GROUNDWATER MAPPING OF MAKUENI COUNTY, EASTERN KENYA USING REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (GIS) TECHNOLOGIES

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ABSTRACT

Occurrence of groundwater in the basement complex terrain of Makueni County, Eastern Kenya is controlled by secondary porosity developed through weathering, fracturing and cracking of the bed rocks. Makueni falls in semi-arid region that is characterised by erratic rainfall. Surface water from a very few rivers is inadequate and the only option to supply both human and animal population is groundwater. To avoid the ever common incidences of borehole failing to yield any water or drying up soon after commissioning, groundwater mapping is paramount. In this study, remote sensing (RS) and Geographical Information System (GIS) techniques have been used to identify and map groundwater potential zones using rainfall, drainage and drainage density, lineament, geology, soil texture, slope and land cover. These thematic layers were selected for groundwater mapping based on literature and geophysical investigations and data appropriately weighted in a modified DRASTIC model based overlay scheme. Land cover was derived from Land sat imagery classification with lineament density being obtained from the same satellite imagery/product. The Geospatial evaluation produced a groundwater potential map in which the study area was characterized into zones; very good, good, moderately good and poor. The map showed that the central and eastern regions of Makueni County are the most suitable for groundwater exploitation.

KEYWORDS: Groundwater exploration, DRASTIC modelling, Land-cover classification.

INTRODUCTION

Groundwater is one of the most important water sources more so in the Arid and Semi-Arid Lands (ASAL) regions of Kenya such as Makueni County in Eastern Kenya where surface water sources are scarce. Several researchers have shown that groundwater is vital resource for domestic water supply, agriculture and even industry[10,13,16,18].Sinking of boreholes in ASAL lands is however erratic at best with dry boreholes and borehole that become dry shortly after commissioning standing at 30% in Makueni County in recent times. Information on potential occurrence of groundwater is therefore very crucial. Different techniques to give information on potential occurrence of groundwater are used with most of these utilizing geophysical and geotechnical knowledge. These techniques are expensive and time consuming. There is therefore need to exploit new technologies that employ remote sensing and geographic information system (GIS) in the exploration of groundwater[12,23].

GIS and geospatial technologies have been used for groundwater exploration in various places of the world[5,9,21,24]. Here in Kenya GIS techniques and remote sensing are being adopted in groundwater exploration and exploitation. In Kenya's ASAL theses techniques have been used by Kuria et al., (2012)[12].

Several models for groundwater exploration potential have been develop. One of these models is DRASTIC model which was created through a partnership between the National water well Association and the U.S. Environmental Protection Agency (EPA) to protect groundwater2. It was initially designed to evaluate groundwater vulnerability but has now been modified to evaluate groundwater potential. The modified DRASTIC model uses lithology, surface drainage density/lineament, soil type, slope steepness, rainfall distribution, land cover and topography. Influence of topography on borehole yield is such that wells on valleys and flat areas show generally higher yields compared to wells on slopes and hill tops[7,8]. The other important exploration aspect in this exploration is lineament identification[4,25].

The rainfall of the area and the subsequent runoff from a basin are very important in determining recharge rates[15]. Areas with low rainfall would have low recharge rate although gneiss and schists rocks are in many cases the obvious factors in explaining variation in borehole yields particularly if such rocks have faults, cracks and fracture zones. These factors are weighted, ranked and then combined to obtain a final ranking value using a groundwater potential algorithm[12, 17]. The resulting weighted overlay then depicts the potential for each spatial region.

Materials and Methods

Landsat imageries (30m resolution) were downloaded from the United State Geological Survey (USGS) website, Topographical maps were bought from Survey of Kenya while the rest of the data was obtained from the International Livestock research Institute (ILRI).

Remote sensing (RS) has become a quick and cost effective tool for assessing, monitoring and conserving groundwater resource[6,12,22]. On the other hand Geographic Information System (GIS) has become a powerful tool for data base development. These two technologies were employed in the study. Two parallel pathways were followed. These are the remote sensing processing path and the ancillary data and processing path. First the remote sensing data was processed to determine the land cover classes. This was done through image classification on the ENVI 4.7 platform. Thereafter supervised classification using the maximum likelihood classification method was carried out.

