previous case studies on identification of groundwater potential zones Click or tap here to enter text.

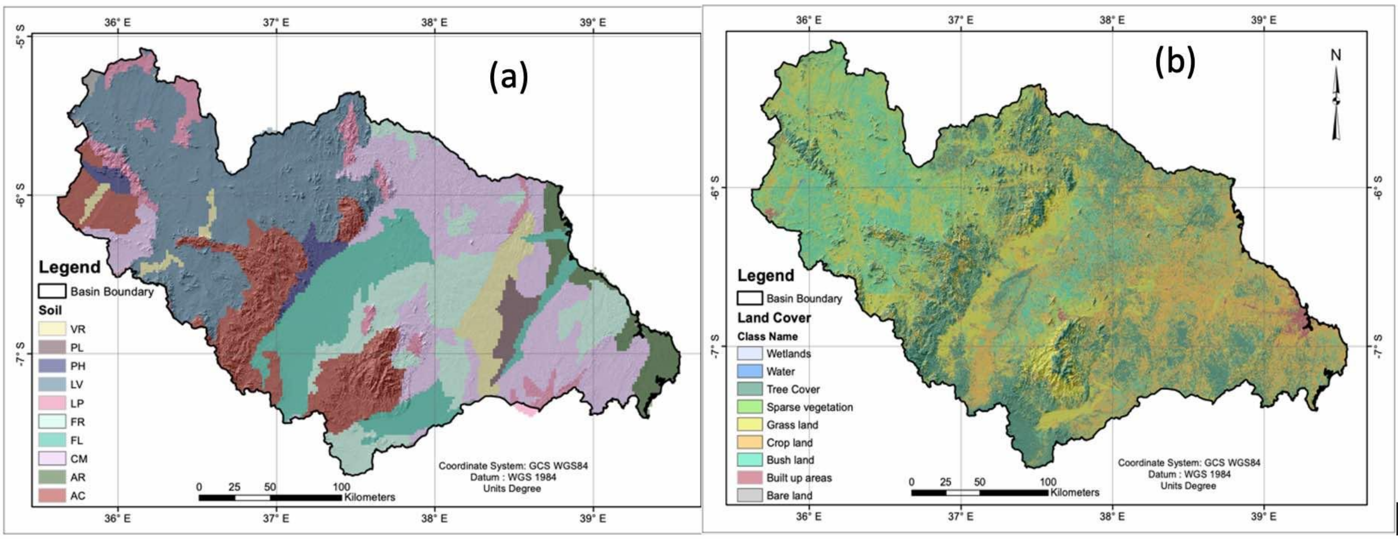

Figure 3*: (a) Soil distribution based on dominant soil group: VR= Vertisols, Planosols (PL), Phaeozems (PH), LV= Luvisols, LP= Leptosols, FR= Ferralsols, FL= Fluvisols, CM= Cambisols, AR= Arenosols and AC= Acrisols. (b) Land cover distribution based on type.*

studies (Abrams et al., 2018; Allafta et al., 2021; Biswas et al., 2020; Das et al., 2018; Ganapuram et al., 2009; Hussein et al., 2017; Makonyo & Msabi, 2021; Tolche, 2021). About Eight (8) thematic criteria have been selected. All the collected data were processed so as to obtain the groundwater prospective mapping criteria layers. The data processing steps in creation of criterion layers included; DEM derivatives generation slope, topographical wetness Index (TWI), drainage and lineament density; rasterization, reclassification, Analytical Hierarchy Process (AHP), Weighted Overlay Analysis, and map generation as summarized in Figure 4.

a) Slope

Slope is a measure of steepness which represent the angle between a line linking a tangential line to a certain point on the earth's surface(Lentswe & Molwalefhe, 2020). It is the rate of change of elevation and it determines the gravity effect on water movement. Slope drives the water flow energy. The lower the slope value the low the steepness and this indicates higher potential for underground water. The higher the slope value the higher the steepness and this indicates low potential for ground water. Slope is expressed either in degrees or in percentage rise. The slope of 45 degree equal to 100 percentage rises. The higher the degrees the slope percentage rise goes to infinity. Figure 5a depicts the prepared slope layer using the SRTM DEM.

b) Topographic Wetness Index

The topographical wetness index (TWI) is also known as compound topographical index (CTI) used to quantify topographical control on hydrological process. It is an estimator of water availability based on accumulation of water in an area caused by terrain variability. It is a function of both slope and the upstream contributing area per unit width orthogonal to the flow direction. TWI is computed as the ratio of the upslope catchment area per unit contour length (A_s) and the local gradient (tan β) as given in Equation 1 (Biswas et al., 2020; Makonyo & Msabi, 2021) .

$$TWI = ln\left(\frac{A_s}{tan_\beta}\right) \quad (1)$$

where by A_s stands for a the particular basin area; and tan β is the slope angle of the particular grid, used to replace roughly the local hydraulic incline under stable state conditions. The generated TWI layer is presented in Figure 5b.

