

DELINEATION OF GROUND WATER POTENTIAL ZONES USING REMOTE SENSING MALAWI, BLANTYRE CITY

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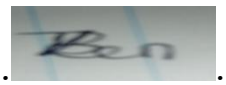
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ABSTRACT

The increase in population Increases the water demand, delineation of groundwater is one of the best approaches for overcoming water scarcity problems. This study delineated the Blantyre city's potential groundwater zones using geographical information systems and remote sensing. Blantyre is one of the most populated cities in Malawi it faces water scarcity problems. using remote sensing, Geographical Information System (GIS), and Analytic Hierarchy Process (AHP) the study evaluated the groundwater potential zones using criteria's which were lineament, slope, land use and land cover, soil, and drainage. Groundwater is the water present beneath the earth's surface in soil pores and the fractures of rock formations (). Groundwater consumption is more reliable and fresher compared to surface water due to it being more convenient and less vulnerable to pollution (MDPI, 2019). Digital Elevation Model (DEM) of Blantyre city was used to generate lineament and the lineament density, the slope map, Hydrography provided was used to generate drainage density. Soil map and land cover land use map were also created using remote sensing data. All the thematic layers were prepared and generated in QGIS and ArcGIS software, the parameters and their classes were assigned weights using AHP techniques, and normalization of weights was conducted and from this, a map of the Groundwater potential zone of Blantyre city was generated.

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ACRONYMS/ABBREVIATIONS

AHP, stands for analytical Hierarchy process, qualitative method for ranking decision

ARCGIS, software which operates

ASTER, aster is a satellite sensor

LANDSAT, Landsat is a satellite sensor

DEM, stands for digital elevation model, representation of topographic surface with the elevation or ground height above any geodetic datum

USGS, stands for united states geological survey

LULC, land cover land use

Delineation, mapping or drawing a boundary of were something is contained

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1. INTRODUCTION

1.1. Background

Water is one of the most essential commodities for mankind. It is considered one of the most significant natural resources which support both human needs and economic development. The tremendous increase in agricultural, industrial, and domestic activities has increased the demand for good and quality water. Malawi is one of the countries in the world facing water scarcity problems. Blantyre city is one of the highest populated cities in Malawi and the population is still increasing so is the demand for clean and safe water. According to the national statistical office of Malawi, Blantyre's 2020 population was estimated to have reached 830 073 people.

Groundwater is the water that exists underground in saturated zones beneath the land surface (https://www.usgs.gov). Groundwater is considered the largest available source of water on earth (Bear and Verruijt 1987). Delineation of groundwater is the process whereby water boundaries are mapped by drawing lines around the water-containing area (Merriam-Webster. April .2021). To meet growing population demand there is a need for a reliable solution and groundwater is considered the best alternative as it has a lower level of contamination and has a wider distribution than surface water (Biswas Arkoprovo). Delineation of groundwater potential zones is one of the best approaches which have been done in overcoming water problems in many areas. Groundwater potential zones are delineated using GIS and remote sensing through the AHP technique whereby different aspects contributing to a groundwater potential zone are given ranks, assigned weights based on the impact they pose on the ground storage potentiality to be used in the analysis to identify the groundwater potential areas.

Though many efforts water scarcity still remains a big problem in Blantyre city, this research focused on delineating the potential zones in Blantyre city which will help in solving the water scarcity problems as it will help in not only the building of

boreholes but also wells, which can be used by the people for example in Agriculture mostly the irrigation sector, industries among another day-to-day domestic use.

1.2. Problem Statement

Blantyre is one of the cities experiencing rapid urbanization in southern Africa, estimated at 8.1% per annum (NSO, 2008). The population of people in Blantyre increases every passing year and so does the demand for potable water for human consumption, agriculture, and industrial uses. About 46% of slum dwellers have access to water through the kiosk, 11% have piped water at home, 13% walk long distances to access piped water and the rest acquire water from other sources. 80% of formal settlement residents have access to piped water (NSO, 2008). During dry seasons the water becomes scarce leaving 80% according to NSO in water demand. People tend to turn to rivers nearby as their water source but most of these water sources are heavily polluted. For example, Makata industrial area lies between Mudi and Nasolo which most people turn to for water but are highly polluted and unsafe to be used, calling for a need to find an alternative solution to solve this, though different approaches and researches water scarcity remains a big problem in Blantyre city. These projects were done on large scale and also did not use the geospatial technology limiting the details found.

1.3. Research Questions

1) How can we delineate groundwater potential zone using geospatial technology?

2). How to assess the best contributing factors in groundwater potential mapping

3). How can we Standardize the criteria for selecting factors used in mapping groundwater potential zone to a common scale and perform weighted overlay analysis?

1.4. Research Objectives

1.4.1. Main Objective

- The study aims to Delineate groundwater potential zone using geospatial technology.

1.4.2. Specific Objectives

- Assess the best contributing factors in groundwater potential mapping
- Standardize the criteria for selecting the factors used in mapping groundwater potential zone to a common scale and perform weighted overlay analysis.
- Produce groundwater potential map showing zones potential for groundwater sources.

1.5. Significance of the study

with the increased population in Blantyre city there is high demand for water, and high rate of water pollution which deprives people of having safe and clean water, therefore calling for a need to find an alternative solution to solve this which brings us to this project since, Groundwater productivity is quite high compared to surface water (Jana Ardasa and Sarma Shashi Prakash), and groundwater is less vulnerable than surface water sources to climate fluctuations in an undisturbed aquifer system hence acts as a key buffer against drought and normal variations in rainfall. Reliable supply of groundwater also led input to increase yields, reducing agricultural risk, stabilizing income and thus leading to higher levels of social and economic security (Moench, 2003)

This research aims at delineating potential groundwater zones to produce a guide map which will assist in exploration and exploitation of ground water, for example in building of wells, boreholes among other things helping in the provision of water throughout the year to meet the community's need for clean water. Despite many attempts in locating groundwater zones, no much change has been made and water scarcity remains a big problem in Blantyre city. This project has mapped all the potential groundwater zones in Blantyre city specifically now and with the use

of geospatial data making it more detailed and accurate and an updated version. This map will be made accessible to people and by verifying through ground surveying people can easily locate the places where they can find groundwater and if water is found, in case of no fund to build boreholes people can dig wells which can be helping them in accessing water mostly in dry seasons.

2. LITERATURE REVIEW

2.1. Ground Water Potential Zones

Groundwater is the water present beneath the earth's surface in soil pores and the fractures of rock formations. There is about 30% of the world's freshwater concealed and reserved as groundwater, whereas surface water accounts for only 0.3% in the form of lakes, marshes, reservoirs, and rivers (mdpi, journal, water.2019). Groundwater availability serves as the source of an essential component in domestic, agriculture, and socio-economic development (Ayazi et al.,2010; Pradan2009). Primary sources of groundwater include rainwater and snowmelt which flow in the aquifer through soil poles. An aquifer is a unit of rock or unconsolidated deposit and can yield quantity water. Groundwater consumption is more reliable and fresher compared to surface water as it is more convenient and less vulnerable to pollution (MDPI, 2019). several factors affect the occurrence and movement of groundwater, such as lithology, geological structure, slope, drainage pattern, land use or land cover, and climate (Jaiswal et.al., 2003; Thapa et al.2017). From these factors, groundwater potential zone can be derived using GIS. Water scarcity problems mostly in dry seasons which mostly result from an increase in a population tend to make people turn to underground water both for domestic, industrial, and agricultural use. To Most people this is just a try and error as they are not sure of the places where they can find groundwater, this research aimed at mapping those areas using GIS and remote sensing techniques and help in easy identification of these water containing zones and help in solving the water scarcity problems.