The modified DRASTIC model

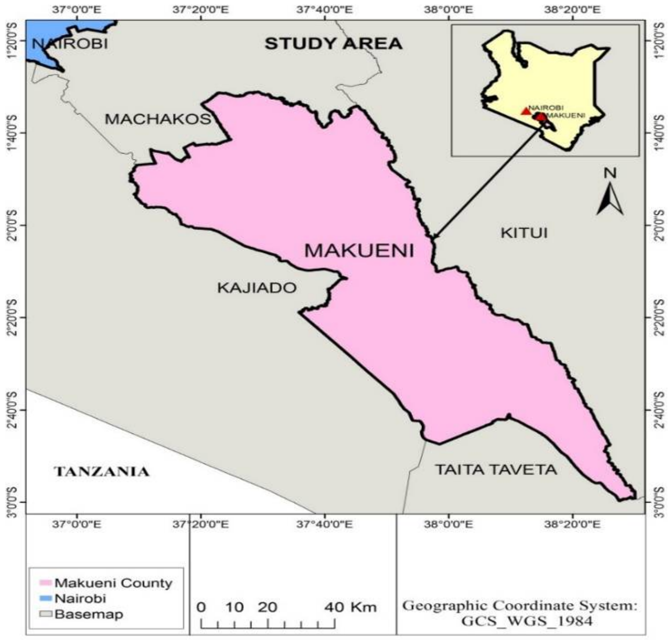
To assess groundwater potential the DRASTIC index was used. The original drastic model was developed to map groundwater pollution potential. The model featured seven factors; depth of water, recharge, aquifer media, soil media, topography (slope) impact of the vadose zone and conductivity of the aquifer. These factors are weighted according to the significance of each factor in determining pollution potential[1,2]. The resultant weighted overlay then depicts the pollution potential for each spatial region. There are three significant parts; weight, range and ratings with each factor being assigned a weight relative to the other factors. Table 1 shows the weight applied in this research.

Table 1: Weights applied in the DRASTIC based overlay scheme:

Feature	Classification	Rating	Drastic Weight	Total Weights	Weightage %
Lineament Density	0.126 – 0.528	1	5	5	23
	0.528 – 0.734	2		10	
	0.734 – 0.929	3		15	
	0.929 – 1.113	4		20	
	1.113 – 1.543	5		25	
Slope (%)	31.23 – 75.120	1	4	4	18
	17.68 – 31.23	2		8	
	9.43 – 17.68	3		12	
	3.83 – 9.43	4		16	
	0.00 – 3.83	5		20	
Topography (M. A.S.L.)	1467 – 2138	1	4	4	18
	1176 – 1467	2		8	
	961 – 1176	3		12	
	747 – 961	4		16	
	259 – 747	5		20	

Land cover	Bareland	1	3	3	17
	Cropland	2		6	
	Shrub	3		9	
	Forest	4		12	
	Woodland	4		12	
	Water	5		15	
Rainfall Distribution (mm)	200 – 400	1	2	2	9
	400 – 600	2		4	
	600 – 800	3		6	
	800 – 1200	4		8	
	1200 - 1600	5		10	
Lithology	Basalt, basalt igneous rock, granite, igneous rock, Intermediate igneous rock	1	2	2	9
	Sandstone, greywacke, arkose	2		4	
	Eolian unconsolidated rock, Pyroclastic unconsolidated rock	3		6	
	Fluvial	4		8	
	Acid metamorphic, Gneiss, magmatite, quartzite	5		10	
Soil texture	Clay	1	1	1	6
	Clay loam/ Silt loam	2		2	
	Loam	3		3	
	Clay loamy sand	4		4	
	Loamy Sand	5		5	

Most of these rivers are ephemeral with the Athi River which forms most of the County's Northern border being the only permanent water course with meaningful water flow. Makueni County lies within the Arid and Semi-Arid (ASAL) region of Kenya. The temperatures in this county vary considerably with altitude. The highland areas are usually cool, with mean temperature ranging from 20 ^{o}c to 25 ^{o}c while the low lying areas of the South and South east are usually hot. These low lying areas are generally semi-arid and have a mean minimum and mean maximum temperatures of 14 ^{o}c and 31^{o}c respectively [14,18,19].