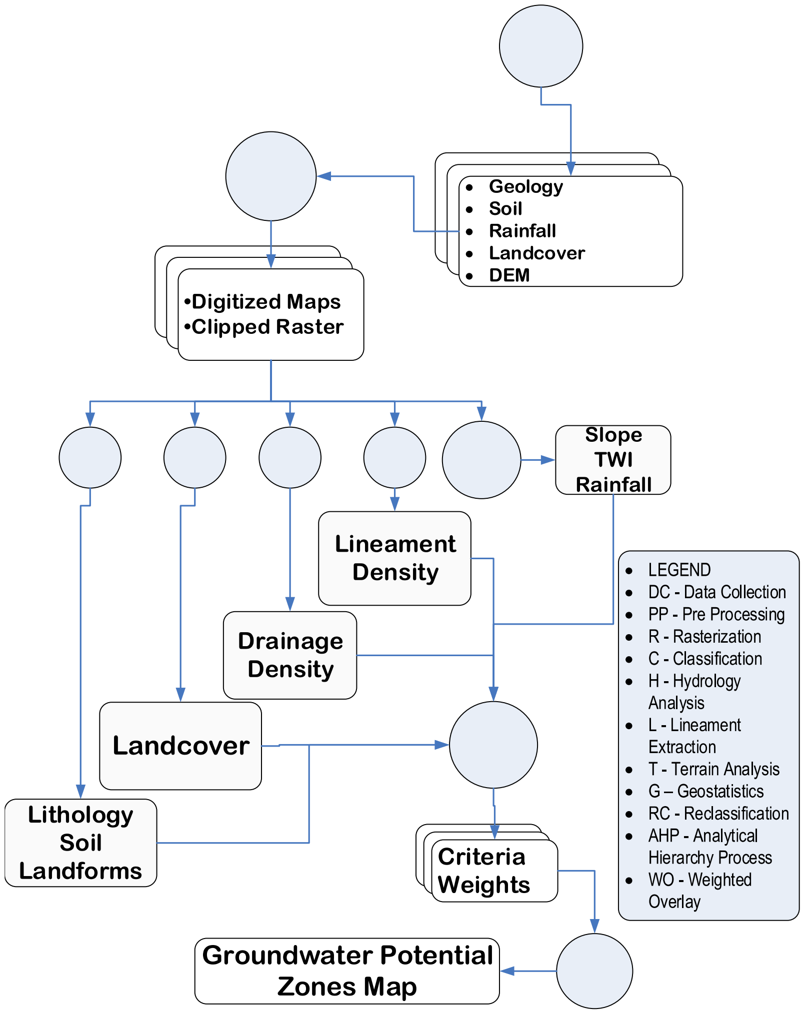

Figure 4: *The flow of utilized methodology.*

c) Drainage density

Drainage Density (DD) is the total length of all the streams and Rivers in a Drainage basin divided by the total area of the drainage basin. A dense drainage network is a good indicator of flow accumulation pathways and of areas with a high potential for flooding. Drainage density is defined as the total length of channels per unit area. DD is a quantity used to describe physical parameters of a drainage basin (Equation 2).

$$DD = \frac{\sum L}{A_{basin}} \qquad (1)$$

When determining the total length of streams/rivers, both perennial and ephemeral streams should be considered. Drainage density is indicative of infiltration and permeability of a drainage basin. Figure 5c illustrates the distribution of the drainage density.

d) Lineament Density

Lineaments are structurally controlled linear or curvilinear features that represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. Normally lineament appears as a fault-aligned valley, a series of fault or fold-aligned hills, a straight coastline or a combination of these features. Lineament density (LD) is the frequency of fractures per unit area. LD increases hydraulic of an area. Lineaments can be identified from the satellite imagery or DEM by their relatively linear alignments(EL-Omairi et al., 2024; Ombiro et al., 2021). Lineaments of the Wami-Ruvu area are extracted using hillshade layers created from the DEM at different angles and digitization from the Tanzania structural map provided by the Geological Survey of Tanzania. Figure 5d presents the spreading of lineament density.

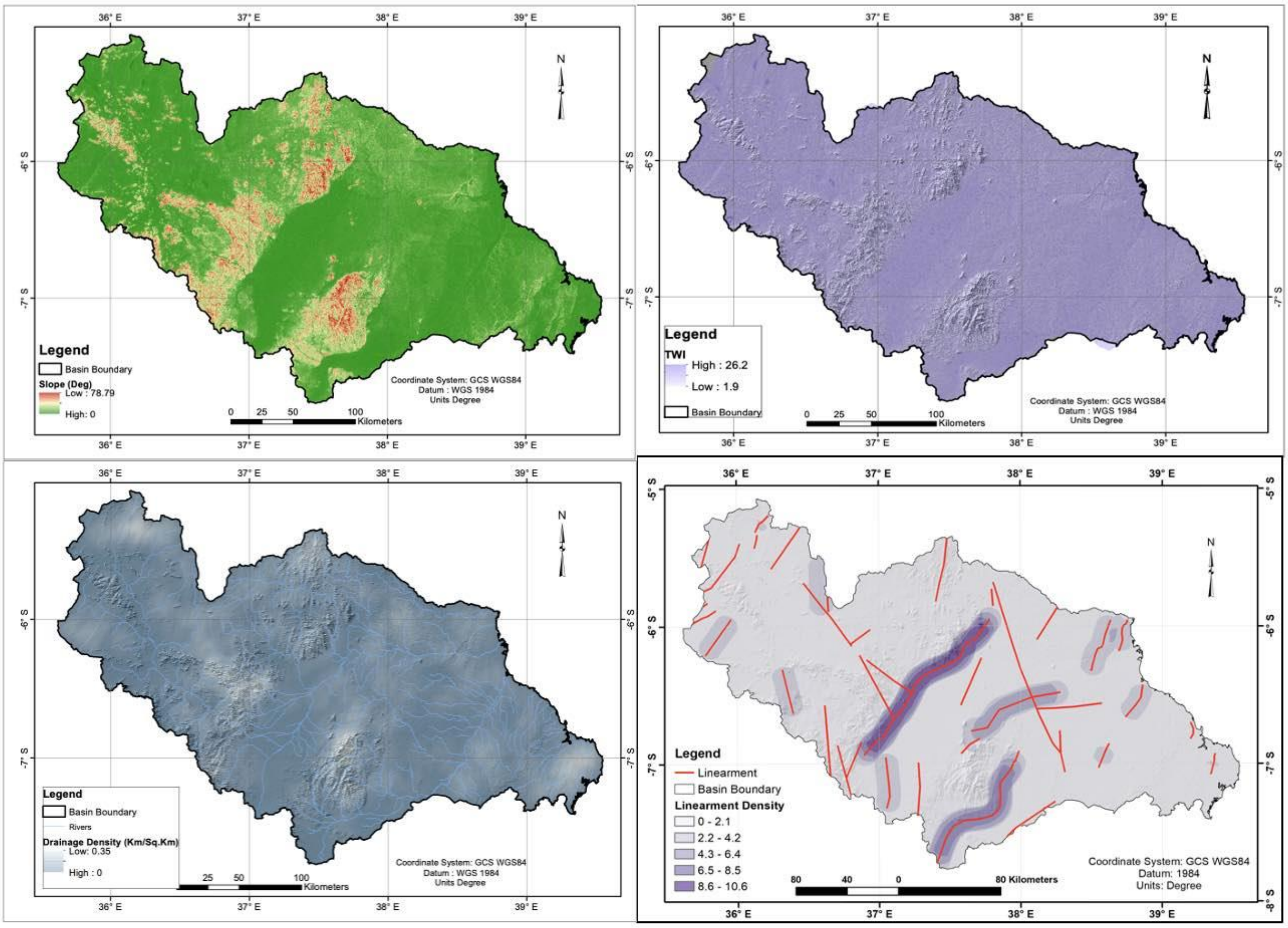

***Figure 5**: Lineament density.*

e) Geology

The occurrence of ground water is largely influenced by geological/lithology conditions. Geological settings play a significant role in the occurrence and distribution of ground water in any terrain. The coverage of geological types in Wami-Ruvu basin were extracted from the Tanzania Geology map(Godfray & Tembo, 2022) as presented in Figure 6. The geological classes in Wami-Ruvu basin include;

i) Continental-marine deposits (sandstones, clays, marls, limestones)
ii) Gneiss-granite-migmatite complex (Dodoman and Isangan Group)
iii) Granulite - gneiss - meta-sediment complex including eclogite (Isimani Group)
iv) Mafic - felsic granulite complex
v) Marble formation
vi) Marine and fluvio-marine sandy-clayey sediments
vii) Marine deposits (detrital and reef limestones, marls, sandstones, ooliths)
viii) Meta-gabbro - anorthosite complex
ix) Meta-sediment - meta-igneous complex
x) Migmatite - granitoide - meta-sediment complex
xi) Predominantly alluvial and eluvial sediments
xii) Terrestric clastic sediments, partly with coals (Karoo Supergroup)
xiii) Terrestric coarse clastic sediments, higher coastal terrace, laterite and alterite