2.2. GIS & Remote sensing

GIS is an abbreviation for geographic information system and it is a system designed to capture, store, manipulate, analyse, manage, present all types of geographical data (Research Guide, Madison Libraries). GIS can be used as a tool in problem-solving and decision-making processes as well as visualization of data in a spatial environment. Spatial data is the data that has been referenced to the

location on the earth. geospatial data can be analysed to determine the location of features and the relationship to other features where the most or least of some feature exist, the density of features in a given space for example groundwater zone identification.

Remote sensing on the other hand is the art and science of obtaining information about phenomena without being in physical contact with them (Aronoff 1995). remote sensing can be used as fuel for GIS, it provides the data which we use as a GIS to analyse. (Geo Afrikana Sep 9, 2019).

GIS is the best and easy approach in identifying potential groundwater zone for example an integrative GIS approach using different groundwater recharge potential zones has been used increasingly in the last two decades in many countries for instance India, Turkey, and Eritrea (Solomon and Quel,2006; Hammouri et.al 2012; Patil and Mohite 2014). Remote Sensing integration with GIS has emerged as a direct method and cost-effectiveness to map groundwater resources, exploratory, and management systems (Adiat&Abdullah 2012). In this project, the GIS was used through the digital elevation models and the geology which helped in coming up with the maps for the contributing aspects which later on were assigned weights and were used in generating a map in ArcGIS for the potential groundwater zones.

2.3. Analytical Hierarchy Process

AHP is an analytical hierarchy process that is a pairwise matrix that is used in evaluating the normalized weights of the contributing factors or criteria. AHP stands for analytical Hierarchy Process, it is a method for organizing and analysing complex decisions, using math and psychology .it was developed by Thomas L. saaty in the 1970s and has been refined since then. AHP converts evaluations into numbers that can be compared to all of the possible criteria (Hummel, et, al).

Multicriteria analysis on the other hand is a sub-discipline of operation research that explicitly evaluates multiple conflicting criteria in decision making. AHP is just one of the methods of multi-criteria analysis and is considered the best. AHP has been applied in several studies of water resource management and underground water study by integrating multi-criteria decision analysis (Saaty,1980,1986,19994).

AHP together with remote sensing and GIS is regarded as a straightforward, transparent, efficient, and reliable method of multi-criteria decision analysis (Machiwal et al.2011a,2011b). AHP and multicriteria analysis can be used in coming up with the drainage pattern of an area of which drainage is one of the aspects considered for a groundwater zone.

Slope, Soil, lineament, land cover land use, and drainage density are the contributing factors to a potential groundwater zone that were considered in this research. The relationship between these parameters and their impact on delineating a potential groundwater zone was weighed and ranked depending on the strength of a parameter. a parameter with a high weight has a greater impact and the ones with a lower weight have a lower impact on being a possible groundwater zone.

2.4. Previous Work

In Kashmir Valley, NW – Himalayas an effort was made to delineate potential groundwater areas using GIS and Analytical Hierarchy method (AHP) by incorporating remote sensing data with data from other sources. These data sets were used to prepare eight thematic layers of a slope, soil texture, drainage density, land use/land cover (LULC), lithology, geomorphology, lineament density, and rainfall. The analytical method of the AHP pair-wise matrix was used to evaluate the normalized weight of these thematic layers. All the thematic layers and their corresponding classes were allocated ranks and weights based on their impact on groundwater potential. The area was classified into five different potential groundwater recharge zones; excellent (28.97%), good (19.99%), moderate (21.70%), poor (27.16%), and very poor (2.15%).

In the Southern region of Banjar Negara Regency, Central Java, Indonesia a study to evaluate groundwater potential zones using remote sensing, Geographical Information System (GIS), and Analytic Hierarchy Process (AHP) was conducted. Lineament, lithology, slope, drainage, and rainfall were some of the aspects used in identifying the groundwater potential zones. Hydrography data provided by the Indonesian Geospatial Agency was used to generate drainage density. Geological

maps which were generated from remote sensing interpretation were provided from the Geological Survey Center of Indonesia. Rainfall data were provided by BPS-Statistics of Banjar Negara. 52 springs and 2 bore wells data were used for result validation. All 5 thematic layers were prepared in GIS. All factors and their classes were assigned weights using AHP techniques and normalization of weights was conducted through the AHP. Groundwater potential zones maps were generated.

In the coastal part of Ganjam district, Orissa a study was done to select and delineate various groundwater potential zones. using remote sensing and GIS technique. Satellite IRS-IC LISS III, Landsat TM digital, and SRTM data were used in the study to prepare various thematic maps, geomorphological, geological, slope, drainage density, lineament density map was some of the factors that were considered to come up with the map. Within each thematic map, a ranking was made for each of the features. All the thematic maps were registered with one another through ground control points and integrated step by step using the normalized aggregation method in GIS for computing groundwater potential index. Based on this final weight and ranking, the groundwater potential zones were delineated; it was observed that an integrated approach involving remote sensing and GIS technique can be successfully used in identifying potential groundwater zones in the area.

