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Full Length Research Article

MODELLING OF POTENTIAL SITES FOR UNDERGROUND WATER IN SEMI ARID AREAS

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ABSTRACT

Kajiado experiences insufficient amount of rainfall and people living in this region face alot of water shortage.The main economic activities include pastoralism, livestock herding, tourism and agriculture which require sustainable water source. The current water sources include a few rivers out of which most are seasonal and there are few boreholes which are distances apart. This study was prompted by the fact that these current sources of water need to be complemented with other reliable and sustainable water sources. Underground water is adequate and available throughout the year and location of it would help in solving this problem. To address the problem of water shortage, GIS and remote sensing techniques were applied in analyzing and locating suitable sites for underground water in Kajiado County. Underground water sourcing requires one to identify the necessary variables and these were identified by assistance from experts and literature review. Current water resources were characterized, a geodatabase created and a model for underground water developed. Land cover, Slope, Lithology, Soil, Lineament and Climate were the six parameters used as the data. GIS technology was integrated with Analytical Hierarchy Process (AHP), a tool in Multi Criteria Evaluation (MCE) which enabled flexibility and accuracy in decision making especially in evaluating the effective factors to locate suitable areas. Identified criteria were combined using weighted overlay method within ArcGIS and the results indicate that 51% of Kajiado County is viable for underground water. Exploitation of this resource would mean sustainable source of water. The suitable locations are well distributed in the county except in Kajiado Central constituency which is generally unsuitable. Remote sensing and GIS are suitable tools for use in locating underground water. Decision makers would adopt this study to make informed decisions on where to sink new boreholes.

Key words: AHP, GIS Modeling, Kajiado County, Suitable Site, Underground Water.

INTRODUCTION

All forms of life depend on water. Sustainable development, good maternal health, proper feeding of the nation and a healthy nation cannot be realized without sufficient water. The county's natural water resources do not provide an equitable delivery of water to the various regions of the country and the water basins do not reach an equitable area of the country (Snyder 2016) leaving most of the population without fresh water. Rural areas of Kenya are without enough water and urban areas are not much better. Kenya's water shortage also means that a large population of women and children spend up to one-third of their day fetching water in the hot sun from the nearest fresh water source. This backbreaking work leaves roughly half of the country's inhabitants vulnerable to serious dangers and exposure to the elements and risk of attack by predators and are also the most susceptible to water-borne diseases. Samantha Marshall (2011) reported that there were about 40 million people living in Kenya and forty three percent of them have no access to clean water.

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For decades, Kenya has suffered from severe water crisis due to various causes; among them are droughts, degradation of forests, floods, lack of water supply management, water contamination and population growth. Less rainfall and lack of it affects ability to acquire food. This has resulted to eruptions of violence among some Kenyan communities. In many areas, the shortage of water in Kenya has been amplified by the government's lack of investment in water, especially in rural areas. In a short period, Kenya's population is expected to grow. This means that there will be need to tackle this water crisis and its effects. Ramamoorthy et al. (2015) stated that groundwater resource is an important natural resource for its use in domestic, agriculture, and industries purposes. There has been a tremendous increase in the demand for groundwater due to increase in population, advanced irrigation practices and industrial usages. Groundwater is a significant natural resource in present day, but of limited use due to frequent failures in monsoon, undependable surface water, and rapid urbanization and industrialization have created a major risk to this valuable resource. According to Kuria *et al* (2012), groundwater and its development can play a big role in a country's economy.

It becomes a usable resource when the water bearing formations are permeable enough to allow water to infiltrate through them to yield adequate quantity of good quality water for use through boreholes, hand dug-well and springs and can be replenished from recharge sources to permit continued exploitation. Groundwater can therefore be exploited if potential areas with abundant quantity can be identified. Teresia et al (2014) argued that inadequate and unequal access to water is both a result and cause of poverty and can be termed as a denial of human rights, good health, adequate nutrition, literacy and employment. Access to adequate amounts of clean water is essential for maintaining good health, agricultural activities for sustainable food production and further stated that access to safe drinking water is also very critical to the attainment of the Millennium Development Goals. Some of these millennium development goals supported by availability of water are; eradication of extreme poverty and hunger, improving maternal health, achieving universal primary education, promoting gender equality and empowerment of women, reducing child mortality.

MATERIALS AND METHODS

Kajiado covers an approximated area of 21,900.9 square kilometers. The County is divided into five administrative Sub-Counties, seventeen administrative divisions, one hundred and five locations and five parliamentary constituencies. It is located in Rift Valley region and borders Narok County to the West, Nakuru County, Kiambu County and Nairobi County to the North, Machakos County, Makueni County and Taita-Taveta County to the East and Tanzania to the South.