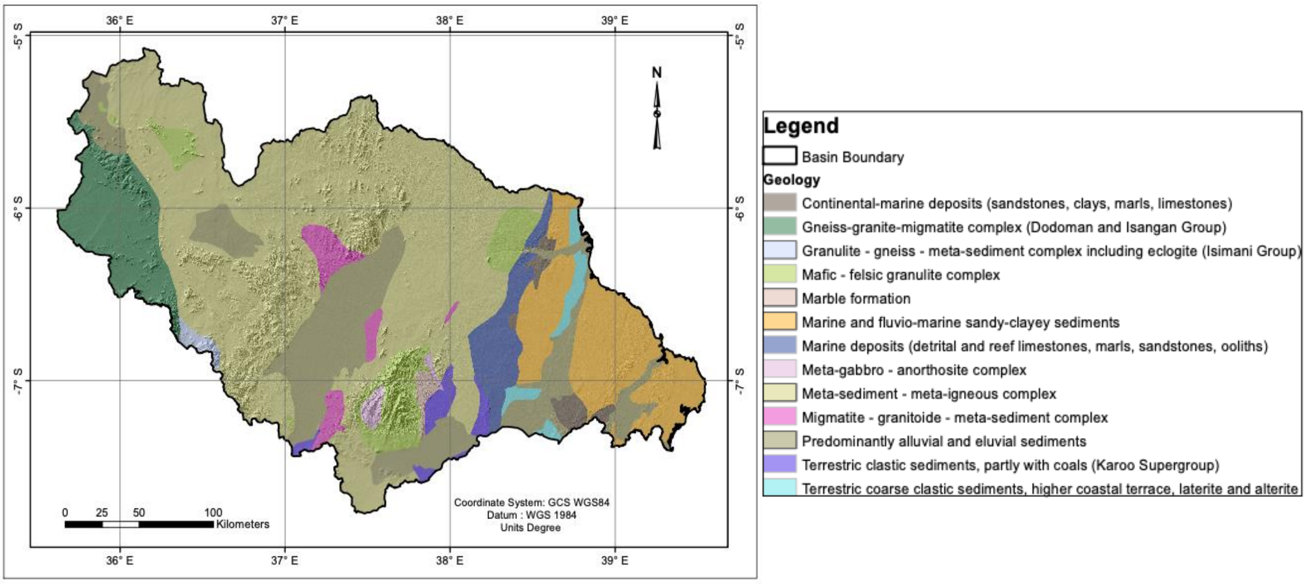

Figure 6: *Distribution of geological classes.*

2.2.2 Criteria layers (re)classification

Raster thematic files of 30m resolution were generated for each criterion using the map algebra and reclassification procedures. Reclassification is the process of reclassifying data in different systems or for different purposes. If the input dataset is a result of a classification, we call it reclassification. In this process we assign codes based on specific attributes. In reclassification process you can also remove details from an input dataset to divide it in different classes. All eight utilized thematic layers were reclassified into five categories representing very low, low, moderate, high and very high potential zones ranging from 1-5. These include: slope, rainfall, TWI, geology, land cover, soil, lineament density and drainage density. Each final criteria map was then normalized using the min-max methodology to ensure uniformity and reduce the subjectivity generally inherent in the AHP technique.

2.2.3 Multicriteria decision analysis and weighted overlay analysis

Multi criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well-known GIS based method for delineating groundwater potential zones(Abrams et al., 2018; Arulbalaji et al., 2019; Biswas et al., 2020; Das et al., 2018; Hilal et al., 2024; Sangana et al., 2019). This method helps integrating all thematic layers. This process is used to assign weights to criteria and check the consistency of the decision made. Normally, in AHP and GIS based overlay analysis four key steps are involved;

i. Description of the problem, in this case groundwater potential zones mapping
ii. Identification and selection of groundwater potential area influential criteria
iii. Creation of a pairwise comparison matrix and assigning weights for thematic layers and
iv. Weighted overlay analysis for generation of groundwater probable zones

The size of the pairwise matrix depends on the number of your criteria. In this research the pairwise matrix comparison of size 8 by 8 was created using criteria weights. The weights are assigned and the consistency ratio (CR) is computed. The consistency ration must be less than 0.1 i.e. CR<0.1. If the consistency ratio CR<0.1 then the pairwise matrix is contemplated accurate and consistent. If the consistency ration is greater than 0.1 the weights must be adjusted. The consistency ratio (CR) is obtained by dividing the consistency index (CI) by the Ratio Index (RI) where, the matrix will be considered consistent if the CR<0.1. The consistency Index (CI) and CR are obtained using Equation 3 and 4 respectively (Biswas et al., 2020; Makonyo & Msabi, 2021).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

$$CR = \frac{CI}{RI} \tag{4}$$

Whereby, n is the number of criteria, $\lambda_{\max}$ is the maximum Eigen value. To check for the consistency and weights of the criteria a pairwise matrix was developed and calculated by using AHP. After creating the pairwise matrix according to the scale, the CR value and the associated weights of for all criteria were computed. The weightage of each criterion is assigned according to Saaty's scale of relative importance value(Saaty, 1987). The weights are allocated to exemplify their relative significance to groundwater recharge(Arulbalaji et al., 2019; Biswas et al., 2020; Makonyo & Msabi, 2021).

After generation of the weights, a GIS based weighted overlay analysis was carried out to obtain the groundwater potential zones. All these layers were analyzed so as to obtain one output which shows the groundwater prospective areas ranging from very low, low, moderate, high to very high as estimated using Equation 5(Dar et al., 2021).

$$GWPZ = LD_w \times LD_{wi} + GL_w \times GL_{wi} + SP_w \times SP_{wi} + TWI_w \times TWI_{wi} + DD_w \times DD_{wi} + RF_w \times RF_{wi} + LC_w \times LC_{wi} + SL_w \times SL_{wi} \quad (5)$$

GWPZ indicates the groundwater prospective areas; LD, GL, SP, TWI, DD, RF, LC and SL stands for Lineament density, geology, slope, topographical wetness index, drainage density rainfall, land cover and soil respectively. The layer weight and weight of the specific criterion layer is denoted by w and wi, respectively which were overlayed on a pixel basis as presented in Equation 5.

