Identification of Groundwater Potential Zones using Remote Sensing and GIS in Lake Chala Watershed, Kenya

W. B. Mwega, M. M. Bancy, J. K. Mulwa, and G. M. Kituu

Abstract- Groundwater is a natural resource of the earth that sustains and supports domestic, agricultural and industrial activities. It is distributed fairly and evenly throughout the world and over half of the world's population depends on groundwater for drinking water supplies. Its usage is increasing due to rapid population growth, high rate of urbanization, industrial growth and agricultural utilizations. This has resulted to rapid depletion of groundwater which leads to water stress and degradation of these resources. The situation is further worsened by inadequate information on groundwater resource which has been and is still a big obstacle to the proper management of these resources. Remote sensing and GIS techniques have emerged as very effective and reliable tools in the assessment, monitoring and conservation of groundwater resources. The purpose of this paper was to identify and delineate groundwater potential zones in Lake Chala Basin in Kenya using Remote sensing and GIS. In the process of groundwater delineation in the area, different thematic maps on lithology, land use/land cover, drainage density, slope and rainfall were prepared, assigned with different weightage values as per their importance on groundwater occurrence and overlaid using spatial analyst tool in ArcGis 10 to generate groundwater potential map. The generated groundwater potential zone map was classified into four groundwater potential zones namely, very high, high, moderate and low. The study revealed that the area have very high groundwater potential. The generated groundwater potential map will be used for further groundwater exploration, proper planning, sustainable utilization and management of groundwater resources in the Lake Chala Watershed.

Keywords- Groundwater, Remote Sensing and GIS, Groundwater Potential zone, Thematic maps

I. INTRODUCTION

Groundwater is natural resource of the earth that sustains and supports agricultural, domestic and industrial activities. Groundwater accounts for the largest percentage of the world's fresh water. It is distributed fairly and evenly throughout the world. It is an important water resource which contributes to around 34% of the total global annual water supply [7]. About half of the World's population depends on groundwater for drinking water supplies. About 30% of the public water supplies in the UK, 50% in the USA, 99% in Denmark and 70% in Germany are derived from groundwater sources [1]. Groundwater resources in Kenya are mostly used for public water supply, domestic, industrial, agricultural and livestock purposes. At present, groundwater abstraction rate is estimated at 57.21 million m^3 per year which is below the recommended rate of about 193 million m^3 per year, [4]. Groundwater usage is increasing due to rapid population growth, high rate of urbanization, industrial growth and agricultural utilizations. This has resulted to rapid depletion of groundwater which leads to water stress and degradation of these resources [2]. Groundwater usage can only be optimally sustained if the quantity and quality of the resource is well assessed, planned and managed. Inadequate information on groundwater resource has been and is still a big obstacle to the proper management of these resources because groundwater occurs in complex subsurface formations. It is therefore crucial to determine groundwater potential zones as well as monitor and conserve these important natural resources [8]. Remote sensing and Gis techniques have emerged as very effective and reliable tools in the study of groundwater [8]. Since groundwater cannot be directly seen on the earth's surface, GIS and Remote Sensing provide reliable information about its occurrence [12]. They help in analyzing and integrating large number of multi-spectral, multi-temporal, multi disciplinary and multi- sensor geographic data of the earth's surface and in particular water resources and present the results in form of a map [8]. They also help in delineating potential areas of water bearing capacity through integration with several factors such as drainage, lineament, geology, slope and land use that influence the occurrence and movement of groundwater where further exploration work could be taken up thus reducing time and cost involved in water exploration [3].