Geology and soils of the study area

According to Dodson (1953)[3]the geology of the area is composed of mainly metamorphics invaded by volcanics and alluvial sediments as shown in Figure 2a. These metapmrphic rocks are of Archean age of the Mozambique Belt of Kenya. Gneisses are the dominant rocks especially the biotite and the granotoid gneisses. The rock units are oriented in the North-South direction which conforms to the strike of the rocks in the Mozambique Belt. The biotite gneisses are characterized by foliations clearly indicated by the arrangement of biotite grains. Most of the study area is covered by biotite gneiss as shown in Figure 2a

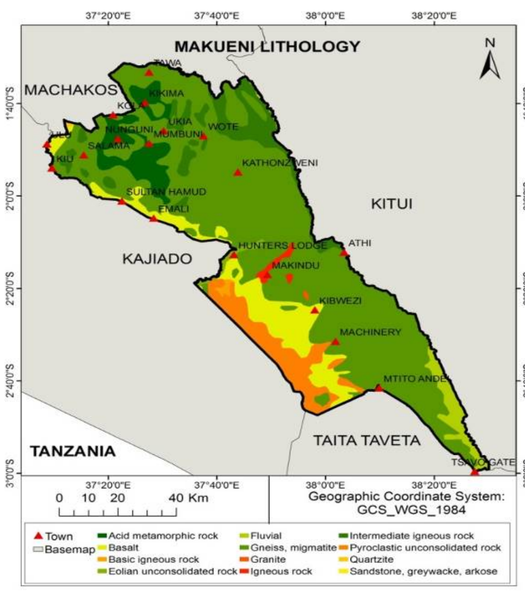


Figure 2 (a). The lithology of study area.

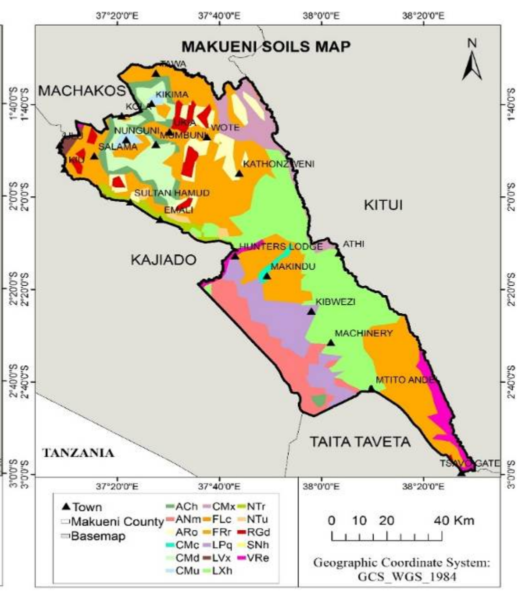


Figure 2 (b). The Soil map of study area

Outcrops of granitoid gneiss are found in Mwaani, Unoa, Muvau, Nzueni, Nzauui among other places where they form hills standing from a relatively level ground due to their high resistance to weathering. These rocks are compact with virtually no integranular (primary) porosity. However, these impervious and non-porous rocks develop secondary porosity which means they can hold water in the cracks, joints, fractures, or faults or along contact zones between various rock types. When these rocks are subjected to adverse weather climatic conditions they undergo weathering resulting in conditions favourable for the infiltration and storage of groundwater. The thickness of the weathered layer also plays an important role in determining the amount of groundwater it can hold. Other factors that determine the amount of water are soil texture, topography, drainage pattern, rainfall and evaporation. The soils in the study area are shown in Figure 2 (b). These soils are mainly well drained to excessively drained, shallow to moderately deep and in many places rocky with low water holding capacity. These soils have poor structure with poorly held soil aggregates.