3. Results and Discussion

3.1 Reclassified Criteria Layers

3.1.1 Geology

The occurrence of groundwater is largely influenced by geological conditions. Geological settings play a significant role in the occurrence and distribution of groundwater in any terrain. The geology has been reclassified into five classes; very high, high, moderate, low, and very low as presented in Table 1 and Figure 7 respectively.

Table 1: Categorization of Geology.

Geology	Level of influence	Rating
Continental-marine deposits (sandstones, clays, marls, limestones)	High	4
Gneiss-granite-migmatite complex (Dodoman and Isangan Group)	Very low	1
Granulite - gneiss - meta-sediment complex including eclogite (Isimani Group)	Moderate	3
Mafic - felsic granulite complex	Very high	5
Marble formation	Moderate	3
Marine and fluvio-marine sandy-clayey sediments	High	4
Marine deposits (detrital and reef limestones, marls, sandstones, ooliths)	Moderate	3
Meta-gabbro - anorthosite complex	Low	2
Meta-sediment - meta-igneous complex	Moderate	3
Migmatite - granitoide - meta-sediment complex	Very low	2
Predominantly alluvial and eluvial sediments	Very high	3
Terrestric clastic sediments, partly with coals (Karoo Supergroup)	High	4
Terrestric coarse clastic sediments, higher coastal terrace, laterite and alterite	High	1

3.2 Land cover and Soil

All land cover classes were reclassified into five classes ranging from 5 to 1 for very high, high, moderate, low, and very low as displayed in Table 2 and Figure 8 respectively. Wami-Ruvu basin soil data has ten (10) groups of soils. The Soil influence on groundwater occurrence is recategorized as presented in Table 2:

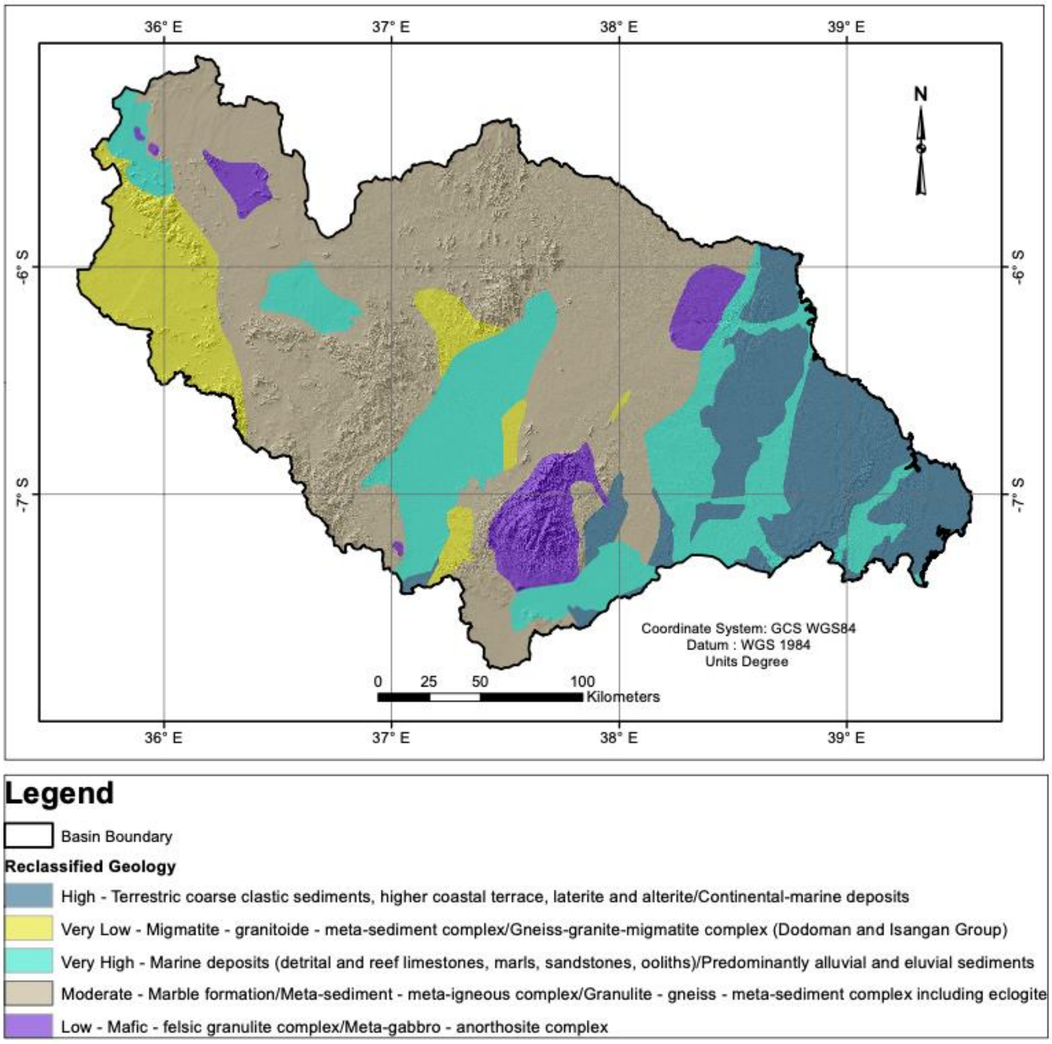

Figure 7: *Recategorized Geological Classes*

Table 2: Categorization of Land Cover and Soil Types

	Land Cover	
Land cover Class	**Level of influence**	**Rating**
Trees Cover	Very high	5
Shrub land	Moderate	3
Grassland	Low	2
Cropland	High	4
Wetlands	Very high	5
Sparse vegetation	Moderate	3
Bare land	Very Low	1
Built up areas	Very low	1
Open water	Very high	5
	Soil	
Acrisols (AC)	Moderate	3
Arenosols (AR)	High	4
Cambisols (CM)	Very high	5
Fluvisols (FL)	Very High	5
Ferralsols (FR)	Very low	1