Several researchers have successfully utilized Gis and Remote sensing technologies in identification of groundwater potential zones around the world. [12] used remote sensing and Gis for spatial analysis of groundwater potential in Kanyakumari and Nambiya basins in India. [5] have used the GIS technique for generation of groundwater prospect zones towards rural development. [6] have demarcated ground water potential zones through Remote Sensing and Geographical Information

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System. [9] have applied GIS and Remote Sensing to evaluate groundwater potential zones in Gaimukh watershed, Bhandara district, Maharashtra. [10] also have used GIS and Remote Sensing for groundwater prospect zoning in Dala–Renukoot Area, Sonbhadra District Uttar Pradesh. This paper therefore aim to provide information about groundwater potential zones in Lake Chala Watershed using Remote Sensing and GIS techniques for further groundwater exploration, proper planning, sustainable utilization and management of groundwater resources in the Lake Chala Watershed.

I. STUDY AREA

The Lake Chala catchment area lies at the foot of Mt Kilimanjaro, 9.654 kilometers North of Taveta Town, between longitude 037^0 29' E and 037^0 45' E and latitudes 03^0 6' S and 03^0 29' S covering an area of about 16.23 km^2 (fig 1).

Fig 1. Lake Chala Watershed Location Map

II. MATERIALS AND METHODS

In order to identify the ground water potential zones in Lake Chala Watershed different data were used to prepare various thematic layers of the study area. The data used include: Elevation data, Satellite images, river data, geology and soils data and drainage data. The data and satellite images were first registered to WGS84 for geometrical correction and then to UTM Geographic Coordinate System using the projection and transformation tool in Arc Catalog version 10. A vector layer of the area of interest was digitized from an overlay of elevation and rivers network data. The area of interest vector layer was used to clip the slope, land use/cover, rainfall, drainage and lithology data layers using the Extract tool under Arc Map 10 Analysis tools. The clipped data layers were then converted into raster formats using the Arc Map convert commands under image analysis. Using the reclassify command under spatial analyst tools, all the data layers were assigned scale values with a rating scale range of 1 to 9 depending on their influence on the movement, storage and groundwater occurrence (Table 1). In the scale, the lowest score represent high groundwater potential areas while the highest score represent low groundwater potential areas. Finally, all thematic layers were assigned weights based on their influence on the occurrence, movement and storage of groundwater and then integrated to generate groundwater potential map as shown in fig 2