RESULTS AND DISCUSSION

GENERATION OF LAND COVER SHAPEFILE

A shape file was created through the classification of a 30m resolution Makueni County Landsat 8 image. The image was classified into six classes: Forest, shrub, woodland, bareland, cropland and water. The forest refers to the vegetation type consisting of a continuous or closed stand of trees at least 10 m tall with an interlocking canopy while the woodland is a vegetation type consisting of an open stand of trees at least 8 m high with at least 40% tree canopy and shrubs less than 10%. Shrubs are perennial woody plants having multiple stems with a height not exceeding 6 m and diameter is less than 10cm. The bareland is the land without appreciable vegetation cover which excludes built up areas while the cropland refers to the land that is suited to or used for crops. The overall classification of land cover was found to be was 79.65 with a Kappa coefficient of 0.74 as seen in Table 2. These figures mean that the land cover as shown Figure 4(a) is fairly representative.

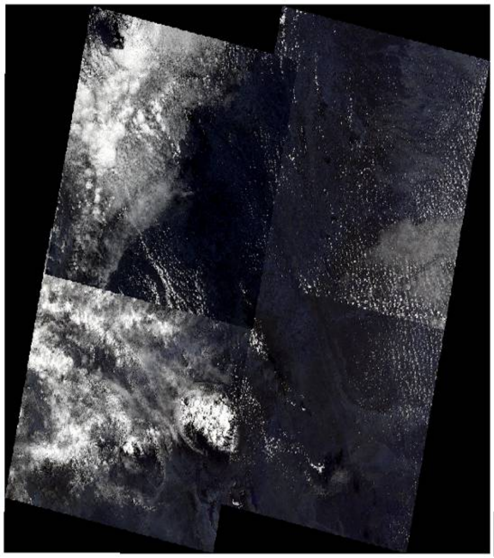


Figure3(a). The Mosaicked image Figure 3(b). The corresponding subset of the study

Table 2showing image classification assessment

Classification								
Reference (Ground Truth)								
Class	Cropland	Shrub	Bareland	Water	Forest	Woodland	Total	User's Accuracy
Cropland	1334	21	0	1	0	0	1356	0.98
Shrub	141	453	0	0	0	0	594	0.76
Bareland	6	0	835	0	0	0	841	0.99
Water	267	0	0	170	0	0	437	0.39
Forest	719	0	0	0	387	0	1106	0.35
Woodland	0	0	0	0	0	1343	1343	1
Total	2467	474	835	171	387	1343	5677	
Accuracy Assessment								
Producer's Accuracy	0.54	0.95	1	0.99	1	1		
Overall Accuracy = 79.65						Kappa Coefficient = 0.74		

PHYSIOGRAPHY

Slope is a major factor in hydrogeology in that it defines the drainage characteristics of a water catchment. STRM data of the area was used to derive the DEM and then using 3D analyst tool the slope of the area was derived. The ratings as specifies in Table 1 were used to make the suitability map. The eastern side of Makueni County is gently sloping but as one moves westwards, the angle of slope increases. This is as a result of residual hills on the western and northern parts of the map. The hills are oriented in an almost N-S direction conforming to the strike direction. Figure 5(a) shows the topographical map of the study area.

The highest point lies at an1altitude of 2138 M, while the lowest at a height of 259m above sea level. Greater rates of infiltration are common in areas of gentler slopes than those with steep slopes. Physiography (ground elevation) is significant due to piezometric head of boreholes if drilled. The areas having elevation values ranging between 259 – 747 m are gently sloping while elevations ranging between 1467 – 2138 m represent areas with very steep slopes.

SOIL TEXTURE

This represents the top soil layer extending only a few meters from the surface. It is generally a weathered zone and has a significant impact in the movement of recharge water which infiltrates deeper into the aquifer6. On a scale of 1 to 5 the soils in this county were classified as clay with a rating of 1 and clayey sand rated 5 in light of infiltration capacity. The DRASTIC weight of soil texture was 6 as shown in Table 1.