Leptosols (LP)	Very Low	1
Luvisols (LV)	Low	2
Phaeozems (PH)	Moderate	3

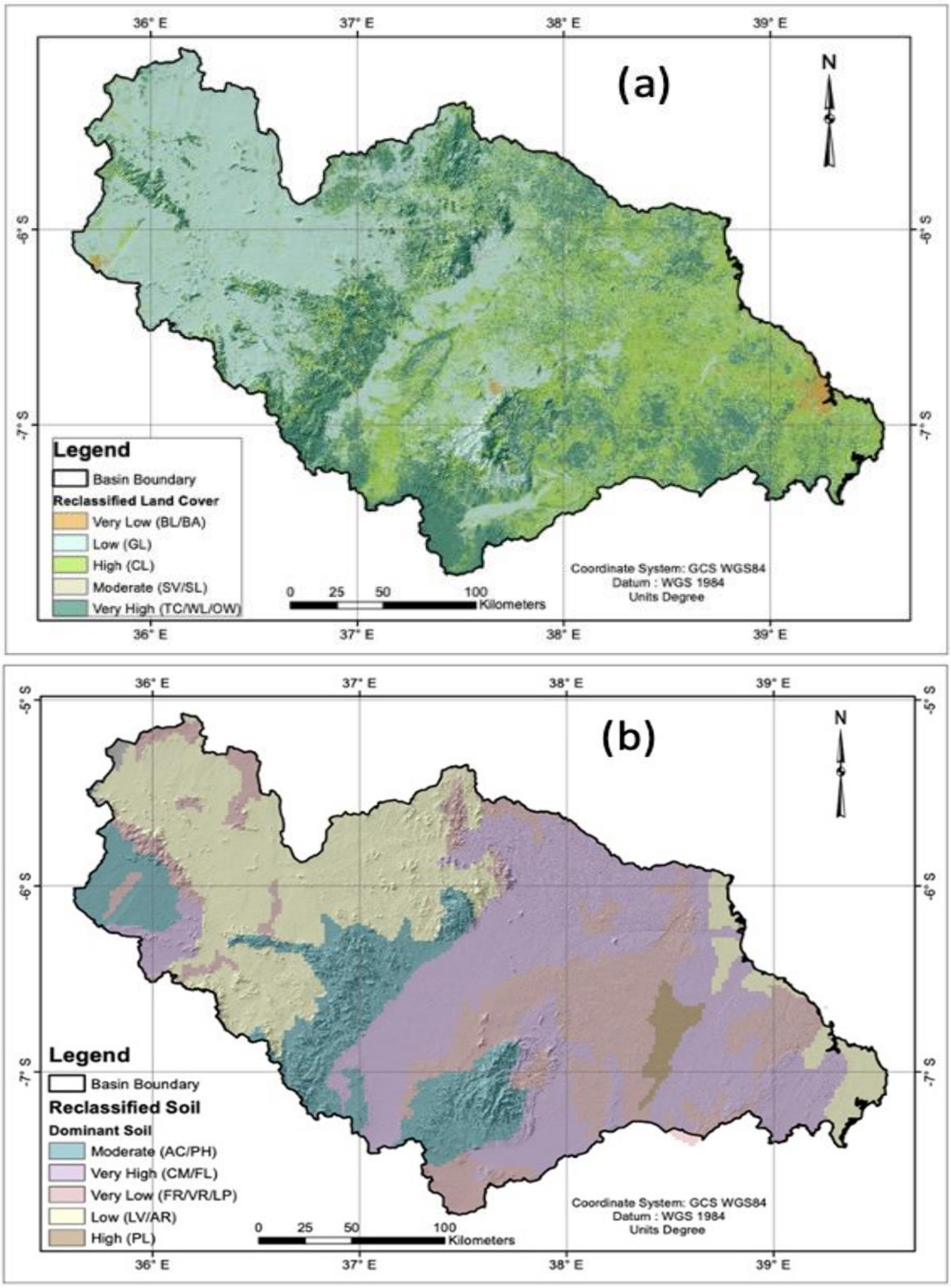

Figure 8*: (a) Reclassified Land cover: BL= Bare Land, BA=Built up Areas, GL= Grass land, CL=Clop land, SV=Sparse Vegetation, SL=Shrub Land, TC=Tree Cover, WL=Wetland and OW= Open Water. (b) Reclassified Soil: AC=Acrisols, Arenosols = AR, Cambisols=CM, Fluvisols = FL, Ferralsols =FR, Leptosols =LP, Luvisols =LV, Phaeozems = PH, Planosols = PL and Vertisols =VR.*

3.3 Rainfall, Slope, Topographic Wetness Index and Drainage density

The rainfall, slope, TWI and drainage density thematic layers were reclassified and assigned new values ranging from 1 to 5 for very low to very high respectively. The reclassified layers are presented in Figure 9a-d.