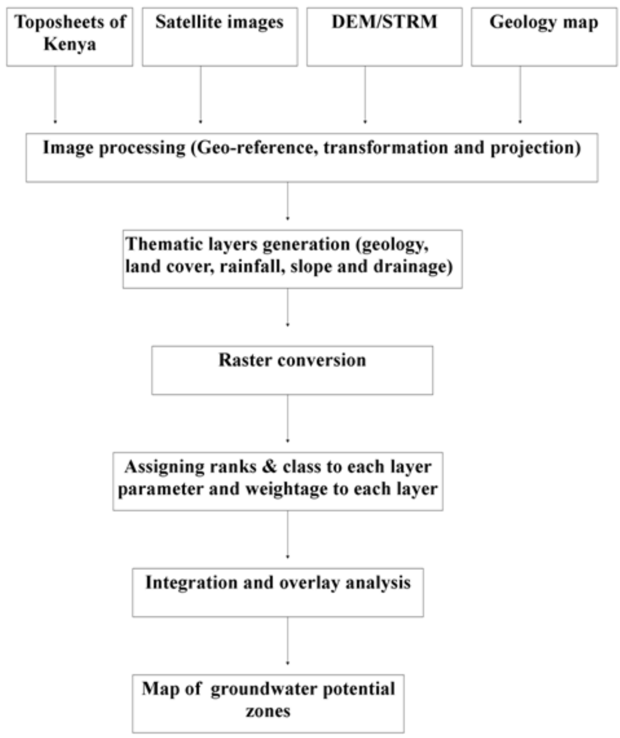

Fig 2. Methodology Flowchart For Delineating Groundwater Potential Zones

III. RESULTS AND DISCUSSION

TABLE 1
Rank and Weightage Of Thematic Layers For Groundwater Potential Zones

Thematic layers	Classes	Rank (reclassified)	Groundwater potential	Weight (%)
Rainfall	2000-2400	1	Very high	20
	1600-2000	2 } 1	Very high	
	1400-1600	3	Very high	
	1200-1400	4	Moderate	
	1000-1200	5 } 2	Moderate	
	800-1000	6	Moderate	
	700-800	7	Low	
	600-700	8 } 3	Low	
	500-600	9	Low	
Land cover	Forest	1	Very high	20
	Agriculture	3	Moderate	
	Bush land	2	High	
	Scrubland	4	Low	
	Urban areas	5	Very low	
Litholog y	Sedimenta-ry rocks	1	High	20
	Igneous rocks	2	Moderate	
	Metamorp-ic rocks	3	Low	
Slope (degrees)	0-3	1	Very high	20
	3-8	2	High	
	8-16	3	Moderate	
	16-27	4	Low	
	27-50	5	Very low	
Drainage density (per km)	0-0.3	1	Very high	20
	0.3-0.9	2	High	
	0.9-1.5	3	Moderate	
	1.5-2.3	4	Low	
	2.3-3.9	5	Very low	

IV. RAINFALL

Rainfall is one of the major sources for groundwater. The high rainfall amounts imply the possibility of high groundwater recharge thus high groundwater potential zones while low rainfall indicates low groundwater recharge thus low groundwater potential zones. Spatial distribution of rainfall was generated using annual rainfall data and based on the areas annual rainfall, 9 classes were generated. The generated rainfall classes were then reclassified and ranked based on their influence on the movement and storage of groundwater, fig 3 and table 1

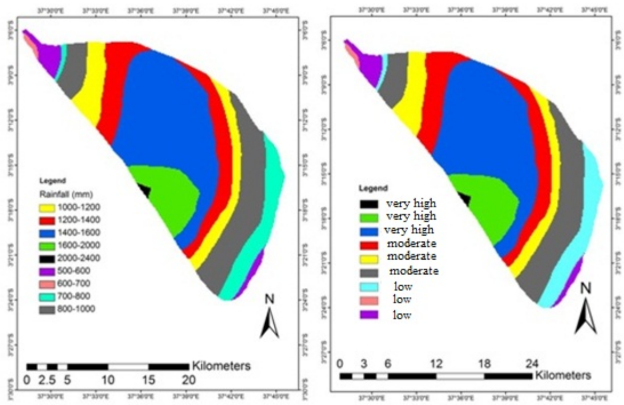

Fig 3. Rainfall and Reclassified Rainfall Maps

V. LAND COVER

Land use/land cover plays important role in the occurrence and development of groundwater Land cover influences the ground water infiltration and alters the rate of percolation of precipitation on the hill slope. Land use/land cover maps were produced to identify the different classes of land from satellite images. Different training sets were delineated for each land cover class. The maximum likelihood decision rule, the most common supervised classification method used with remotely sensed imagery data was used to perform the supervised classification. The study area was classified into 5 land cover classes namely, forest, bush land, agriculture, scrubland and urban areas. The classes were then reclassified, ranked and weighted based on their ability to hold surface water which eventually infiltrates and recharge groundwater, fig 4. Forest cover was given the highest rank and urban areas were assigned the lowest rank as shown in table 1

