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Full Length Research Paper

Mapping groundwater potential in Kitui District, Kenya using geospatial technologies

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Kitui district is a semi-arid region characterized by erratic and unreliable rainfall. Despite this, the main economic activity is rain-fed agriculture, with irrigation agriculture taking place on small parcels adjoining riparian reserves. During the dry season, local people travel long distances in search of water, necessitating groundwater potential mapping to support exploitation and complementing other water sources in the district. In this study geospatial technologies are used to identify and map groundwater potential zones using climate, geophysical and geological data. These datasets were appropriately weighted in a modified DRASTIC based overlay scheme. Land-cover data was derived from landsat imagery classification, with lineament density obtained from the same satellite products. A groundwater potential zones map was generated which showed that the central and eastern regions of Kitui district are the most suitable for groundwater exploitation. Existing water points (which were not considered in the study) are situated in this region, hence validating the study.

Key words: Groundwater prospecting, DRASTIC, lineament density, land-cover classification.

INTRODUCTION

Groundwater is one of the earth's most important resources 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. It is a vital resource for agriculture, domestic water supply and industry (Murthy, 2000). It is also the single largest and most productive source of irrigation water and it plays a critical role in maintaining agricultural production during droughts. Groundwater can therefore be exploited if potential areas with abundant groundwater can be identified. A variety of techniques are used to give information on potential occurrence of groundwater since it cannot be seen directly from the earth's surface. Systematic planning of groundwater development using modern techniques is essential for proper utilization and management of this natural resource. The existing methods of groundwater exploration using geophysical and geo-electrical techniques are expensive and time consuming hence there is a need to exploit new technologies of remote sensing and Geographical information system (GIS) in the exploration of groundwater (Sener et al., 2005). There are a number of works where groundwater potential has been estimated using geospatial technologies. Rao et al. (2009) carried out hydrogeological mapping coupled with hydrogeological investigations for evaluating groundwater potential in Madhurawada, India using GIS. Ganapuram et al. (2009) mapped ground water potential zones in the Musi basin using remote sensing data and GIS. Kamaraju et al. (1996) performed an evaluation of groundwater potential of a district in India using GIS approaches. Shahid et al. (2000) used GIS in the analysis of hydrogeological data acquired from remote sensing and surface geophysical techniques in the assessment of groundwater condition of a soft rock terrain in Midnapur District of India.

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The original DRASTIC model was developed to map groundwater pollution potential developed by Aller et al. (1987). It features seven factors (depth to water, recharge, Aquifer media, soil media, topography (slope), impact of the Vadose zone and Conductivity of the aquifer), that are weighted according to the significance of each factor in determining pollution potential. The resulting weighted overlay then depicts the pollution potential for each spatial region. Similar approaches have been used within the GIS context to map groundwater potential, in which case, the factors that are used are Lithology, Surface drainage density, Soil types, Slope steepness, Rainfall distribution, land-cover and topography, with the spatial overlay concepts used in the DRASTIC methodology being applied (Tweed et al., 2007; Sankar, 2002). In this paper, this approach is referred to as the modified DRASTIC model or simply the DRASTIC based model. This is essentially an overlay scheme that replaces the initial DRASTIC factors with those that influence groundwater occurrence which are dependent on surface characterization. Groundwater resources should be developed in the arid and semi-arid areas to supplement the highly erratic and unreliable rainfall for both domestic and agricultural use (Mati et al., 2005) as is the case for Kitui district. Currently groundwater resources of Kenya are underdeveloped with only 0.18 billion cubic meters per annum extracted from a total estimated safe yield of 1.08 billion cubic meters. There is therefore the need to identify and map the groundwater potential zones for groundwater development and for effective water resource management.

The main objective was thus to utilize geospatial technologies in estimating the groundwater potential in Kitui district. This was achieved through preparation of land-cover maps from classification of Landsat imagery, generation of lineament density maps, evaluation of the various parameters using a modified DRASTIC model and delineation of groundwater zones in the form of a groundwater zonation map.