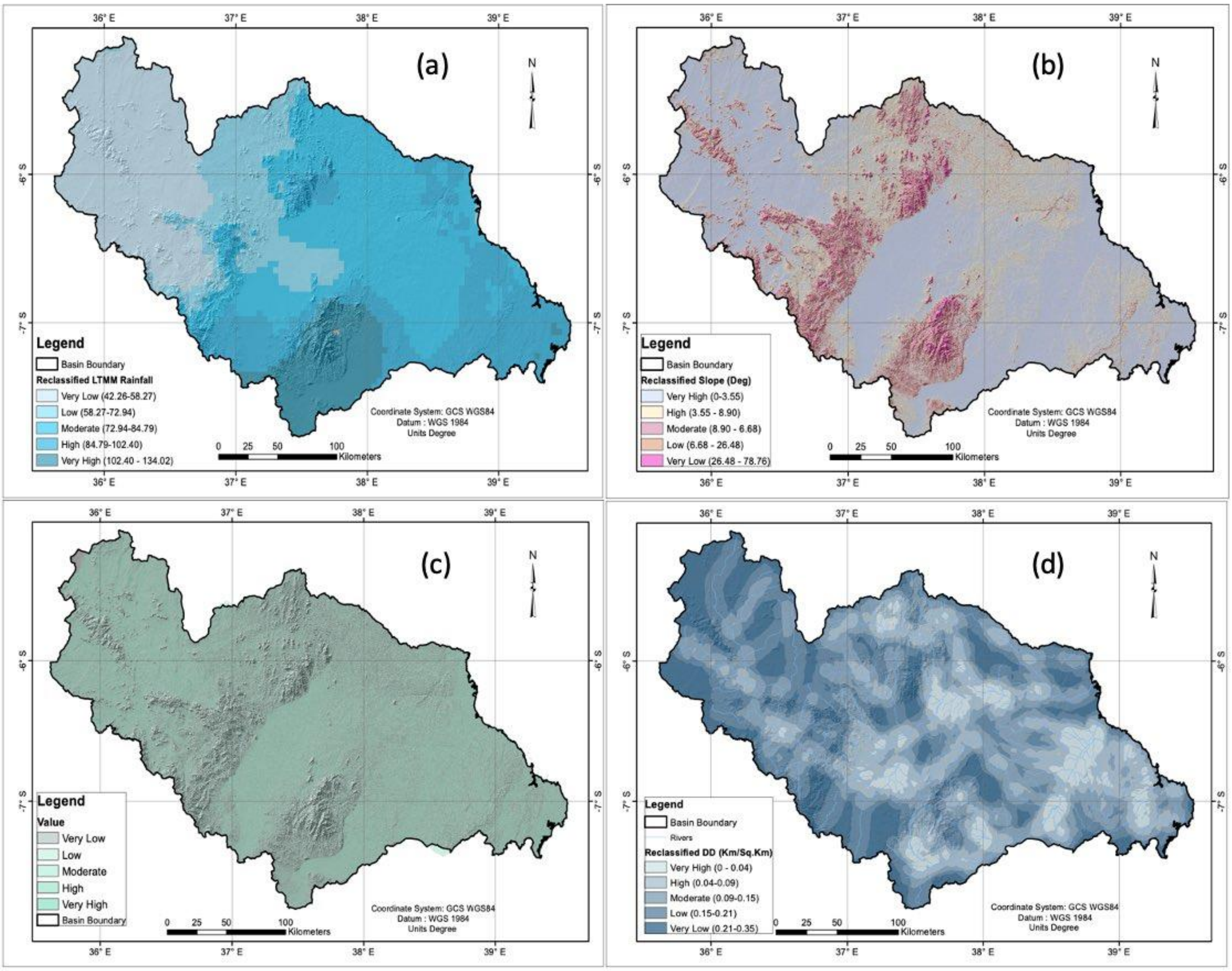

Figure 9: *Reclassified (a) LTM monthly Rainfall (mm), (b) Slope, (c) Topographical Wetness Index and (d) Drainage density.*

3.4 Lineament Density

The lineament density was reclassified into five categories ranging from 1 to 5 indicating very low to very high ground water potential. The ranks are given for lineament density based on proximity of lineaments. It is revealed that the intensity of groundwater potential decreases with increasing distance from the lineaments. The reclassified lineament density map is displayed in Figure 10.

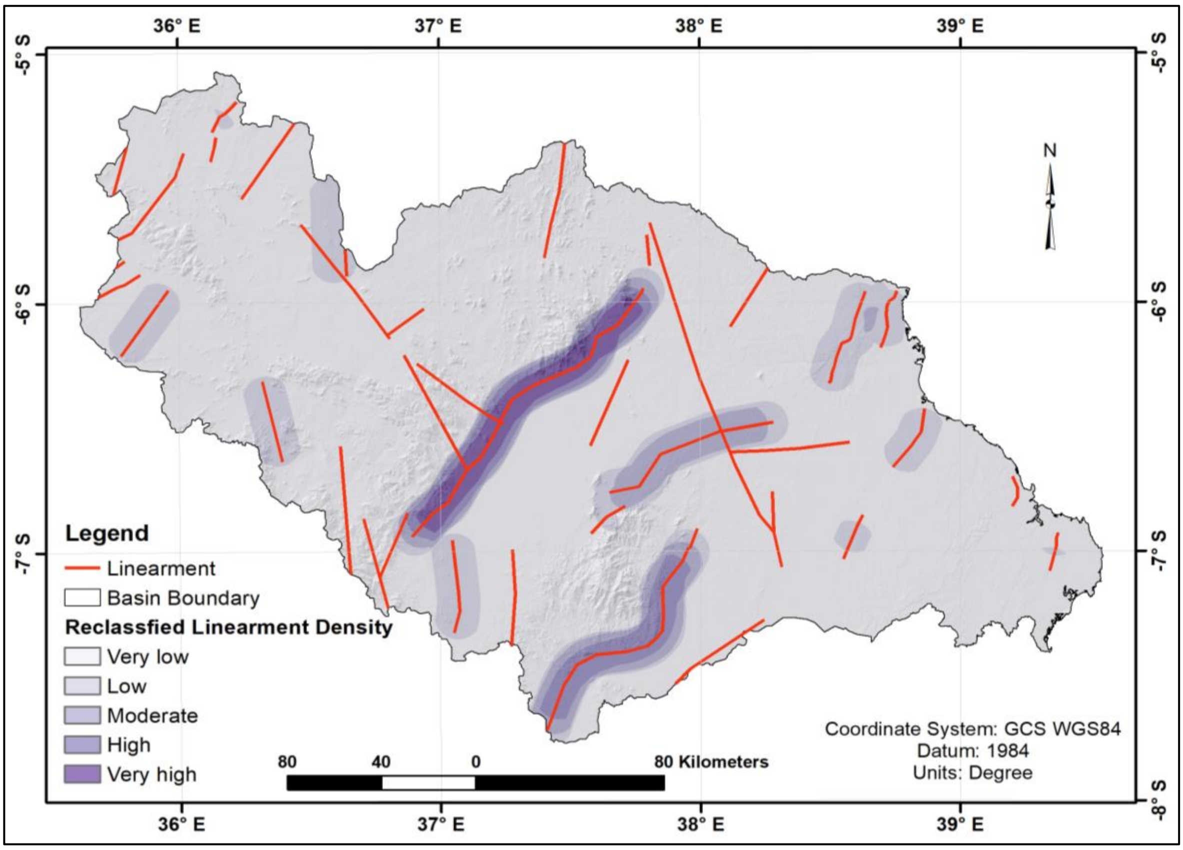

***Figure 10**: Reclassified Lineament density.*

3.5 Assigned weights

A total of Eight (8) different criteria (thematic layers) were considered for this research. These 8 thematic layers are supposed to control factor of flow and storage of water in the area. All identified criteria are weighted according to their reaction for groundwater occurrence and expert opinion. The criteria contribute to ground water recharge differently such that weighting and raking is used to identify the significance of every criterion. A criterion with a high weight illustrates a layer with high impact while a criterion with a ow weight indicates a small impact on groundwater potential. Thus, the greater the weight the higher the influence on groundwater re-charge. Depending on re-classification, weights are assigned to every thematic layer based on their relative importance and water holding capacity. The CR of 0.001 was obtained and it is acceptable. The generated weights are presented in Table 3.

Table 3: Assigned weights

Criteria	Weight (% of Influence)
Lineament Density (LD)	27
Geology/Lithology (GL)	23
Slope (SP)	15
Topographical Wetness Index (TWI)	13
Drainage Density (DD)	11
Rainfall (RF)	9
Land cover (LC)	7
Soil (SL)	4

3.6 Delineated Groundwater Potential Zones

The general objective of the study was to map groundwater potential zones in Wami-Ruvu Basin. The groundwater potential areas have been categorized into five categories; very low (0.3%), low (32.0%), moderate (62.8%), high (4.8%) and very high (0.1%) potential areas. Figure 11 depicts the groundwater potential zones in Wami-Ruvu basin overlaid with borehole locations and yield per sub-catchments. The very high and high potential zones are found to be located in the eastern part (Dar es Salaam and Morogoro) of the basin in which Mkata and Mgeta Plain fall under Quarternary aquifer. As explained in the study done by the Japanese International Cooperation Agency (JICA) on water resource management and development in Wami-Ruvu catchment (JICA, 2013), the yield of Mkata Plain is almost twice of Quaternary aquifers found in Mgeta Plain and in the area of Coast catchment. In Kinyasungwe sub-catchment, higher yield boreholes may be distributed in graven (granite rocks) or along the fault zone. In contrast; most of the very low and low zones covered the west and central part of the basin mostly in Dodoma (Mpwapwa and Bahi district) and Tanga region (Kilindi and Handeni district in Wami sub-catchment) respectively. The delineated GWPZ were evaluated by overlaying the generated groundwater potential zone with existing borehole data as depicted in Figure 11. Most of the boreholes are located in the generated very higher, higher and moderate groundwater potential zones.