3. METHODOLOGY

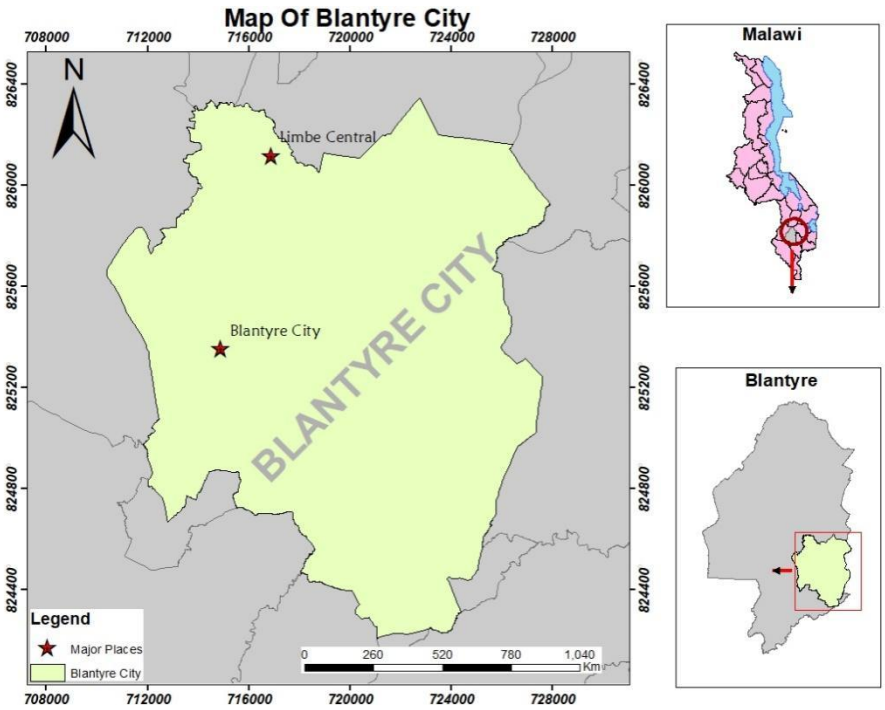


Figure 1; Map of Blantyre City

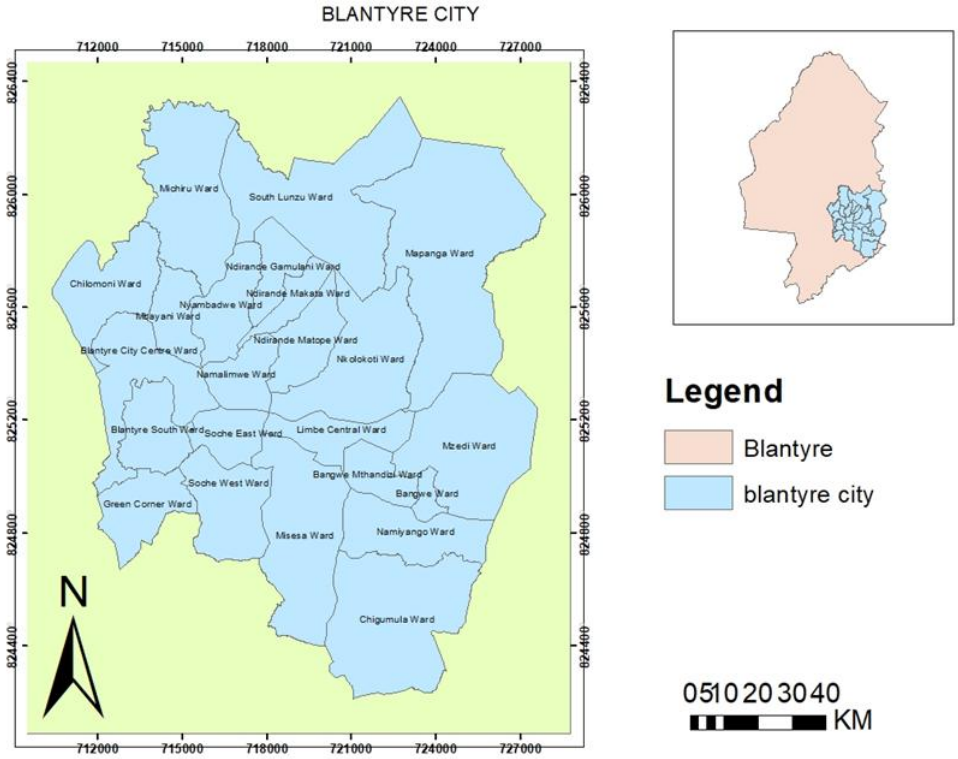


Figure 2; map showing Blantyre City areas

3.1. Study area

3.1.1. Location of Study Area

Blantyre City is the largest commercial and industrial capital of Malawi, is in the Shire Highlands and geographical centre of the Southern Region of the country, and lies 35% east of Greenwich Meridian and 15° 42 south of the Equator.it covers an area of 2,012 km2. it's the second largest city with an enumerated 800,264 inhabitants as of 2018. Blantyre is one of the cities having problems of water scarcity, Blantyre Water Board (BWB) supplies about 79,410mE of water per day from Shire River to Blantyre. Water supply to individuals is on an application basis. The supply network is old frequent pipe bursts that require Constant maintenance which is expensive around 74 percent of public schools have piped water supply.

3.1.2. Climate

The climate of Blantyre is a tropical climate city, specifically a tropical savanna climate, and it is greatly influenced by its location in the tropical zone and altitude. The city experiences a tropical continental climate with two distinct seasons in the year (three proper). the rainy season is from November to April, with continuing light cold showers locally known a Chiperoni from the of May to July. The dry season is from May to October. Blantyre is 1024m above sea level (Academy & Hill, 2009). The climate here is mild and generally warm and temperate. The summers are much rainier than the winters in Blantyre, the wet season is muggy and mostly cloudy the dry season is mostly clear, and I warm. this climate is considered to be Cwa according to the Kopper-Geiger climate classification. The average temperature in Blantyre is 20.6°c|69. 1|F.about 1199mm|47.2 inches of precipitation fall annually. Average high temperature in July 23.1°c average temperature in august 26.9°c. (Laura Kelly , Robert M. Kalin , Douglas Bertram , Modesta Kanjaye & and Hyde Sibande, 2019)

3.1.3. Geology

Blantyre city lies in a hilly area, it has varied topography ranging from an elevation of about 780 to 1,612 meters above sea level. The most dominant feature is hills found in all parts of the city. (Laisi, 2016). these hills are the headwaters of several rivers and stream radiate from the city-forming natural drainage system with nine districts, Likhubula, Lunzu, Mombezi, Lunchenza, Mudi, Chiombezi, Limbe, and Mwapanzi draining the middle southern parts, because of the hilly topography these natural drainage channels are narrow and have steep sides and gradients. Blantyre city Consists of two principal rocks of an ancient basement complex, a result that took place during the late pre-Cambrian period about 500 million years ago. The extensive rock formation consists of pyroxene granulite gneiss that covers more than 50% of the city area. syenitic gneiss on the other hand covering 40%, both of these rock types are impervious hence poor aquifers. Blantyre city is on the eastern edge of the southern branch of the eastern African rift and thus prominent faults occur within the city. the main faults and associated zones of deeply fractured bedrock run from the north of the city in a south-westerly direction and are potential aquifers for groundwater.

3.1.4. Economy

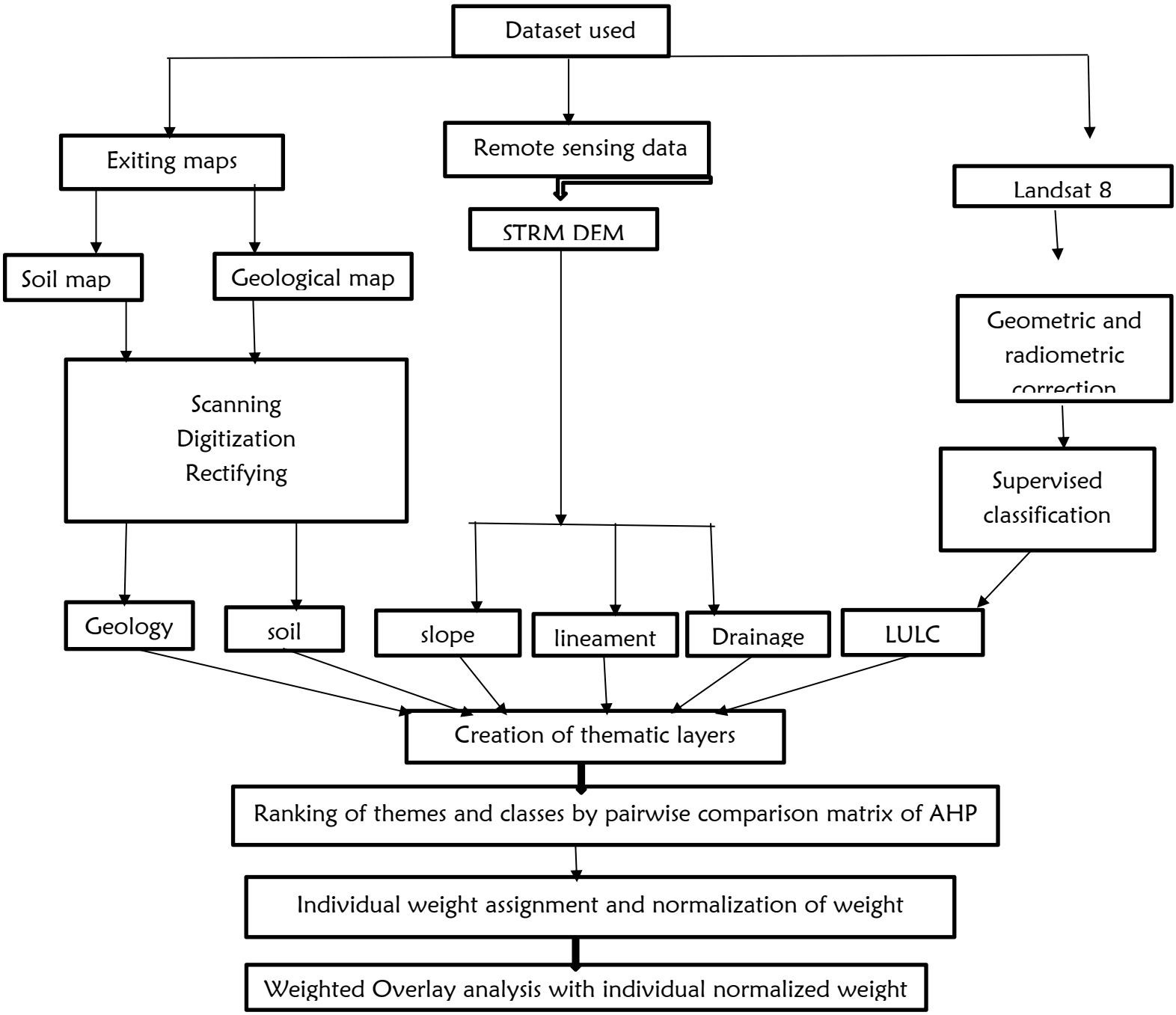
Blantyre city is the commercial and industrial capital.it is the major employment generator and has the greatest effect on the economy, it's the country's industrial Centre (UN-Habitat, 2011), the popular industrial areas are Makata, Ginnery Corner, Maselema, Limbe, Chirimba, and Maine. the industrial is located along the banks of main rivers or streams of Blantyre city hence a high level of water pollution happening. For example, Makata industrial area lies between the mudi and Nasolo river whilst the Ginnery Corner area is around the Mudi river, Maselema industrial area exists along the Naperi river and the Chirimba stream hosts Chirimba industrial area.