Study area

Kitui District is an administrative district in the Eastern province of Kenya 150 km east of Nairobi. The district has a population of 1,012,709 according to the 2009 census. It has an area of 20,402 km² including 6,290.3 km² at the southern end of the district which is occupied by the Tsavo East National Park. It lies between 0° 10' S 3° 10' S and 37° 40' E and 39° 10' E. Figure 1 shows the extents of the study area.

Kitui is a semi-arid region characterized by highly erratic and unreliable rainy periods. The main economic activity is rain-fed agriculture. Irrigation agriculture only takes place on small plots on the river banks and water availability is often a limiting factor of sustainable agricultural development.

During prolonged dry periods the farmers depend on relief food from donors. Other economic activities in the district include charcoal burning, brick making and basket weaving. During periods of prolonged drought, women and children walk up to 10 to 20 km in search of water hence the need for groundwater exploration and exploitation in the district.

Elevation ranges between 400 and 1800 m above sea level with the western and central parts characterized by hilly ridges separated by wide, low lying areas and has slightly lower elevation of between 600 and 900 m above sea level.

METHODOLOGY

Remote sensing (RS), with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very rapid and cost effective tool in assessing, monitoring and conserving groundwater resources (Sankar, 2002). Geographical information system (GIS) on the other hand, is a powerful environment for real time database development, especially in studies such as delineating groundwater pollution potential zones (Evans and Myers, 1990; Merchant, 1994; Panagopoulos et al., 2006) and recharge sites (Tweed et al., 2007), groundwater modeling studies (Sener et al., 2007; Shahid et al., 2000) among others. These two technologies were employed in this research.

Table 1 show the various data used in this work and the associated sources. Landsat imageries (30 m resolution) were downloaded from the United States Geological Survey (USGS) website, topographic base map from the survey of Kenya with the rest of the data being obtained from the International Livestock Research Institute (ILRI).

Figure 2 shows the methodology adopted in this work. Two parallel processing pathways were followed: the remote sensing processing path and the ancillary data and processing path. Remote sensing data was processed separately from the other data from which land-cover classes were determined through image classification. Additionally, lineaments in the study area were identified visually. Ancillary data was further processed to provide the layers, and classes for each layer needed for the DRASTIC based map algebra operations.

Satellite data preprocessing performed included mosaicking and image sub setting. Supervised classification using the maximum likelihood classification was performed on the mosaicked image. The software used for this work were ArcGIS version 9.2 for the DRASTIC based map algebra operations, while ERDAS Imagine version 9.1 was used for image processing and land cover classification of the Landsat remotely sensed imagery. For the DRASTIC based map algebra operations, the various contributing layers were weighted according to the weights in Table 3.

Figure 3a shows the mosaicked image comprising five scenes that cover the area. The image was processed to ensure that contrast and gray scale intensities for each band were harmonized across the mosaic. Figure 3b shows the subset image of the study area.

RESULTS AND DISCUSSION

Figure 4 shows the results classified image. To obtain this, the maximum likelihood classifier was used. Three main land-cover classes are in the area and are identifiable