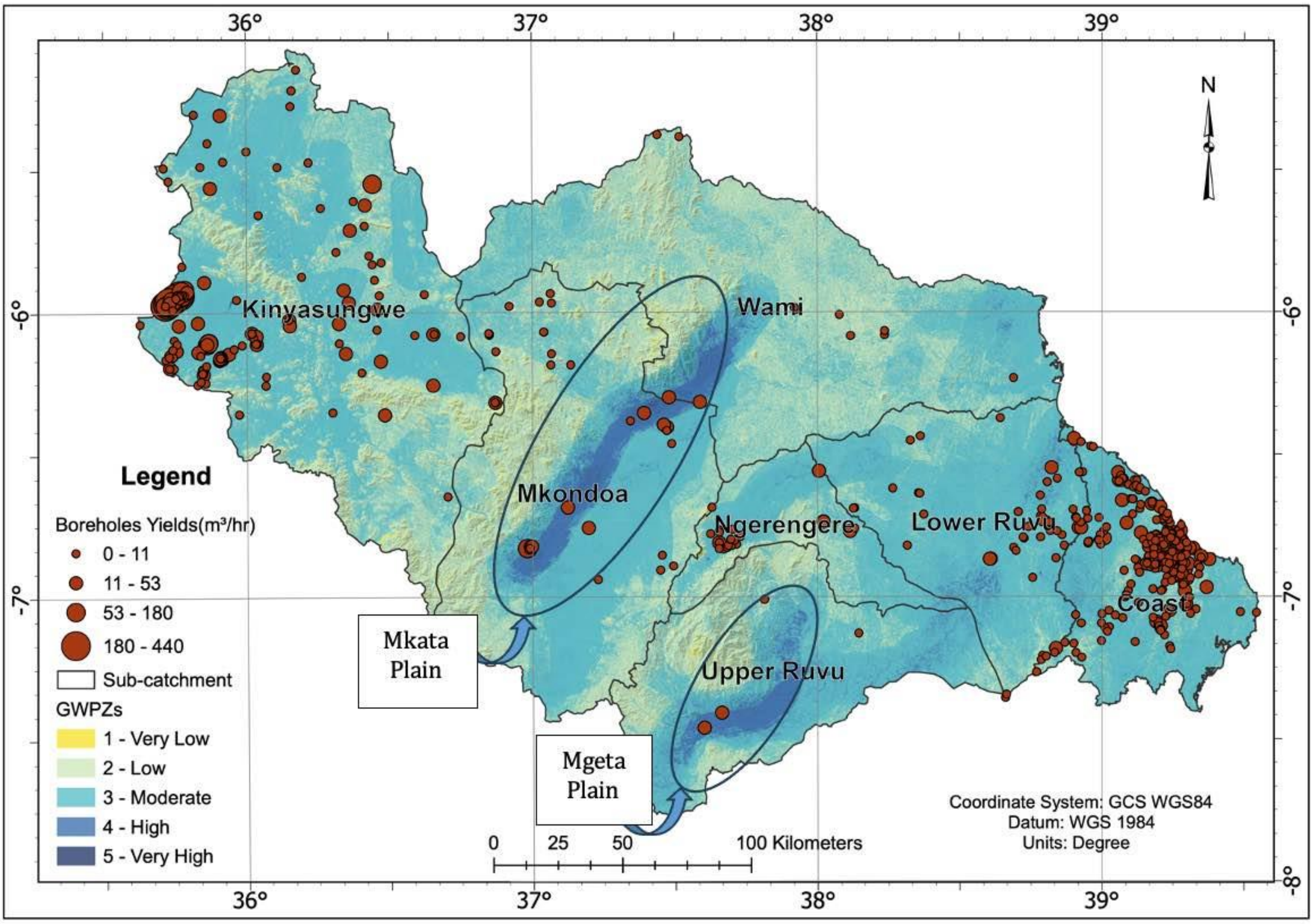

***Figure 11**: Groundwater Potential zones distribution in Wami-Ruvu Basin Water Board.*

4. VALIDATION OF THE IDENTIFIED GROUND WATER POTENTIAL ZONES

Results were validated using data collected form boreholes found inside the basin. This data contained a number of information including specific yields, borehole depths, aquifer types, water temperature and location of the boreholes with reference to administrative boundaries. The yields were categorized into four classes (Very Good, Good, Moderate and Poor). (Basavarajappa, Dinakar, & Manjunatha, 2016) categorized the quality of specific yields as very good (>11.356 m^3/h), good (7.57-11.356 m^3/h), moderate (3.785-7.57 m^3/h) and poor (<3.785 m^3/h). Figure 12 shows percentage distribution of boreholes falling under each category, where 60.7% of all boreholes fall in GWPZs categorized as Moderate, Good and Very Good. Resulting GWPZs were cross-validated with most recent specific yields measured from the boreholes. Yields measured from the year 2011 to 2013 were used for validation, the analysis in Figure 13 reveal a positive correlation with a coefficient (R^2 = 0.576) between areas identified as having high ground water potential.