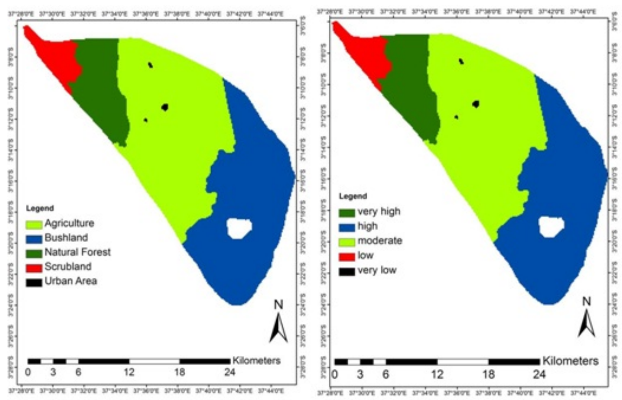

Fig 4. Land Cover and Reclassified Land Cover Maps

VI. SLOPE

Slope is an important factor for the identification of groundwater potential zones. Slope plays significant role in infiltration versus runoff and is also a very important factor influencing groundwater because it governs the occurrence and movement of groundwater. In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater and hence comparatively less infiltration. The slope map of the study area was prepared based on SRTM data using the spatial analysis tool in Arc Map 10. Based on the slope, the study area was divided into five slope classes namely; flat, gentle, moderate, steep, and very steep slope. The generated classes were then reclassified and ranked depending on their influence on groundwater as shown in fig 5. The lowest rank was assigned to very steep slope because they results to high runoff and low infiltration thus little or no groundwater recharge. The highest rank was assigned to flat slope because of its ability to hold water thus facilitating high infiltration that results to groundwater recharge.

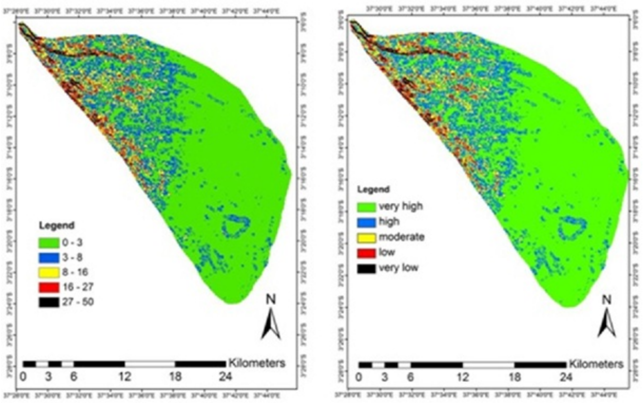

Fig 5. Slope and Reclassified Slope Maps

VII. LITHOLOGY

Lithology is major factor controlling the quantity and quality of groundwater occurrence in a given area. It is represented by the distribution of different rock units characterizing the area under study. Three types of lithological units which are igneous rocks, sedimentary and metamorphic rocks were observed in the study area, ranked and classified according to their groundwater yield capacity as indicated in table 1 and fig 6. Sedimentary rocks were considered as having a high potential for groundwater due to their high porosity and permeability while metamorphic was considered as having the lowest groundwater potential due to their low porosity and permeability.

VIII. DRAINAGE DENSITY

Drainage density is the closeness of spacing of stream channels. It is a measure of the total length of the stream segment of all orders per unit area. Drainage density indirectly indicates the groundwater potential of an area due to its relation to surface run-off and permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface run-off. Groundwater potential is found to be poor in very high drainage density areas as major part of the water poured over them during rainfall is lost as surface runoff with little infiltration to meet groundwater. On the contrary low drainage density areas permit more infiltration and recharge to the groundwater and therefore have more potential for groundwater occurrence. Drainage density of the study area was generated using kernel density analysis tool in ARCGIS 10 software. The resulting drainage density map of the area was grouped in to five classes, 0-0.2km, 0.2-0.7km, 0.7-1.18km, 1.18-1.80km and 1.80-3.06 based on their importance to groundwater. Reclassification of the density was done using reclassify command in ARCGIS and then ranked based on its influence on the groundwater movement and storage with the highest rank (1) assigned to areas with low drainage density and lowest rank (5) assigned to areas with high density fig 7.