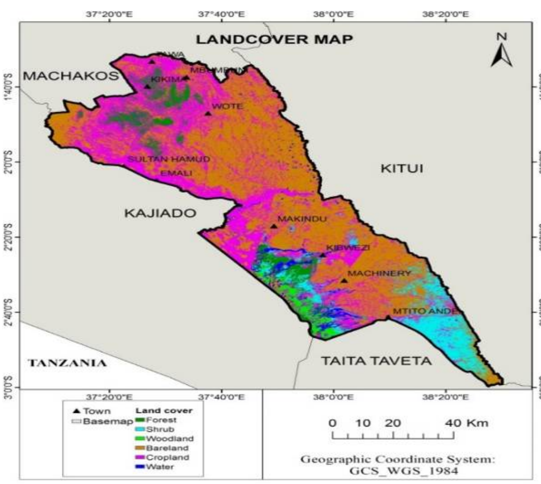


Figure 4(a): Land cover map

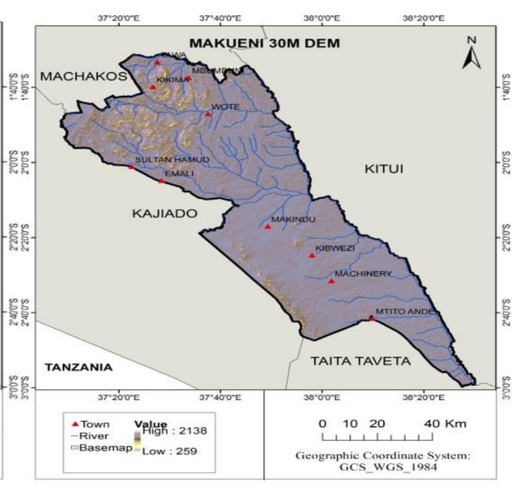


Figure 4(b): Elevation map

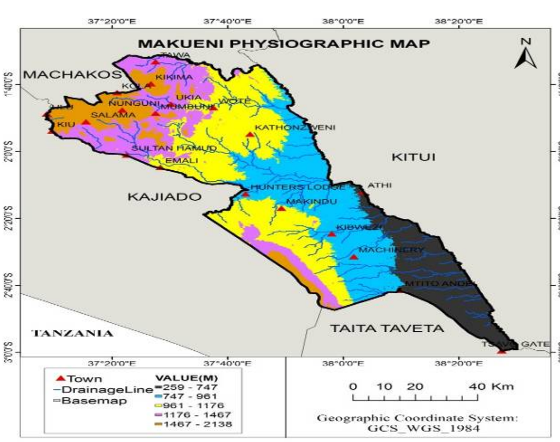


Figure 5(a): Topographymap

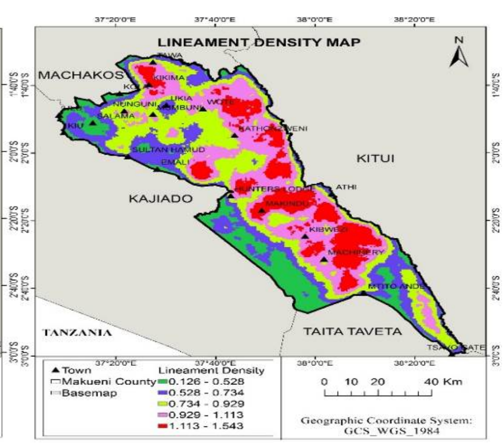


Figure 5(b): Lineament density map

According to O'leary et al. (1976)20lineament in groundwater exploration refers to linear features of a surface that differ in pattern from adjacent features that can justify presumption of a subsurface cause or change. In this study linear guide map has provided information on sites that have faults, fractures and cracks. These features indicate presence of groundwater because it is through them that recharge can take place11.Lineament was given the highest weighting at 23 in the development of groundwater potential map.

Groundwater Potential map

The integration of thematic maps resulted in the production of groundwater potential map of the study area (Figure 6 (a)). As shown in the map, the area with high groundwater potential constituted about 38.93 % of the study area while 52.78 % of study area fell in the moderate groundwater potential area. 8.27 % was found to be in low groundwater potential. Boreholes that have been sunk near rivers have relatively high yields. The groundwater potential map have come up with same conclusion (Fig 6 (b)). For example Wote Town, hunters lodge, Makindu, Kathonzweni, TawaUkia , Mumbuni have high yielding boreholes that are next to rivers that are also in high yielding localities in the groundwater potential map.