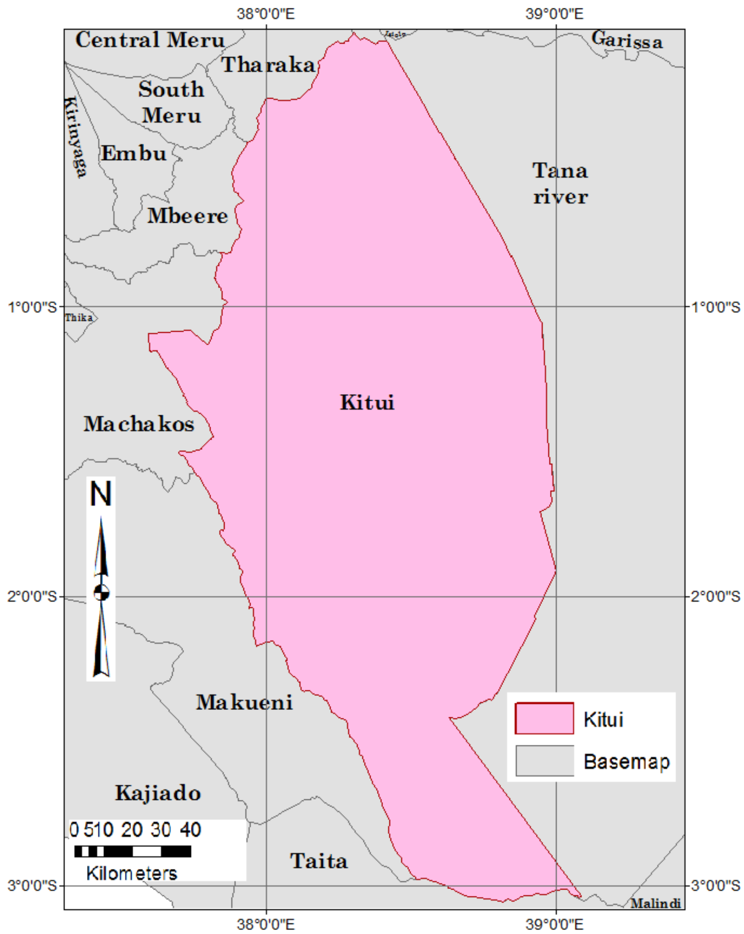

Figure 1. The study area.

Table 1. Data and sources.

Data	Source
Landsat ETM+ (5 scenes)	United States Geological Survey (USGS)
Soil information	International Livestock Research Institute (ILRI)
Lithology	
Elevation	
Rainfall data	
Topographic base map	Survey of Kenya

on the classified image. These are woodlands, thickets and bare ground. Woodlands refer to areas that are dominated by trees with an average height higher than 4 m, while thickets are areas dominated by shrubs and short trees with heights less than 2 m, and bare ground is land without appreciable vegetation cover, which does not contain built-up areas.

Table 2 shows the confusion matrix for the classification step. These values show that there is more confidence with respect to thicket class as it returns the highest producer's accuracy and user's accuracy. The other two classes have higher incidences of misclassification. Overall the classification exercise yielded acceptable results.

Table 3 shows the various weights applied in the determination of the groundwater zonation maps. Surface drainage here includes both the lineament density and the stream density as these represents the potential zones through which groundwater recharge takes place (Rao et al., 2009). Surface drainage due to the impact of recharge zones was given the highest weights, with soil type and rainfall distribution being the lowest. Map