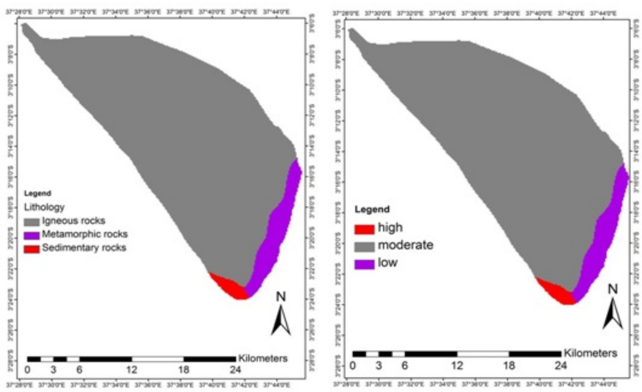

Fig 6. Lithology and Reclassified Lithology Maps

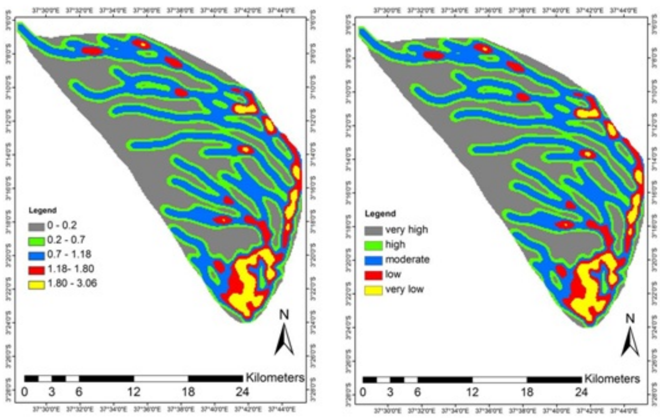

Fig 7; Drainage Density and Reclassified Drainage Density Maps

IX. OVERLAY ANALYSIS

The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay method using the spatial analysis tool in ARCGIS 10. During the weighted overlay analysis, the ranking was given for each individual parameter of each thematic map and weightage were assigned according to the influence of the different parameters as indicated by table 1. The output map of groundwater potential zone of the area was generated and classified into four suitable classes namely; very high, high, moderate and low, fig 7. The groundwater potential map demonstrates that, the study area is dominated by very high and high groundwater potential zone which covers the largest area. Very high and high potential zones are concentrated in areas with

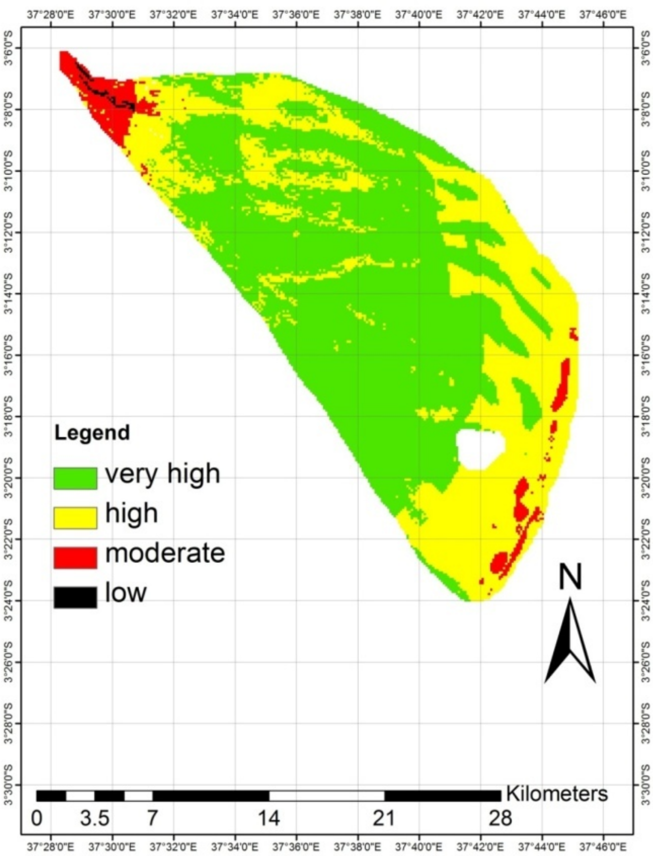

Fig 8. Groundwater Potential Zones Map

CONCLUSION

The groundwater potential map demonstrates that, the study area is dominated by very high and high groundwater potential zones. Areas of very high groundwater potential zones cover the largest area followed by areas of high potential, moderate potential and low potential which cover the least area as shown by the map. This study has therefore demonstrated successful use of Remote Sensing and GIS technology in identifying groundwater potential zones which can be explored further.

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