The County is semi-arid and experiences temperature ranges of between 20°C – 30°C and 500mm to 1,250mm per annum of rainfall. It enjoys two wet seasons, the short rains between October and December and the long rains between March and May. The county is famous for the Amboseli National Park popular tourist destination rich with wildlife and diverse ecosystem of flora and fauna and mineral resources particularly Soda ash from Lake Magadi. The county population as per the Kenya 2009 population census was 687,312 (345,146 males and 342,166 females).

The Study Approach

The required datasets were obtained from different sources. Climate data that was used to generate rainfall and temperature was collected from Kenya Meteorological Department. The data collected was for a duration of 30 years. Soil data was from Kenya Soil Surveys. This was used to obtain soil drainage, depth and texture. Landsat8 images and digital elevation model (STRM images) for the study area were downloaded from USGS website.

Lithology data which is the information about the rock types was attained from International livestock Research Institute (ILRI). The base map data was from Survey of Kenya. The existing borehole data was sourced from Water Resources Management Authority (WARMA). Existing boreholes were used as a check to judge whether they were well located in comparison to the generated suitability map. Table 1 summarizes the datasets used in this research and their source.

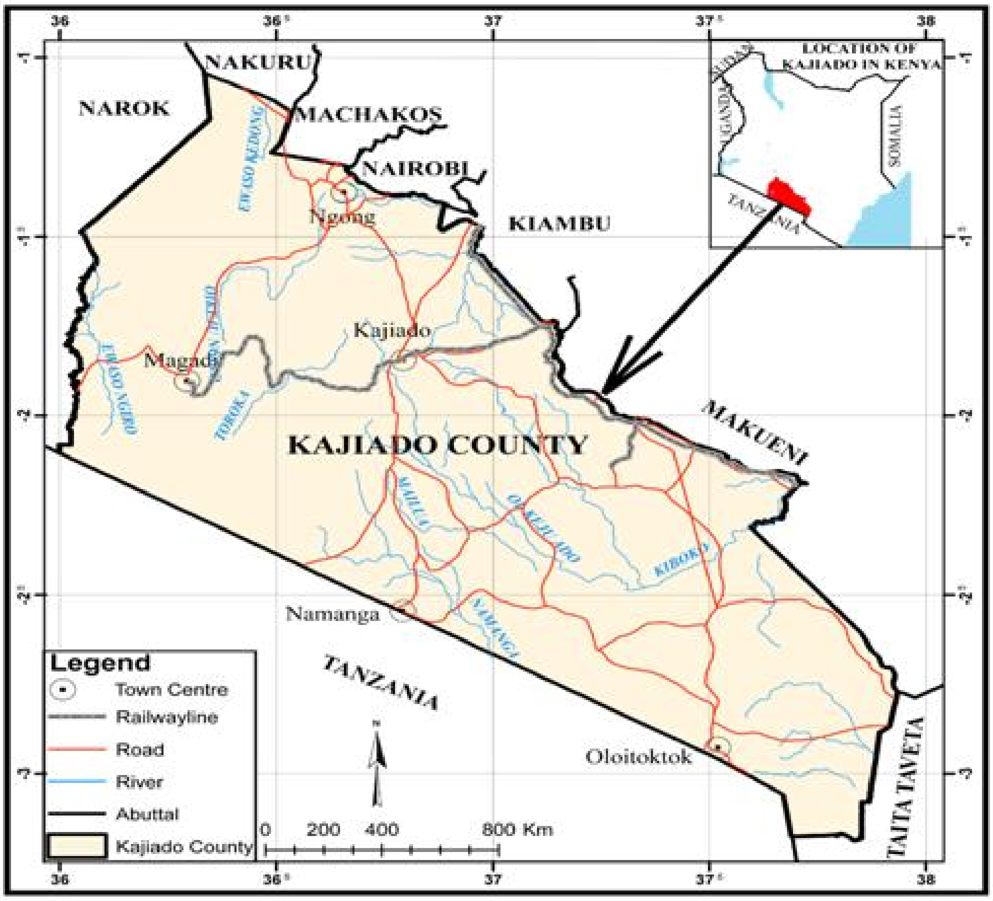

Figure 1. Study Area

The Flow of Study

The flow diagram (Figure 2) represents the steps in locating suitable sites for underground water. The procedure involved determining the factors involved in locating best sites. It also shows data collected, data preparation, data processing, creation of AHP and integrating MCE with the GIS to generate an underground suitability map. After data identification and collection, data standardization, geo-database creation, data modelling and analysis were carried out. Data harmonization and standardization involved transformation of spatial data to a uniform datum and projection while geodatabase creation entailed data vectorization, geo-referencing, digitization and rasterization during reclassification of factors. The spatial analyst tools in ArcGIS were applied to perform all the spatial analysis required.