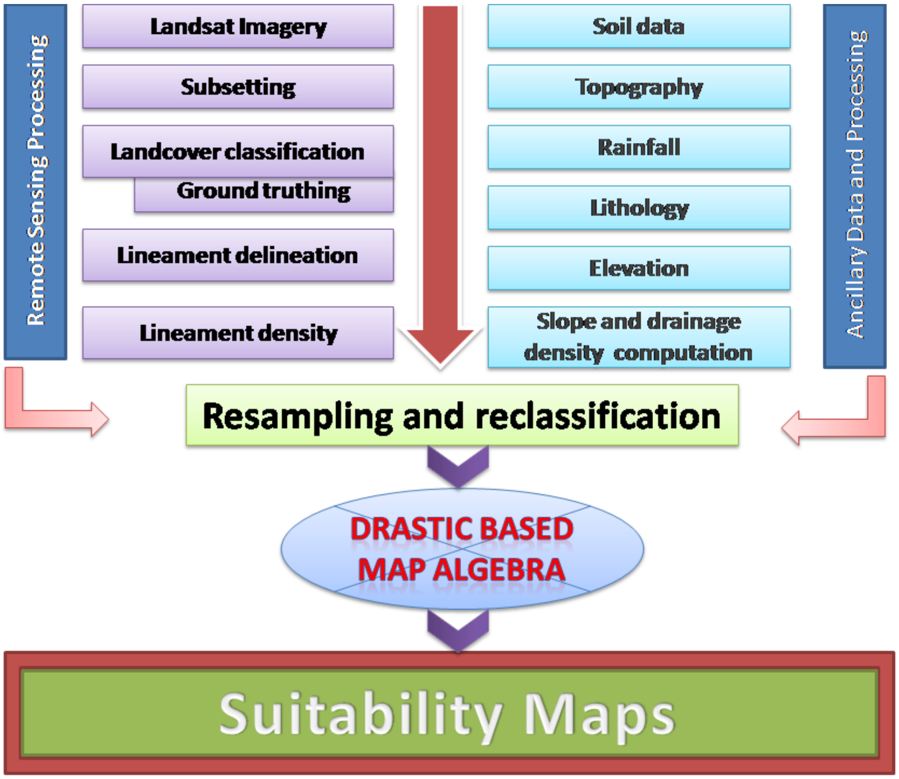

Figure 2. Methodology schema.

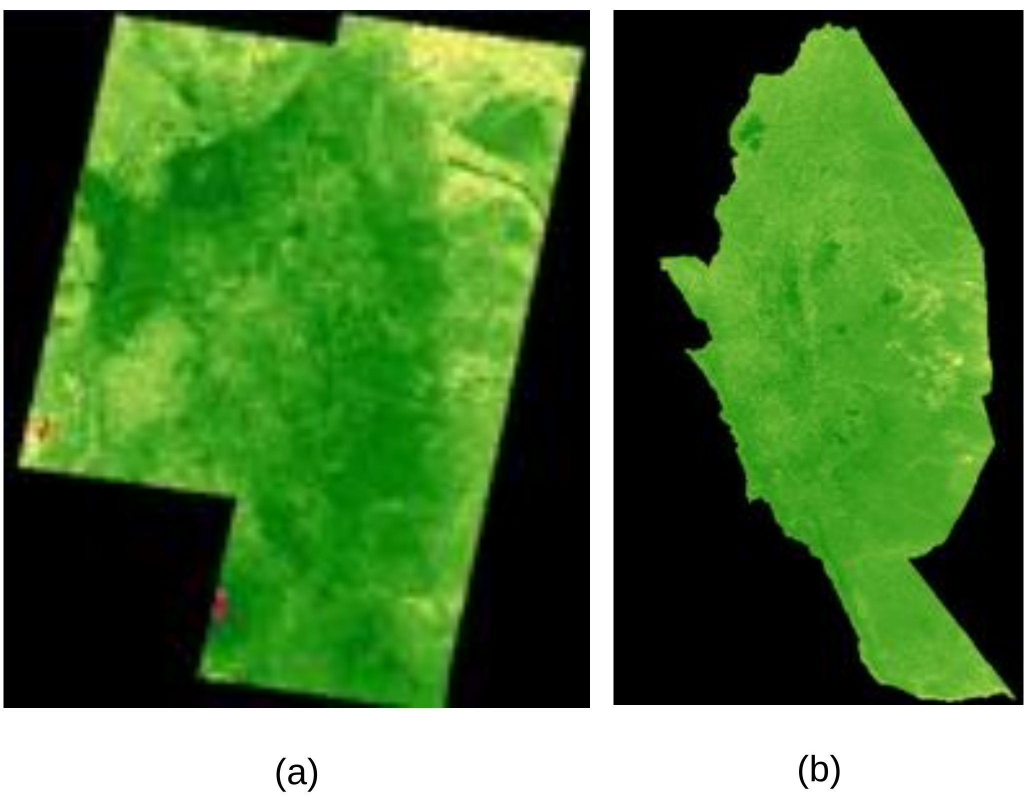

Figure 3. (a) Mosaicked Image, (b).corresponding subset of the study area.