The area around KiimaKiu and the proposed Konza Technological City at the North West corner of the county fall within the moderately to low groundwater potential areas. Due to the increasing population resulting from the migration of people to this area in recent years demand for water is on the increase which has increased the number of applications for authority to sink boreholes in recent months.

Results validation

In order to validate the classification of the study area into different groundwater potential zones (Very high, high, moderate, low and very low) borehole yield data from Ministry of Water, Water Resources Management Authority (WRMA) and Ministry of Water at County level in Wote were collected and evaluated. The data revealed that boreholes from the study area can be categorised into high yield (> 4.2 m3 / hr) moderate (2.1 to 4.2 m3 / hr) and low yield < 2.1 m3 / hr. The yield of the boreholes range between 0.1 m3/ hr to 24 m3 / hr. The depth on the other hand range from 22 m to 182 M.

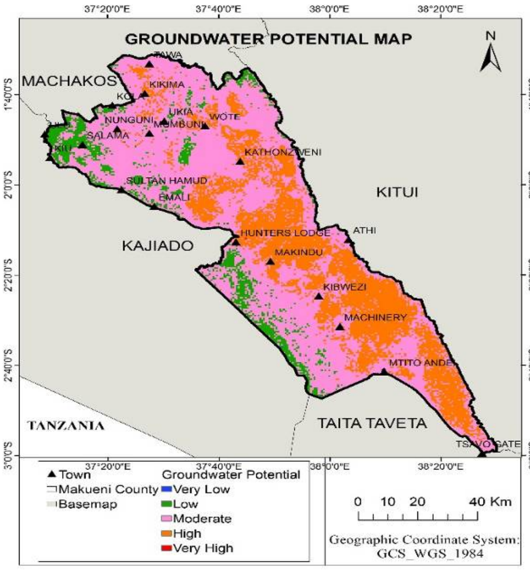


Figure 6 (a):Groundwater potential map

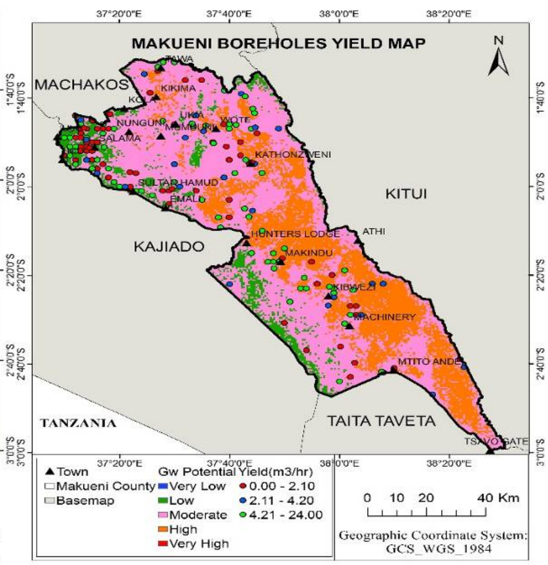


Figure 6 (b): Groundwater potential map with existing boreholes

Conclusion and Recommendations

The already drilled boreholes have been plotted on the suitability map and most of the borehole were found to be sunk on the very areas that were found to have high groundwater potential. This study has highlighted areas of high suitability, medium suitability and low suitability. The groundwater potential map as generated shows that most parts of the study area has groundwater with only 8.27% being ranked as low potential. This low ranked areas are highly mountainous such as parts of Chyulu and Mbooni. Interestingly very few boreholes have been sunk in this areas. Therefore, availability of image data for the interpretation of groundwater is certainly better and much cheaper.

It is recommended that the areas that show potential should be investigated further to verify the possible yields and the quality of water to determine suitability of groundwater extraction in the area. The suitability map that has been generated in this study will be an important tool in groundwater exploration in Makueni County. At the same time this technique for groundwater mapping can be replicated in other areas with similar hydrogeophysical characteristics which will change the lives of many.

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