A model was used in organizing elements of data and to indicate how they relate with one another. It enabled the representation of real geographical elements as graphical elements. The model was used in conjunction with GIS to properly analyze and visually lay out data for better conclusion. In this study, ArcGIS spatial analyst extension tools had been used to find suitable locations for underground water. Manipulation of information in the model occurred in multiple steps, each representing a stage in a complex analysis procedure. First step was to derive slope, Euclidean distance to lineaments, convert polygons to raster, clipping of data to area of study, interpolating rainfall and temperature data. The second step was to reclassify the derived datasets to a common scale. The third step was to weigh the datasets depending on the percentage of influence. After weighting, the datasets were combined to produce suitable locations of underground water.

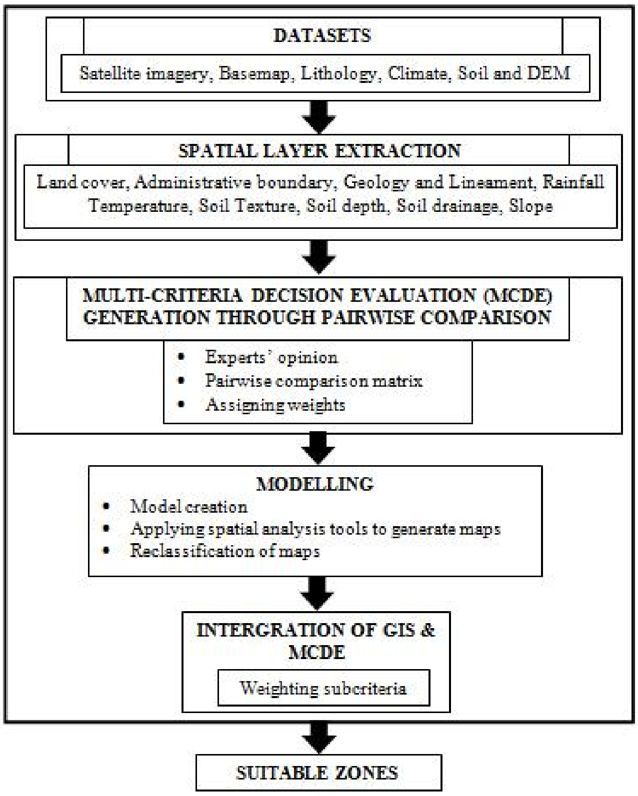

Figure 2. Flow of study

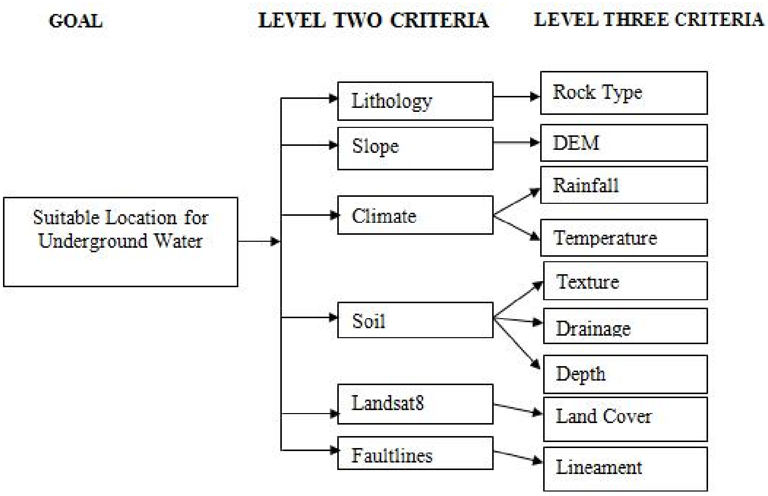

Figure 3. AHP flow diagram

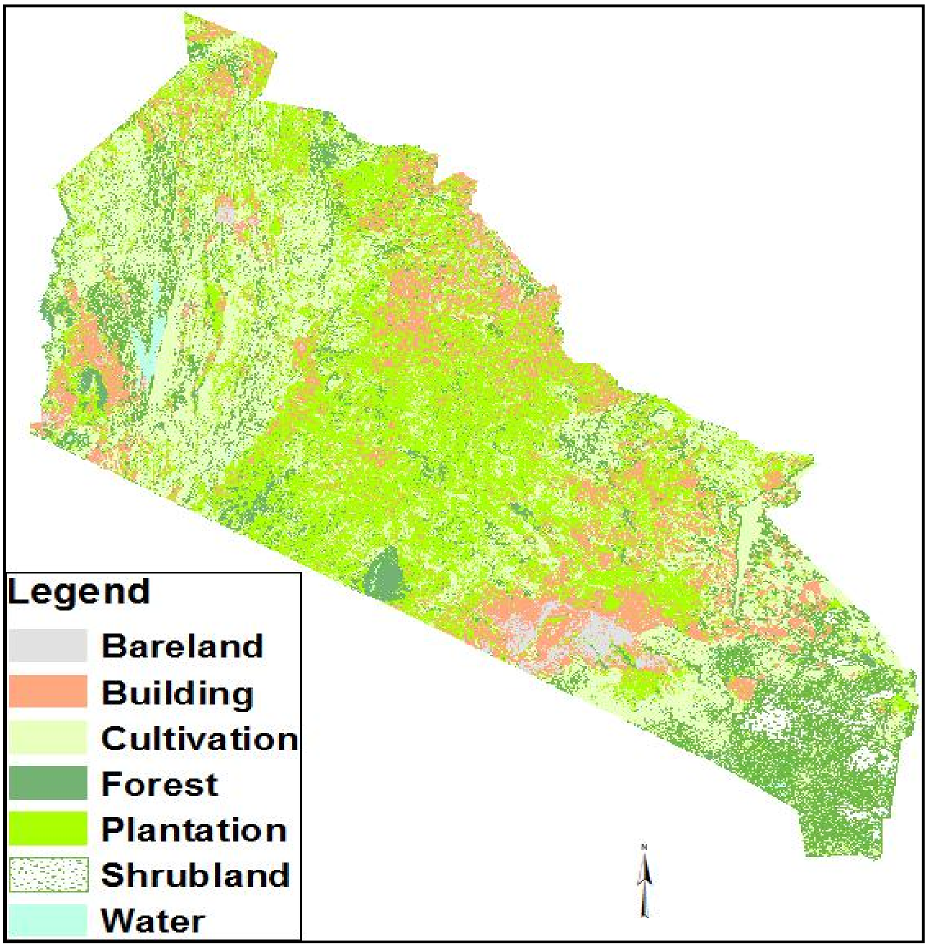