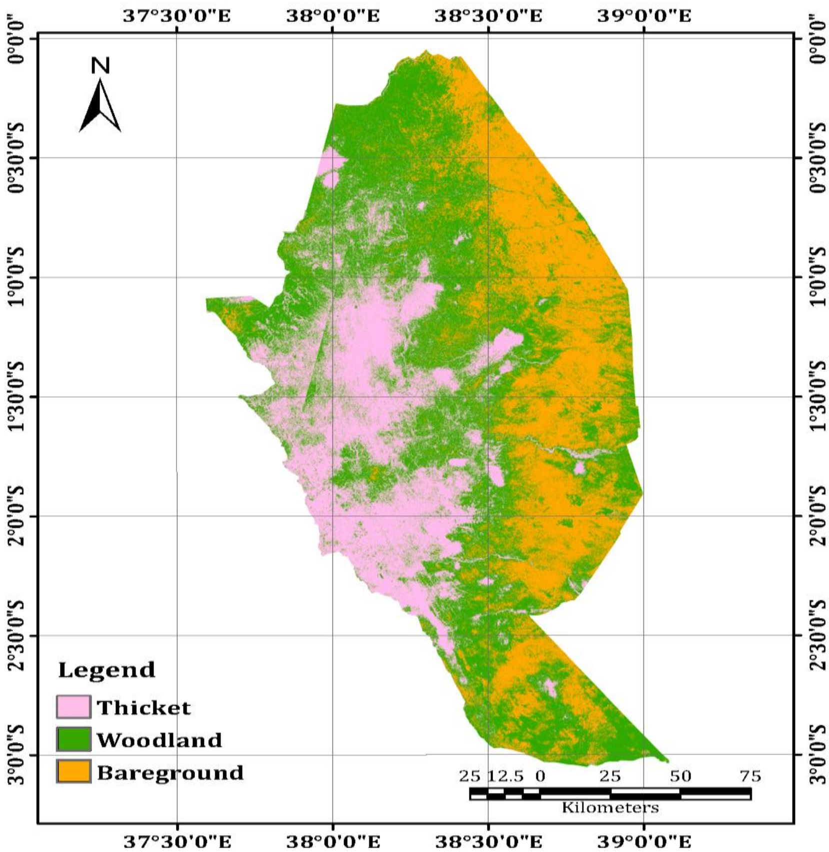

Figure 4. Land covers classified from subset Landsat satellite image mosaic.

Table 2. Image classification accuracy assessment.

Classification					
	Reference (ground truth)				
	Woodland	**Thicket**	**Bareground**	**Row total**	**User's accuracy**
Woodland	1317	1	600	1918	0.69
Thickets	193	1675	22	1890	0.89
Bareground	583	45	1251	1879	0.67
Column total	2093	1721	1873	5687	
Accuracy assessment					
Producer's accuracy	0.63	0.97	0.67		
Overall accuracy	74.61		Khat statistic		0.62

Table 3. Weights applied in the DRASTIC based overlay scheme.

	Factor	Weight (%)
1.	Lithology	10
2.	Surface drainage and lineament density	22
3.	Soil Texture	8
4.	Slope	20
5.	Rainfall distribution	8
6.	Land-cover	12
7.	Topography	20
	Total	100