3.1.5. Data collection

The first phase of data collection involved downloading Geological Data and Geospatial data of Blantyre's Landsat images and USGS Earth Explorer and

STRMDEM data were sourced from the department of the survey. DEM was generated from remote sensing using data from different satellites; LANDSAT and ASTER, which helped in the mapping of the study areas slope, lineament density, and the drainage density, also soil and landcover map were generated after using the Malawi soil data which was clipped to come up with the soils in Blantyre city and supervised classification to make land use a land cover map.

3.2. Conceptual Framework



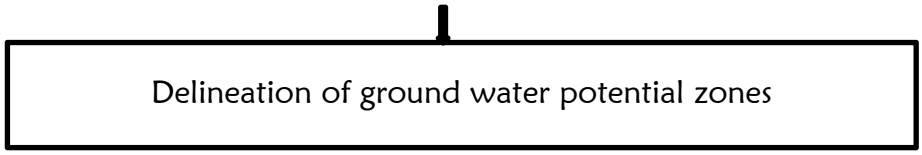


Figure 3; conceptual framework diagram

Flow chart of the methods used for the delineation of groundwater potential zones

3.3. Materials and methods

3.3.1. preparation of thematic layers

To come up with the potential areas where groundwater could be found, the contributing factors for a place to be a potential area for holding groundwater had to be considered and evaluated as groundwater resource and occurrence is believed to be influenced and largely depend on those factors, and these were selected to be slope, soil, lineament, land use Land cover and drainage. These were given weight depending on the impacts, they have on the groundwater potentiality from there they were ranked, and later on, an overlay weighted analysis of the thematic layers was done to come up with a final map showing the potential areas for groundwater zonation classified from low to high potential.

Using the Blantyre city Digital elevation model in ArcGIS we made a slope map, we first added the Blantyre city-data layer, then navigated to the spatial analyst tool surface, then clicked on the slope, selected the output of the Topo to raster tool as the input raster, specified the location of the output raster,select the output measurement and then clicked ok, the slope map was created, after creating it we classified it to five classes by going to the properties and choosing the classified on the symbology .

Lineament density was built in ArcGIS software through the line density tool in ArcGIS. The lineament density was calculated using this and it calculated the linear facility in each cell of the exit grid, the density was calculated in units of length per unit area, then after the calculations, a lineament density map was created as summarized in the figure below



Figure 4: Lineament density map framework

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin (https//gisrsstudy.com). To produce a Drainage density map firstly we had to calculate the drainage density of the area which followed this procedure;

1. Stream order, we open stream order data and also create watershed data, watershed data is the drainage covered area
2. Click geoprocessing >select environments, click workspace and we select the current workspace and scratch workplace.
3. Click processing extend, selected extend the same layer as a watershed we select Raster analysis, choose musk, and elected watershed.
4. We create a grid index, open arc toolbox. open the arc toolbox selects grid features and double click it.
5. Write the output feature name, on input features selected watershed to specify units
6. We open the arc toolbox, spatial analyst tool, expand the density subgroup, select line density and double click it.
7. On line density select input polyline features(drainage)population field selects grid-code the chosen area, set environments, dropdown raster analysis, click mask, choose watershed and click ok, now on-line density click ok and show your density result.
8. Customize drainage density properties on symbology click classified we classify and created our drainage density map.

Land use land cover map was created using classification whereby a Landsat image of Blantyre city was firstly downloaded and loaded and then the important areas were digitized which were classified a bare land, vegetation, built-up area, and

waterbody respectively producing a land-use landcover map using supervised classification.

A soil map was generated using the Malawi soils data whereby the Blantyre city was clipped and then by clicking on its properties and symbology it was classified depending on the surface texture to come up with the Blantyre city soils which included sandy loam, escarpment, clay soil, and clay loam soils.
After coming up with all the contributing parameter maps, they were ranked and given weights based on the impact they posed on the potentiality of groundwater, and then a weighted sum analysis was done to come up with the final map showing the potential groundwater zones of the study area.

3.3.2. Assignments of weight and weights normalization using AHP

The first step of the AHP method is to assign the level of importance of each factor based on Saaty's scale values. Consequently, all factors are compared in a pairwise comparison matrix. The weight which was assigned to different thematic layers is normalized using Saaty's AHP techniques. To control and test the consistency and judgment of the criteria's

assigned weights, the Consistency Ratio (CR) is calculated. The first step to calculate CR is to compute the maximum eigenvalue (λmax). Then the Consistency Index (CI) is calculated, where n is the number of factors. CR is resulted by dividing CI by RI (Ratio Index). The value of RI is given based on Saaty's 1-9 scale. If the value of CR is less than 0.1, the judgment of weights is acceptable and consistent.

3.3.2.1.The Saaty's scale

AHP is one of the most popular multi-criteria decision-making methods .one of the topics under discussion is the AHP scale. saaty and Vargas (2012) describe ratio scales, proportionality, and normalized ratio scale as one of the seven pillars of the Analytical Hierarchy Process. The fundamental AHP scale of absolute numbers I derived from the psychophysical law of Weber-Fechner and use absolute numbers 1,2,3,4…9 or its verbal equivalents. Paired comparisons are made by identifying the less dominant of two elements and using it as the unit of measurement. one

then determines how many times more the dominant member of the pair is than this unit. The reciprocal value is used for the comparison of the less dominant element with the more dominant one.

Table 1; saaty scale

Judgement X	Verbal Equivalent	Comment
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demo-stated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

To come up with the final weights, the following step was used to compute the final weight of all the thematic layers

1. Adding the values in each column of the pairwise matrix using the formula (Table 1) $L_j = \sum CI_j$
   Where Lj=the total values in each column of the pairwise matrix and
   Cij=the number assigned to each criterion at the ith row and j row
2. divide each element in the matrix by its column total to generate a normalized pairwise (Table 3)

In table 3, Showing the criteria weights of each contributing factor which was found by adding the row of each criterion, and the sum was divided by the total number of criteria used, in this study the total number of criteria used was 5.
3.divided the sum of the normalized row of the matrix by the number of criteria used to generate standard weights.