Figure 4: Land cover classified

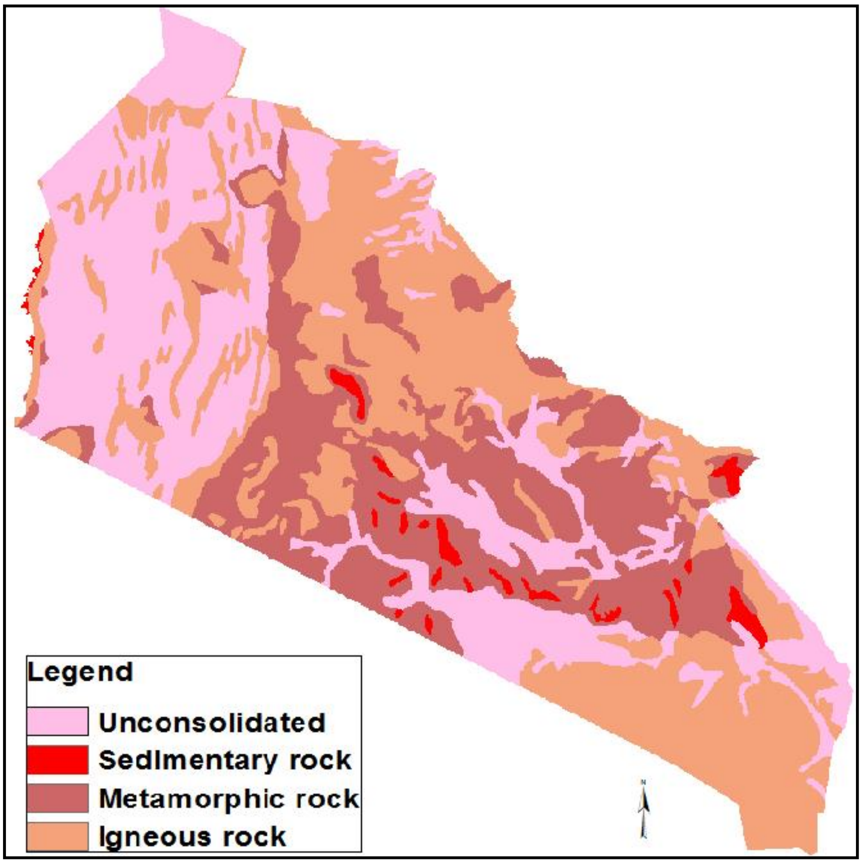

Figure 5: Lithology classified

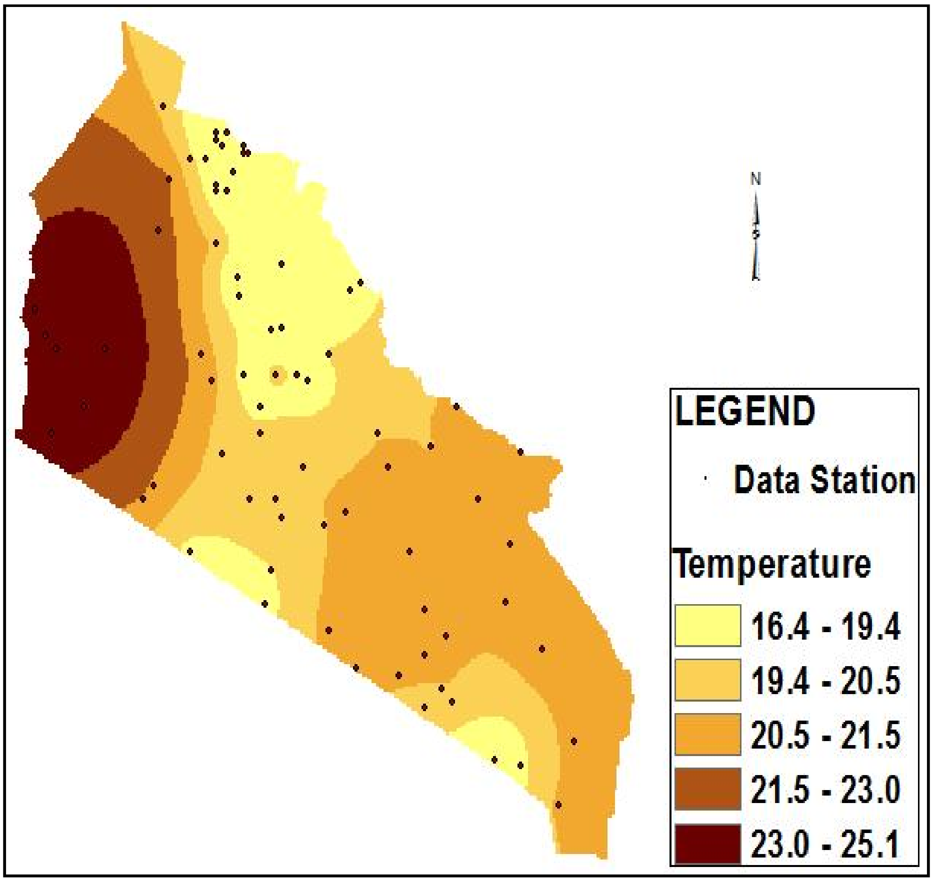

Figure 6: Temperature ranges in Kajiado

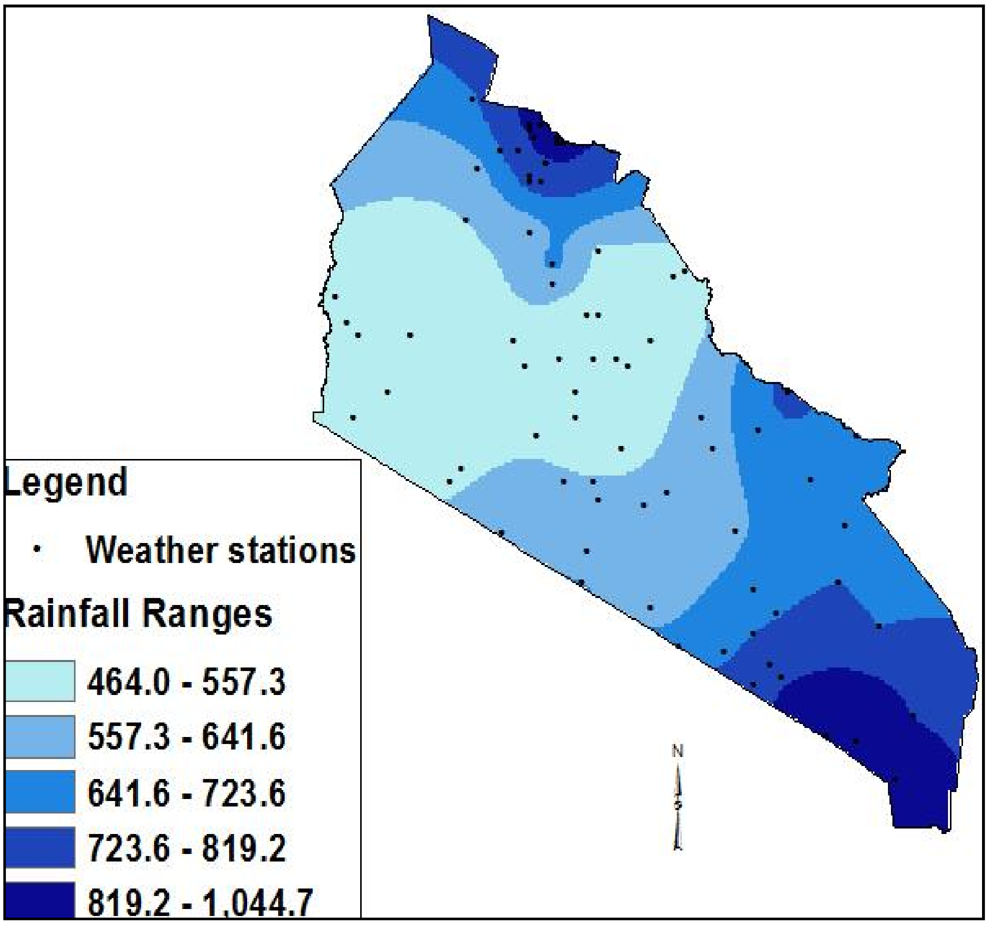

Figure 7: Rainfall ranges in Kajiado

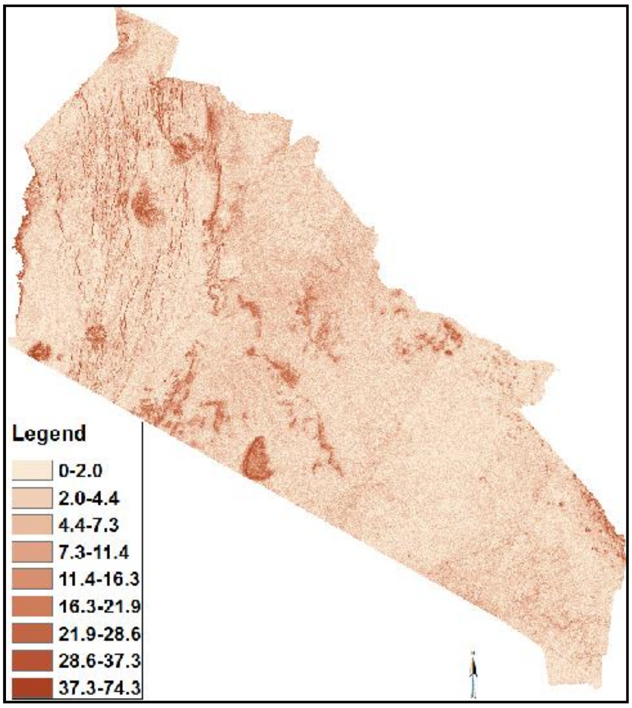

Figure 8: Classified slope map in degrees

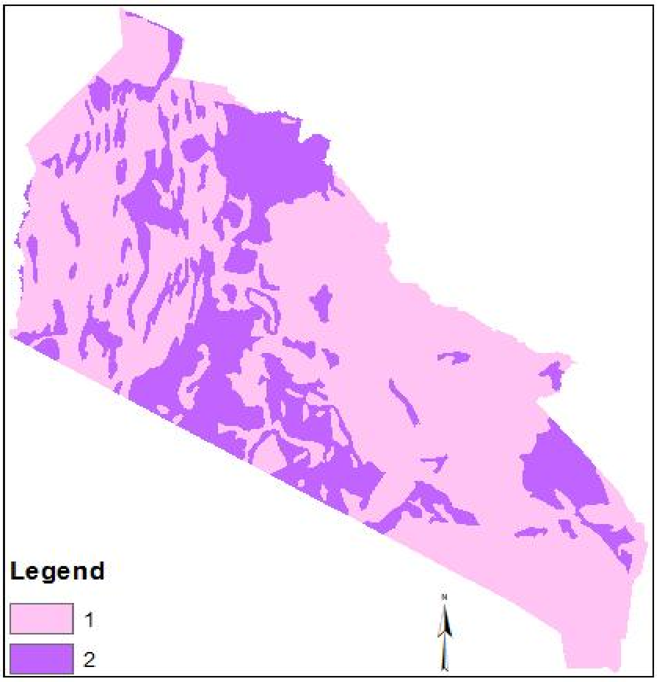

Figure 9: Soil weighted

AHP Ranking

Figure 3 shows the relationships between the three levels. These levels are the criteria i.e. goal, main criteria and sub criteria. A matrix was constructed where each criteria was compared with the other criteria relative to its importance on a scale from 1 to 9. 1 has equal preference between two factors and 9 means a particular factor is extremely favored over the other. Combinations of lithology, slope, climate, soil, land cover and lineament were combined to determine suitable locations of underground water. Pairwise comparison of the criteria was done basing on expert opinion.

RESULTS AND CONCLUSION

This section outlines the results, conclusions and recommendations of the study.