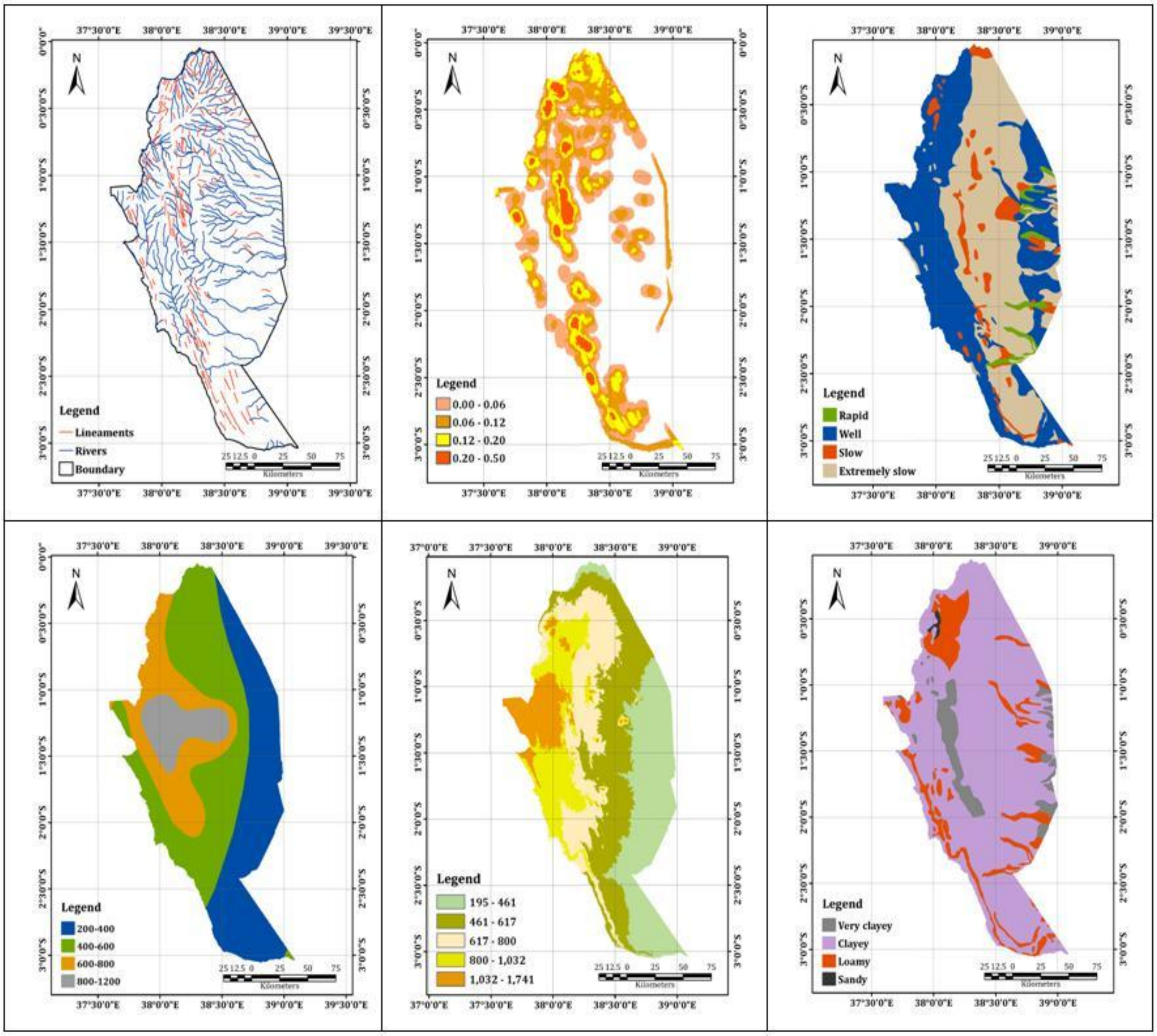

Figure 5. Processing results: lineaments and drainage patterns, lineament density, surface drainage, annual rainfall, topography and elevation and soil types.

overlay was done according to:

$$\text{Groundwater Potential} = \sum_{i=1}^{7} R_i \sum_{j=1}^{c_i} W_j \qquad (1)$$

Where R_i is a class of the factor under consideration with W_j being the corresponding weight for the factor, c_i is the maximum number of classes for the particular factor under consideration.

The weights adopted in this work were arrived at heuristically, based on the interpretation of relative significance of the factors. The most significant factors are surface drainage (related to recharge zones), slope (runoff relationship, with high slope values given low values) and topography (ground elevation is significant due to piezometric head of boreholes if drilled). Lithology while important was thought of having less impact compared to the earlier three factors. Additionally, soil texture to a great extent has a relationship with the lithology, hence the smaller value given for texture. Thus the combined effect of lithology and soil texture matches that of the other major factors. Rainfall, while important as the source for overall surface recharge was weighted less since its interaction with land surface and subsequent infiltration into groundwater depends more strongly on the land surface characterization especially for areas with low rainfall. Land cover was given an intermediate weight since it is the first point of contact with rainfall and coupled with the rainfall weight, these matches the weight of the dominant factors.