Table 2; pairwise matrix of thematic layers

CRITERIA	Land use Land cover	Slope	Lineament Density	Soil	Drainage density
Land use Land cover	1	0.14	0.33	5	0.14
Slope	7	1	1.4	2.33	0.71
Lineament Density	3	0.71	1	1.66	0.6
Soil	0.2	0.42	0.6	1	0.71
Drainage Density	7	1.4	1.66	1.4	1
Summation	18.2	3.67	4.99	11.39	3.16

Table 3;Criterial weights of thematic layers

Criteria	Land use Land cover	Slope	Lineament Density	Soil	Drainage Density
Land use Land cover	1/18.2=0.05	0.14/3.67=0.03	0.33/4.99=0.04	5/11.39=0.43	0.14/3.16=0.04
Slope	7/18.2=0.38	1/3.67=0.27	1.4/4.99=0.22	2.33/11.39=0.20	0.71/3.16=0.22
Lineament Density	3/18.2=0.16	0.71/3.67=0.19	1/4.99=0.20	1.66/11.39=0.14	0.6/3.16=0.18
Soil	0.2/18.2=0.01	0.42/3.67=0.11	0.6/4.99=0.12	1/11.39=0.08	0.71/3.16=0.22
Drainage Density	7/18.2=0.38	1.4/3.67=0.38	1.66/4.99=0.33	1.4/11.39=0.12	1/3.16=0.31
Criterial weight	0.122	0.27	0.17	0.105	0.304

Table 4: Normalised Weights

criteria	LULC	Slope	Lineament Density	soil	Drainage Density
LULC	1*0.122 =0.122	0.14*0.27 =0.0378	0.33*0.17 =0.0561	5*0.105 =0.525	0.14*0.304 =0.0425

Slope	7*0.122 =0.854	1*0.27 =0.27	1.4*0.17 =0.238	2.33*0.105 =0.2446	0.71*0.304 =0.2158
Lineament Density	3*0.122 =0.377	0.7*0.27 =0.1917	1*0.17 =0.17	1.66*0.105 =0.174	0.6*0.304 =0.1824
Soil	0.2*0.122 =0.0244	0.42*0.27 =0.1134	0.6*0.17 =0.102	1*0.105 =0.105	0.71*0.304 =0.2158
Drainage density	7*0.122 =0.854	1.4*0.27 =0.378	1.66*0.17 =0.2822	1.4*0.105 =0.147	1*0.304 =0.304

Table 5; Normalized weight sum and ratio

FACTORS	WEIGHTS	WEIGHTED SUM VALUE	RATIO
LULC	0.122	1.1659	1.1659/0.122 =9.5565
SLOPE	0.27	1.8224	1.8224/0.27 =6.7496
SOIL	0.105	0.5606	0.5606/0.105 =5.339
DRAINAGE DENSITY	0.304	1.9652	1.9652/0.304 =6.4644
LINEAMENT DENSITY	0.17	1.0841	1.0841/0.17 =6.377

3.3.3. Consistency analysis

to calculate the consistency vector, we multiply the pairwise comparison matrix values and normalized pairwise matrix values, and normalized pairwise matrix values of the thematic layers according to using matrix multiplication. For calculating the consistency vector values we used the following formula.

Lambda max=6.377+6.4644+9.5565+5.339+6.7496/5

=34.4865/5

=6.8973

Consistency Index (CI)= $\frac{\text{Lambda Max}-\text{Number of criteria(n)}}{\text{Number of criteria(n)}-1}$

$=\frac{6.8973-5}{5-1}$

=0.4743

Consistency Ratio=Consistency index/Random consistency index (RI)

=0.4743/1.1

=0.42

3.3.4. Overlay Analysis

All five thematic layer maps are integrated using ArcGIS 10.4 as a summation of overall groundwater influencing factors to produce the groundwater potential map (GPM) of the study area. The following formula is used to estimate the groundwater potential map

GPM = (MC1w ×SC1r) + (MC2w ×SC2r) + (MC3w ×SC3r) + (MC4w ×SC4r) + (MC5w ×SC5r)

Where GPM is groundwater potential map, MC1–MC5 is the main criteria (1–5 thematic layer maps), w is the weight of the thematic map, SC1–SC5 is the sub-criteria of each thematic layer map and r is the sub-criteria class ranking, but this calculation is done automatically in ArcGIS.

4. RESULT AND DICUSSION

4.1. The contributing factors

4.1.1. Slope

The slope is the principal factor of the superficial water flow since it governs the effect of gravity on the water movement. Slope defines the variation of elevation in a particular area which influences the runoff (Naghibi et al., 2016). Generally, in gentle slopes, the movement of water is slow which allows more percolation into the ground. On the other hand, a steep slope increases runoff and decreases the percolation and infiltration into the ground. A slope map was generated from Blantyre city DEM data using tools in ArcGIS 10.4. Then, the slope map was presented and classified into five classes which are flat, moderate, gentle, steep, and very steep respectively. Then these were ranked based on their connection with water infiltration, there is a high level of water infiltration in gentle and flat areas therefore it was ranked 5 and 4 as it strongly impacted and influenced the presence of groundwater.