Suitability Variables

The results obtained are presented in figures (4-11) and tables 2-4. The results of land cover mapping are represented in figure 4. The areas with thick vegetation cover protect underground water loss by preventing evaporation in comparison to bare land which allows evaporation.

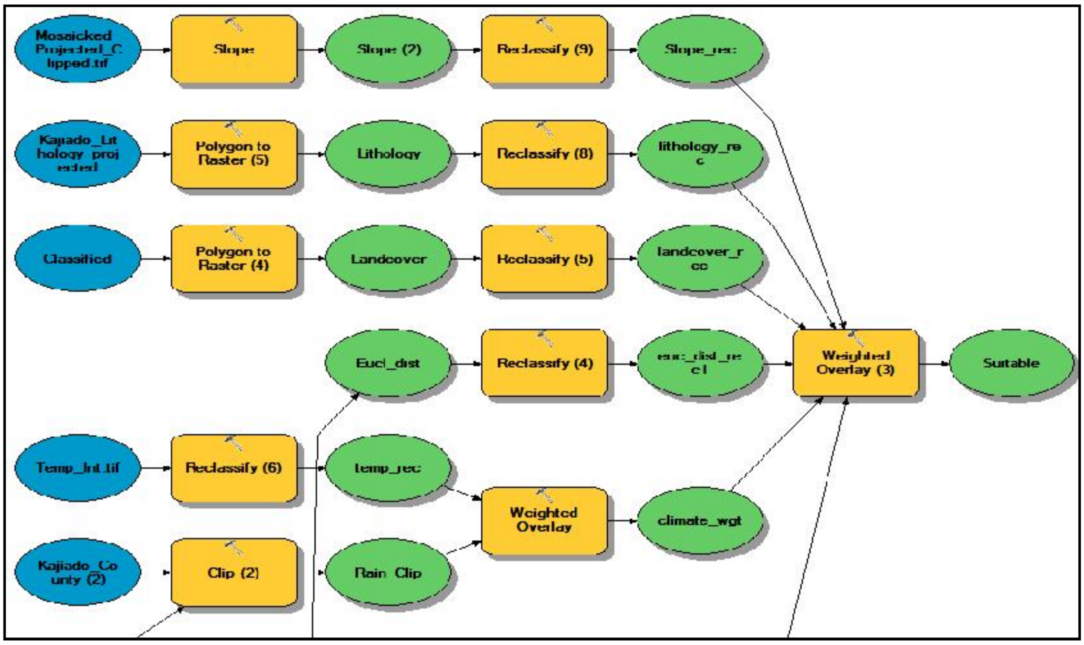

Figure 10: Part of the model

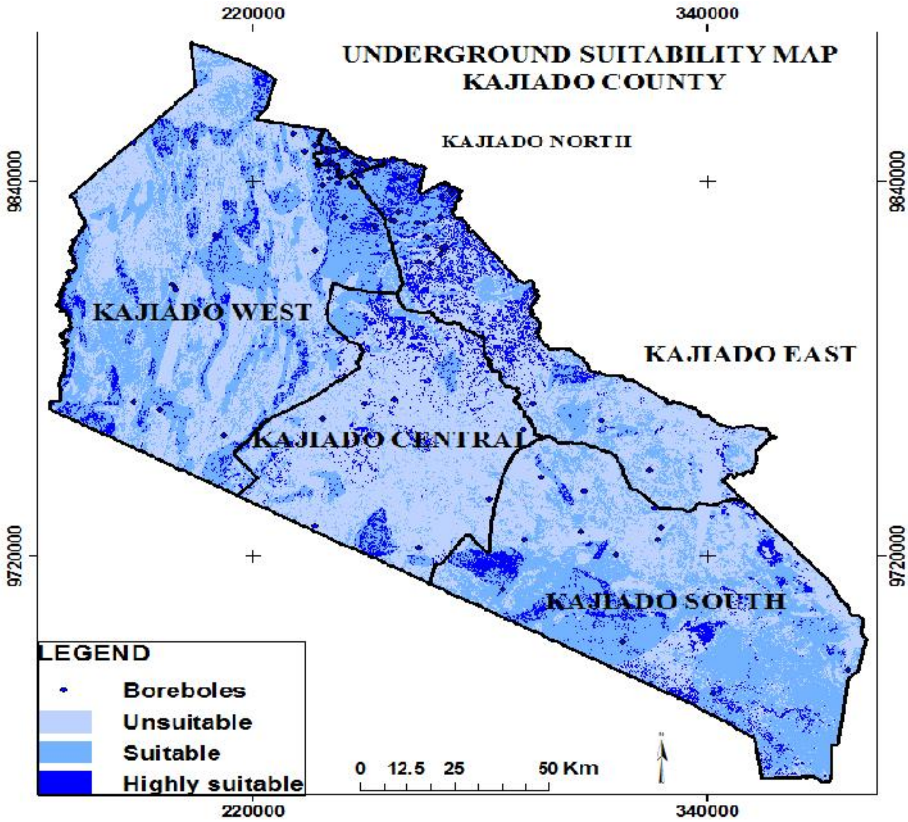

Figure 11: Underground water suitability map

Table 1. Datasets and source

DATA	SOURCE	TYPE	RESOLUTION
Lineament	Mines and Geology Department	Tiff Image	Map of Kenya
Administrative boundaries	Survey of Kenya	Shapefile	Scale 1:50000
Lithology	International Livestock Research Institute (ILRI)	Shapefile	Map of Kenya
Hydrology	Ministry of water	Excel	Current
Satellite imagery	USGS	Image	30m
Climate data	Kenya Meteorological Department	Excel	30 years
Soil Data	Kenya Soil Surveys	Shapefile	Recent
Questionnaire	Interviewing Experts	Table	
Borehole	WARMA	Shapefile	Recent

Table 2. Weights applied in overlay scheme

Criteria	Importance (%)
Land cover	37
Slope	27
Lithology	13
Soil	12
Lineament	7
Climate	4

Table 3: Suitability ranges in Kajiado County constituencies

Region	Area in Ha.	% area	(2+3)
Kajiado North			
1	382.49	3	
2	7,814.15	71	97
3	2,813.25	26	
Kajiado East			
1	151,075.7	49	
2	100,922.5	33	51
3	56,815.26	18	
Kajiado West			
1	337,421.8	44	
2	372,790.78	48	56
3	60,362.81	8	
Kajiado Central			
1	319,055.25	74	
2	75,078.7	17	25
3	34,366.9	8	
Kajiado South			
1	203,020.71	34	
2	335,411.97	57	66
3	51,275.07	9	

Table 4: Suitabilility levels in Kajiado County

Kajiado County	Suitability Level	Area (ha)	Area (%)
	Highly Suitable	205,640.372	10
	Moderately Suitable	892,025.298	42
	Unsuitable	1,010,960	48

Presence of underground water would be favorable more in forested areas than in bare land. The four (4) major classes of rocks that resulted from lithology classification were unconsolidated rocks, sedimentary rocks, metamorphic rocks and igneous rocks as seen in figure 5. Data collected and interpolated shows that the temperature of Kajiado County ranged between 16.4^{o}C and 25.1^{o}C as seen in figure 6. Figure 7 indicates that the rainfall in Kajiado County ranges between (464-1045) milliliters. This represented the mean for 30 years. Figure 8 shows a classified slope map that was developed from the downloaded DEM. The slope was in degrees and ranges from 0 - 74.3 degrees. Three classes of soil were weighted to come up with a weighted map of soil as seen in figure 9. The two classes of soil generated was **1** representing the unsuitable areas and **2** representing the suitable area

