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Land use/land cover, change detection, remote sensing, Landsat TM, Menengai, Kenya

As the population increased, land use and/or land cover in the Menengai Landscape has been changing rapidly due to the increased interactions of human activities like geothermal energy development. These changes are likely to cause a shift in the generation of goods and services from the biophysical environment, and thus need to be understood. As an integral part of geothermal exploration and development one should map, evaluate and monitor those changes.

In the last few years, remote sensing techniques have been increasingly used in managing and monitoring land-cover and land-use and their changes at a variety of spatial scales. With population growth, the land base declines and the exploitation of natural resources increases to meet human needs. Satellite remote sensing techniques have been used to collect and interpret data, and to classify features.

In this study, the supervised classification method was used to generate the land cover maps. Multi-temporal Landsat images (obtained in 1989, 2000 and 2010) together with physical and population data were then used in a post classification analysis with GIS technology to map land use/land cover distribution and to analyze factors influencing the land use/land cover changes. Preliminary results revealed that substantial land use/land cover changes had taken place with population increase (1989-2000). Rapid urbanization, deforestation and energy generation were noted to be the major factors influencing rapid land use/land cover changes. Since the quest for more energy resources is evident, this study recommends a detailed study to accurately detect such changes and thus help understand the relationships between human, geothermal resource exploration and natural phenomena so as to facilitate effective decision-making.

For the last 31 years, the Menengai landscape and its surrounding have been transformed from a sparsely populated and densely forested expanse into an area that is heavily settled, extensively cultivated, and rapidly expanding in terms of urbanization, especially in areas around Bahati (Kundu, 2010). Geothermal exploration activities, which began in 2004 in the area, have further attracted population in search of employment. Land use/cover and geological formations have been shown to affect groundwater recharge, storage and availability. In high investment endeavors such as geothermal exploitation, there is a need to map, evaluate and monitor such changes.

Remote sensing has been experiencing rapid changes in the last few decades, especially from around the 1970s. It is an important technical tool mainly used in managing and monitoring land-cover and land-use and their changes at a variety of spatial

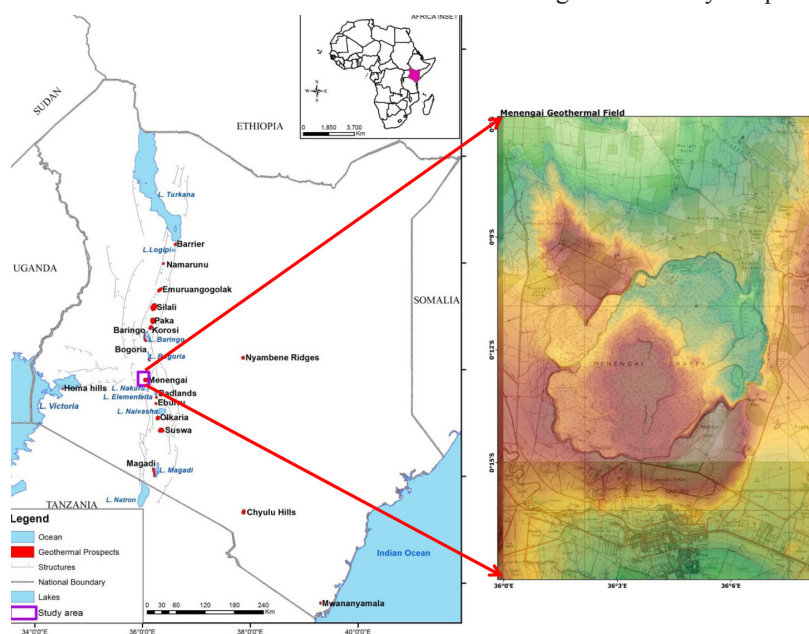


Figure 1. Map of Kenya showing the location of the Menengai geothermal exploration site.

scales (Jensen, 1986). With greatly improved resolution of satellite imagery, remote sensing data has become more readily available in the recent past. One of the main purposes of these techniques is to interpret the observed data and classify features.

In this study, the supervised classification method (Congalton, 1991) was used to generate land covers maps. The aim was to investigate, using image processing algorithms in ERDAS software (ERDAS Field Guide, 2010) the extent of change in land cover/use in the Menengai landscape from multi-temporal data sets. To achieve this objective, multi-temporal Landsat data acquired in 1989, 2000 and 2010, and topographic maps compiled in 1963 by the Survey of Kenya and population census of 1989, 1999 and 2009 were used in a post-classification comparison strategy to identify the extent of land use/cover changes over the period under investigation.