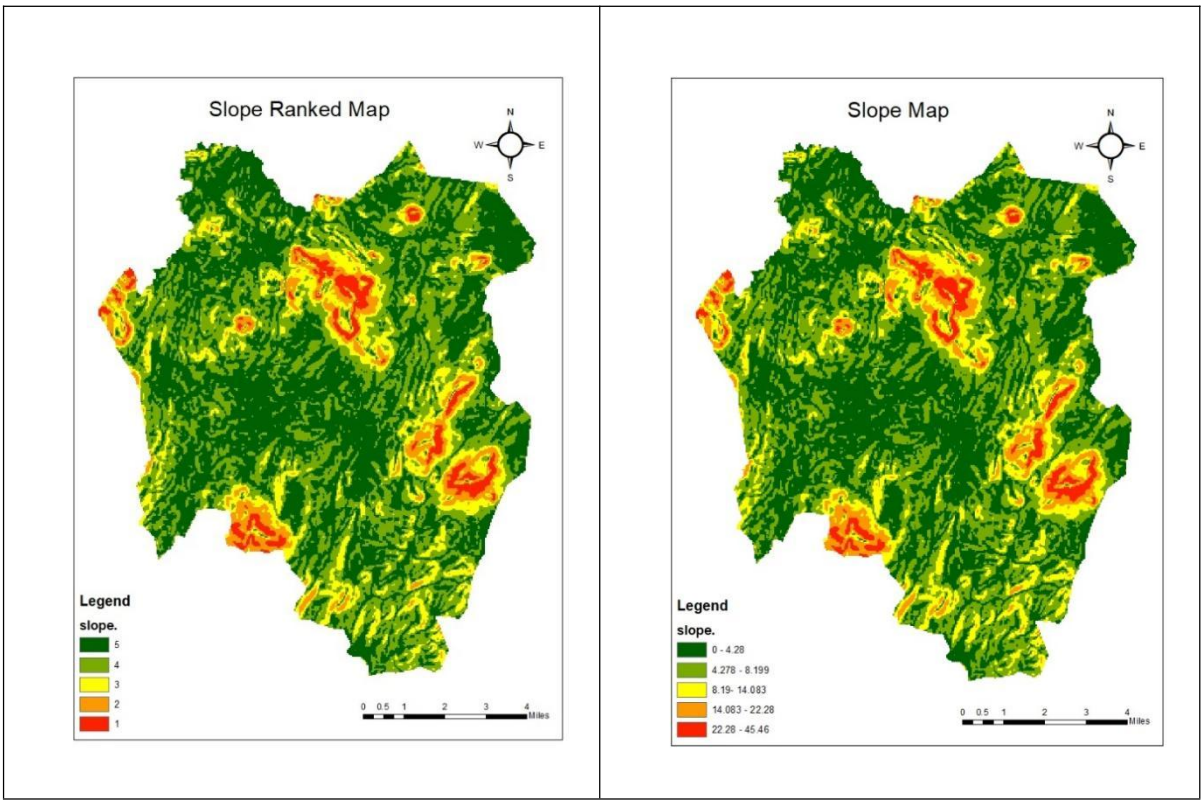


Figure 5; Blantyre city Slope Maps

4.1.2. Soil

Soil is important tool when delineating groundwater potential zones. the rate of infiltration in soil varies spatially and temporally depending on the soil type and properties. Some soils have high infiltration rate compared to other, for example sandy soils have a higher infiltration rate compared to clay soil.Soil texture map of the Blantyre city area was generated using the Malawi soil data whereby Blantyre city was clipped, Blantyre city was found to contain sandy loam soils, clay soil, and loam soils respectively of which sandy soil are very good in terms of infiltration rate, after the map was generated, it was ranked considering the soils which highly influences a groundwater potentiality hence the assigning of 5 and 4 to sandy and sandy loam soils.

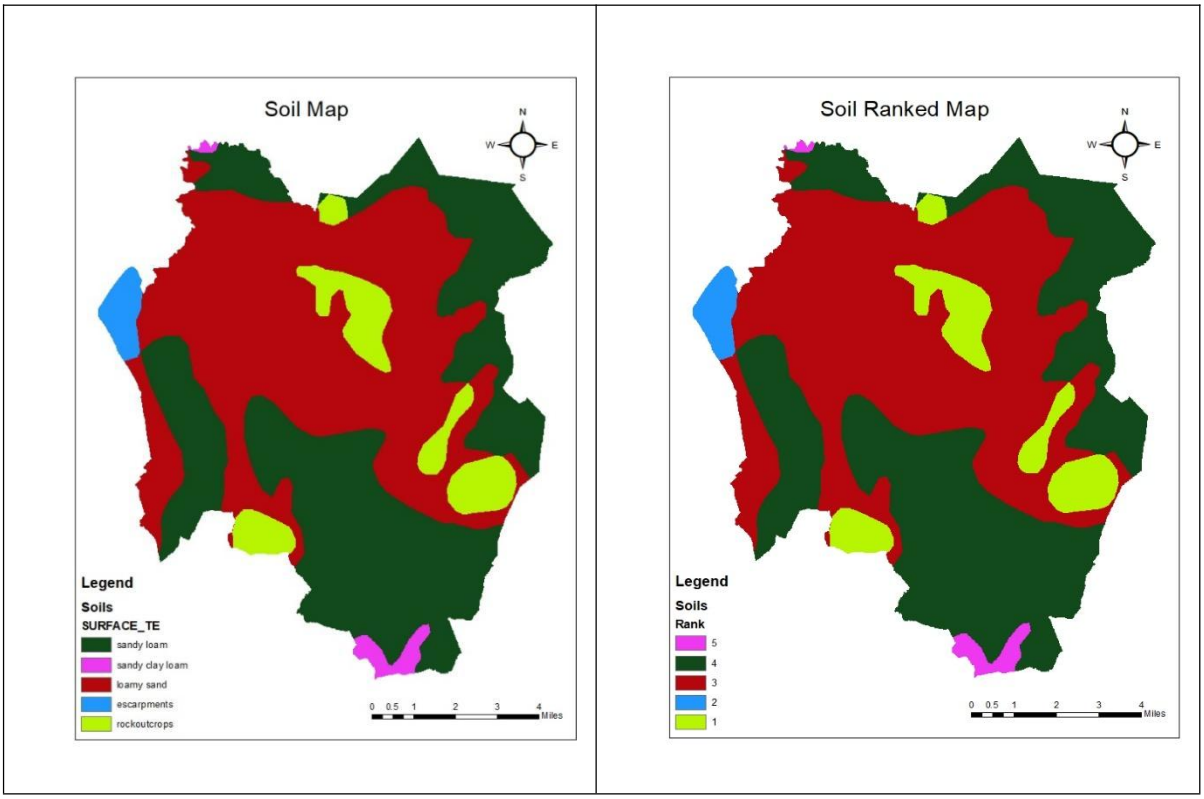


Figure 6; Blantyre City Slope Maps

4.1.3 Drainage density

Drainage density is the closeness of spacing of stream channels, and it is the ratio of the total length of the stream segment of all orders per unit area (Singh et al., 2014). The drainage density is an inverse function of permeability which plays a vital role in the runoff distribution and level of infiltration an area's drainage density relies on the nature and composition of geological information, ability to absorb soil, permeability, and slope. Drainage carries water from the mountain region from precipitation or glacial or snowmelt to the plains. It plays a major role as the groundwater source in a given area. The drainage systems are controlled by structural features like faults and fractures in the area and henceforth drainage acts as a transmitting medium for glacial meltwater movement into the subsurface. High drainage density increases the surface runoff and decreases infiltration. the high drainage density areas are not suitable for groundwater resource production. Drainage of the study area was extracted from ASTER DEM data and verified with satellite image Drainage density per km2 was calculated by line density tool in Arc GIS and it was classified as high and low. The suitability of groundwater potential zones is indirectly related to drainage density because of its relation with surface runoff and permeability.