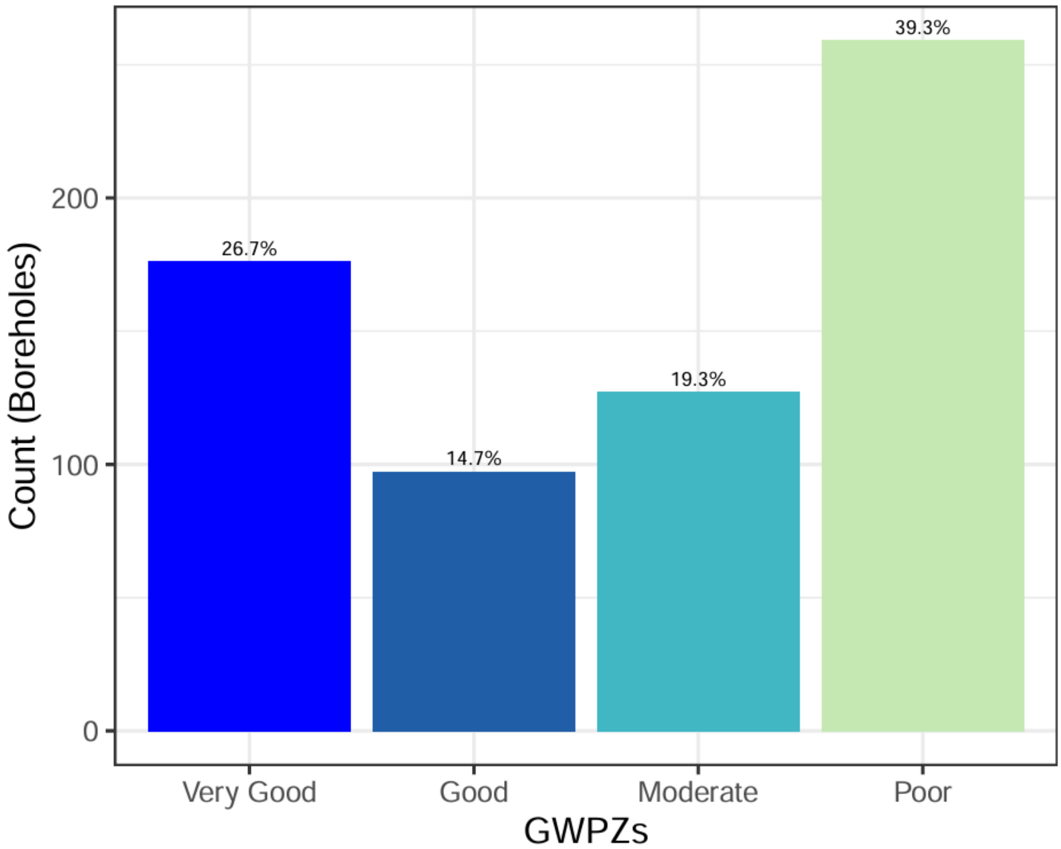

Figure 12: *Distribution of yield measured from boreholes*

The estimated GWPZs show that most areas (62.8%) in the basin have moderate ground water potential, this accounts to most of the boreholes (83.61%) falling under this zone. Figure 13 shows the distribution of categorized borehole yields relative to GWPZs, most of the boreholes (16 out of 21) falling in the zone with high ground water potential have yields categorized as good to very good. Boreholes in areas marked as high ground water potential zones have shallow drilled depth, the average depth of boreholes found in this zone is 59 meters. 87 boreholes fall in the zone identified as having low ground water potential, 35 of the boreholes in this zone have poor yields as expected regardless of some of the boreholes having large depths of up to 200 meters. 32 boreholes in this region have good to very good yields, these boreholes are found in Dodoma and the Coastal regions. Some of these boreholes have exceptionally high yields (Kashaigili, 2010). These areas have mostly been identified as having moderate to poor ground water potential due to low lineament density and low rainfalls particularly in Dodoma region.

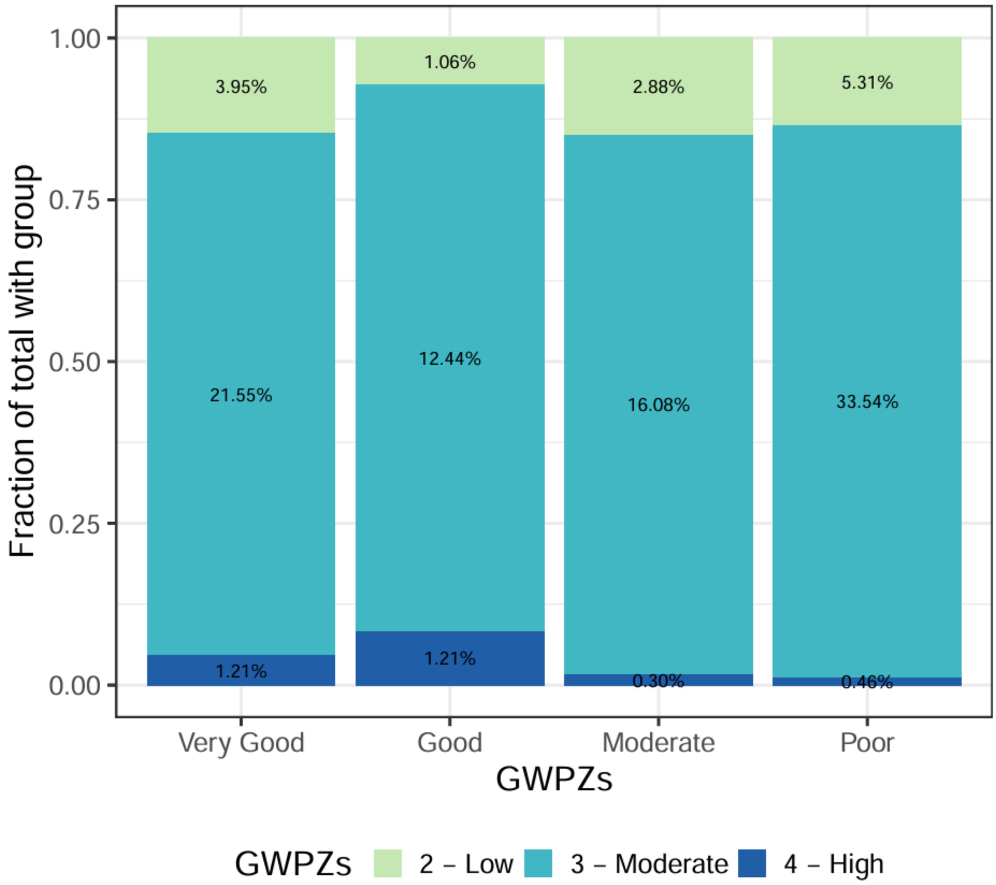

***Figure 14**: Distribution of borehole yields relative to GWPZs.*

5. Conclusion and Recommendation

The identification of groundwater recharge areas and delineation of potential zones are two important aspects for devising sustainable groundwater strategies. The groundwater occurrence depends on various biophysical indicators which were utilized for delineation of the GWPZ. The normalization of weights was calculated based on Saaty's AHP. All parameters were integrated into the GIS environment using weighted linear combination method and GWPZ were delineated for the study area. The overlaid borehole's locations indicated that the integrated approach of remote sensing, GIS and AHP techniques followed for delineating GWPZ in the study area performed satisfactorily. Future work can test the use of machine learning algorithm particularly random forest and deep learning and incorporation of other parameters for delineating groundwater potential zones.

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7. Conflicts of Interest

The authors declare no conflict of interest.

8. FUNDING

There is no funding information

9. AUTHOR CONTRIBUTIONS:

DD prepared the draft of the manuscript, collected the data and analyzed the results, checked on the suitability of the results, edited and did proof reading of the manuscript. JT visualized and validated the results. All authors have read and agreed to the published version of the manuscript.

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