Spatial modelling

Spatial model is an application in ArcGIS. It was used to create, edit, and manage models. Models are workflows that stringed together sequences of geo-processing tools, feeding the output of one tool into another tool as input. Operation tools employed in this study included interpolation method, the polygon to raster, clipping tool, reclassify and weighted overlay. Connectors were added between the model's output and the operation tool and the model was run. Large voluminous files were processed automatically. The model was run in different steps to come up with the suitability map of underground water (figure 11).

Figure 10 shows part of the whole model used to obtain the final suitability map. Six parameters used in this study were all weighted depending on their importance. The percentages assigned depending on the importance were as shown in table 2 to come up with an underground suitability map as shown in Figure 11.

Suitability Percentages (%)

From both the highly suitable areas and the moderately suitable areas, it is possible to attain water. From table 3, Kajiado North is the region with the highest suitability of ground water (highly suitable plus moderately suitable equals to 97%). This is due to the fact that this region borders Kinari and Gitamaiyo forests which are both in the aberdare region which attracts rainfall for underground recharging. From table 4, highly suitable and moderately suitable areas gives 52%. This shows that Kajiado has a lot of underground water that needs to be exploited.

Conclusion

The main objective of this research is to apply remote sensing and GIS techniques in analyzing suitable sites for underground water in Kajiado County to address the problem of water shortage. The results show that remote sensing and GIS technology when integrated with MCE is an important tool to identify suitable sites for underground water. From the results it was conclusive that 50% of Kajiado County is very potential in holding underground water.

Recommendation

We recommend that the suitable areas be investigated to come up with the extractable amounts, the depths of these regions, the quality of this water and the sustainability of the underground water in the suitable areas. We also recommend that since GIS provides scientific ways of making decisions the decision makers should embrace this technology that assists them to make wise decisions.

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