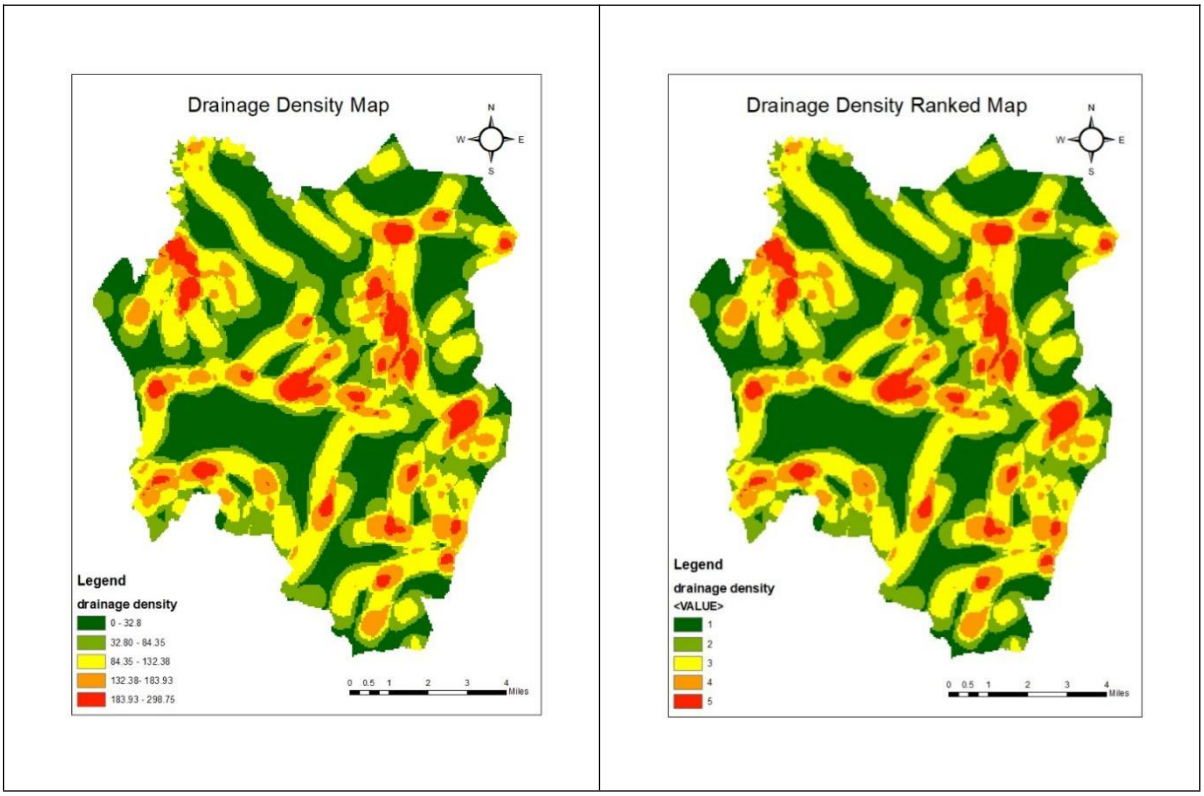


Figure 7;Blantyre city Drainage Maps

4.1.3. Land cover and land use

Land use and land cover of any region play an important role in the runoff, infiltration, and recharge of groundwater. Using the DEM of the area the land was demarcated into five categories which were bare land, vegetation, urban settlements, water, and these were digitized and reclassified to come up with the map. Vegetation strongly influences the infiltration of water the plants hold the water giving time for water to sink into the ground hence was ranked a 5, while waterbodies and built-up area have poor groundwater potential.

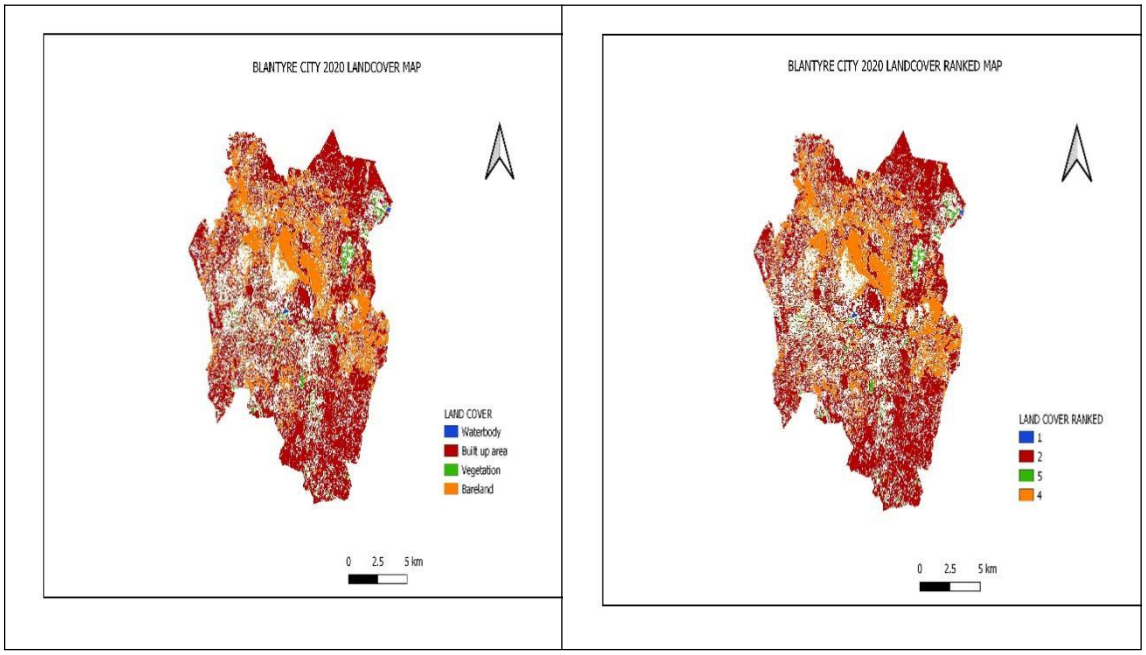


Figure 8;Blantyre city land cover land use map

4.1.4. Lineament density

Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. These factors are hydro-geologically very important as they provide the pathways for groundwater movement. Lineaments occur as straight, curvilinear, parallel, or en-echelon features, Lineaments may represent fracture systems, discontinuity planes, faults, and shear zone in rocks. Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. These features express the surface topography of the underlying structural features. The lineament density of an area can indirectly reveals the groundwater potential since the presence of lineaments usually denotes a permeable zone. Areas with high lineament density are good for groundwater potential zones (Haridas et al., 1998). Lineaments can be identified on satellite images. Lineaments are identified from the Digital Elevation Model (DEM) of Blantyre city. Using ArcGIS, the lineament density map of the study area is generated revealing the high lineament density places and the low ones.