Figure 5 shows some of the results of the processed ancillary data after reclassification, together with the

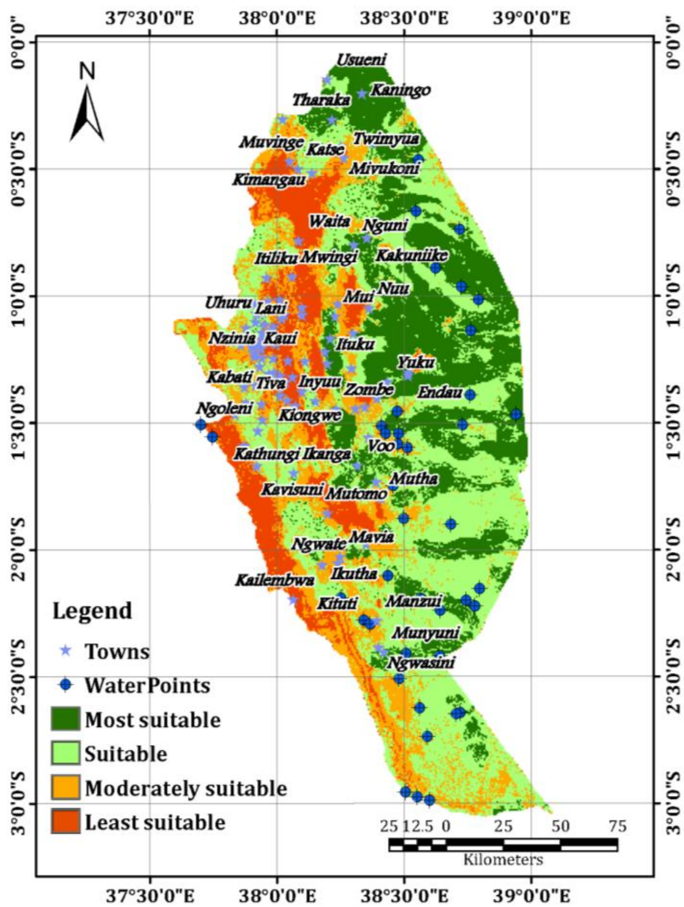

Figure 6. Groundwater suitability map.

lineaments captured from the Landsat images.

Lineaments and drainage patterns map show the eastern part having a large number of drainage channels. This is due to the fact that these areas also correspond to the low lying regions of the study area. Additionally from the soil map, these areas have pockets of loamy soils which are much better drained that the clayey soils.

Figure 6 shows the results of DRASTIC based map overlay. From this figure it can be seen that the central and eastern regions of the study area are more suitable for groundwater exploitation. This is further confirmed by all the water points (mapped boreholes) being in the central and eastern regions. These regions are discharge zones hence high groundwater exploitation potential. An inspection on the factors considered shows that in these high potential areas, all their values correspond to favorable values for example a value of 1 (best) for topography factor, land cover value of 2 (good), slope value of 1 (best) and surface drainage values 1 and 2 (best to good). These results show that geospatial technologies are especially suited for the delineation of groundwater potential areas. From these results further investigations can be embarked aimed at verifying extractable amounts, groundwater quality and sustainability of groundwater exploitation in the study area.

Conclusion

The objective set out was accomplished. In this work the utility of geospatial technologies in estimating the groundwater potential in Kitui district has been demonstrated. This was achieved through preparation of land-cover maps from classification of Landsat imagery, generation of lineament density maps, evaluation of the various parameters using the DRASTIC model and delineation of groundwater zones in the form of a groundwater zonation map.

The most suitable areas for groundwater prospecting were shown to be those in the central and eastern areas of the district. While many of the existing boreholes lie in these areas, there are some boreholes falling outside these areas, but these are still in the moderately suitable areas.

It is recommended that these potential areas should be further studied to verify the extractable amounts, the water quality and sustainability of groundwater extraction in the study area. This will be key to addressing or ameliorating the problem of water scarcity in Kitui District.

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