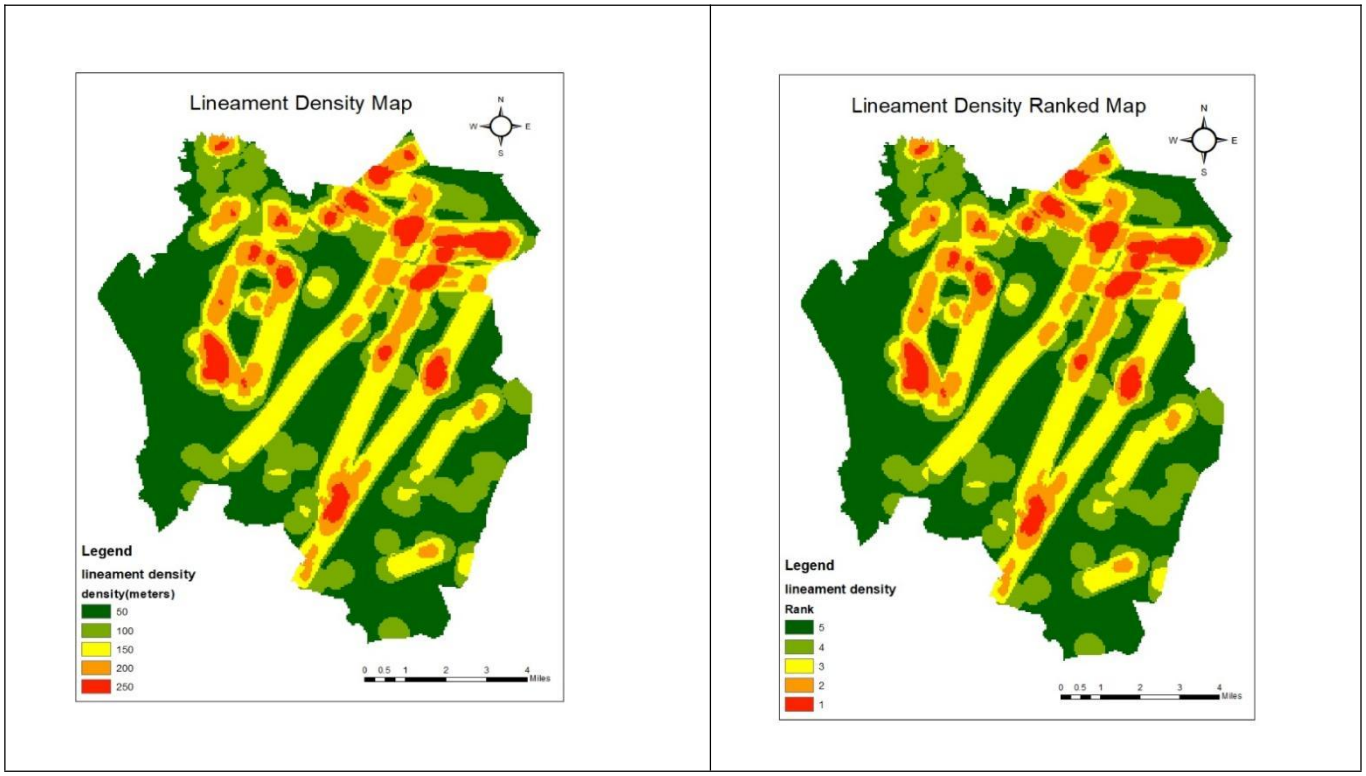


Figure 9;Blantyre city Lineament density Map

4.2. Calculations and Processing

One of the objectives of the research was to find the parameter or criteria contributing to a groundwater potential zone of which we found to be lineament density, slope, drainage density, soil, land use land cover. These were classified further using the AHP scales by their level of importance according to the table. .to analyse and discuss the impact of the different scales on the resulting priorities to support the selection of an appropriate scale for the groundwater potential zones, table 7 is showing the thematic layer and their potentiality influence in the groundwater zone in their respective categories.

Table 5; Ground water potentiality storage rates

Influencing Factors	Category(classes)	Potentiality for ground storage	Rating

Slope	0-4.7% 4.3-8.2% 8.2-14.08% 14.08-22.3% 22.3-45.5%	Very good Good Moderate Poor Very poor	5 4 3 2 1
Land use land cover	Vegetation Bare land Waterbody Built up areas	Very good Good Very poor poor	5 4 1 2
Soil	Sandy loam soil Sandy clay loam soil Loamy soil Escarpments Rock outcrops	Very good Good Moderate Poor Very poor	5 4 3 2 1
Lineament Density	50m 100m 150m 200m 250m	Very good Good Moderate Poor Very poor	5 4 3 2 1
Drainage	0-32.8	Very poor	1

Density	32.8-84.35	Poor	2
	84.35-132.38	Moderate	3
	132.8-183.93	Good	4
	183.93-298.75	Very good	5

BLANTYRE CITY GROUND WATER POTENTIAL ZONE MAP

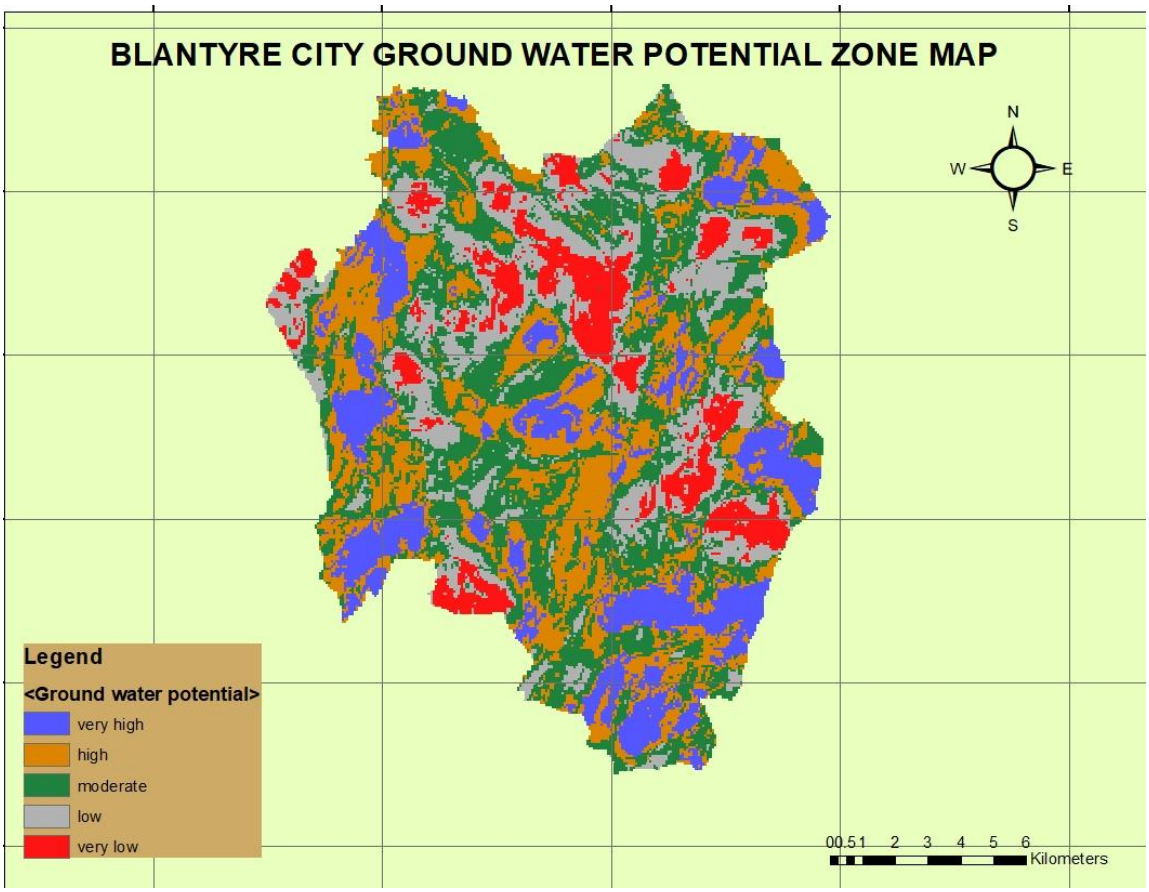


Figure 10;Groundwater Potential Zone map

After the weighted overlay the group water potential zone map (figure 9) showing the areas with the highest, high, very low, low, and moderate potential zones. The high to very high zones were characterized by the presence of high drainage density, sandy loam soils, gentle slope the places with low lineament density which presented interconnected faults occurring zones.

5. CONCLUSION AND RECOMENDATION

5.1. Conclusion

This In this study, Remote sensing and GIS have successfully provided a platform for the analysis and decision making in groundwater studies. And the delineation of the groundwater potential zone in Blantyre city is found efficient as it minimized time labour and money in coming up with the potential groundwater zones, the weighted overlay model was found very useful in mapping the prospective zones. Using Landsat Tm and DEM we assessed and came up with the thematic map of the contributing factors which were standardized and put to a common scale by being assigned weights and ranked equally from 1 to 5 and later on the overlay analysis and weighted sum was done to come up with the groundwater potential zone map which was categorized into five mainly the very high, high, moderate, low and very low area for groundwater potentiality respectively. The zones with high potentiality for groundwater storage followed on the sandy soils, high drainage density, flat, vegetation, and low lineament density areas, this map together with a further ground surveying to verify can help not only the organization but also people in the exploration of the groundwater.

5.2. Recommendations

When delineating ground water potential zones rainfall and lithology also plays a great role, in this project rainfall and lithology were not evaluated due to lack of data ,but when evaluating these groundwater potential zone lithology and rainfall plays a great role in the groundwater potentiality and should be considered as rainfall is the most dominant influencing factor in the groundwater potentiality of any area and is the major water source in the hydrological cycle, it determines the amount of water which would percolate into the groundwater system High intensity and short duration rain possess less infiltration and more surface runoff. Low intensity and long duration rain possess high infiltration than runoff. Lithology on the other side influences both the permeability of the aquifer rocks and the distribution of the fracture pattern.

The government and the people should take into account and seriously afforestation and reafforestation and also enforce rules on the prevention of cutting down of tree and bush fires as they play a major role in the existence of groundwater as they increase infiltration rate.

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