This study was envisaged to be a baseline to evaluate changes that occurred since geothermal energy exploitation commenced in 2010, and will occur as surface exploration continues. The land use/cover changes that have been observed over the years are likely to increase with severe consequences on natural resources; e.g., rainfall amounts and patterns. Climate change is also having a direct influence on water resources. With the current trends of land use/cover and climate change there is a likelihood of future negative impacts on geothermal potential in the study area. Therefore, this investigation is essential in providing the areas that need to be emphasized so that the geothermal resource can be exploited for a longer period in a sustainable manner.

Study Area

Menengai is located about 10 km north of Nakuru, the third-largest city in Kenya. An area of approximate 2183 km² was chosen for this study. The Menengai geothermal prospect (Figure 1) encompasses the Menengai volcano, the Ol Rongai volcanoes, the Ol Banita plains and parts of the Solai graben to the northeast (Lagat et al., 2010). The area is well settled except for parts of the Menengai caldera that is public land.

The study area is occupied by small-scale intensive mixed farming. To the east are sub-urban and urban developments which make the population fairly high. There are also large-scale wheat and dairy farming activities occupying most of the western parts of the Menengai caldera. According to Lagat et al. (2010) most of the area is well serviced by a network of earth roads and a tarmac road through the western part (the Nakuru-Marigat Road) and the eastern part of the prospect (the Nakuru-Nyahururu Road).

Data and Methodology

Data

Three Landsat imageries covering the Menengai landscape acquired in 1989, 2000 and 2010 were selected for this study. Hence, the study period covered about 31 years. Multi-temporal Landsat Thematic Mapper (TM) images for 1989, 2000 and 2010, together with population census data for 1989, 1999 and 2009 were used in a post-classification analysis with Geographic Information System (GIS) technology to map land use/land cover distribution, and to analyze factors influencing the land use/land cover changes. A topographic map at a nominal scale of 1:50,000 compiled in



Photo 1. GIS team during fieldwork.

1963 by the Survey of Kenya was used as reference data and for accuracy assessment.

Methodology

The image processing and data manipulation were conducted using algorithms supplied with the ERDAS Image image processing software (ERDAS Field Guide, 2010), which also incorporates GIS functions. Arc GIS 9-3 was used for GIS overlay analyses. The image processing procedures included image pre-processing, the design of classification scheme, image classification, accuracy assessment and analysis of the land use/land cover changes.

A modified version of the Anderson Scheme (Anderson et al., 1976) was adopted for this study. Six land use/cover classes were established namely water, forest, agriculture, and range, urban and barren land. Some of the factors considered during the design of classification scheme included; the major land use/cover categories found within the study area, differences in spatial resolutions of the three sensors, which varied from 30 meters for TM and ETM+ (Enhanced Thematic Mapper) to 79 meters for MSS (Multi-Spectral Scanner) and the need to consistently discriminate land use/cover classes irrespective of the seasonal differences (Mubea et al., 2009).

No classification is complete until its accuracy has been assessed. Like in all other GIS analyses, the statement “garbage in, garbage out” is also valid for map accuracy assessments. Simple random sampling method of sample collection was used, where the positions of the points were selected randomly and 336 random points were chosen. This comparison was performed by the use of an error (or confusion) matrix. In the error matrix, map data points are often presented along rows, and the ground truth data points along columns. Before embarking on the use of error matrix in the estimation of map accuracy, a number of variables were defined like the number of correctly mapped classes, of ground points, of mapped points and of total points. The overall accuracy, user accuracy, producer accuracy, mean accuracy, areal difference and kappa coefficient were then calculated.

Results

Accuracy

An overall accuracy of about 67.2% and Kappa statistic of 0.57 was achieved, indicating the probability that a randomly selected point on the map was correctly mapped.

Classification

Table 1 and Figures 2-4 show the distribution of land uses for the years 1989, 2000 and 2010.

Table 1. Area and percentage of the land use.

Features	1989		2000		2010	
	(km ²)	%	(km ²)	%	(km ²)	%
Urban	2.05	0.09	2.35	0.11	3.73	0.17
Water	3.57	0.16	2.69	0.12	1.70	0.08
Barren	193.62	8.85	95.54	4.37	67.52	3.09
Forest	120.56	5.51	102.39	4.68	72.38	3.31
Agriculture	1867.04	85.38	1983.87	90.72	2041.51	93.35
Total	2186.84	100.00	2186.84	100.00	2186.84	100.00

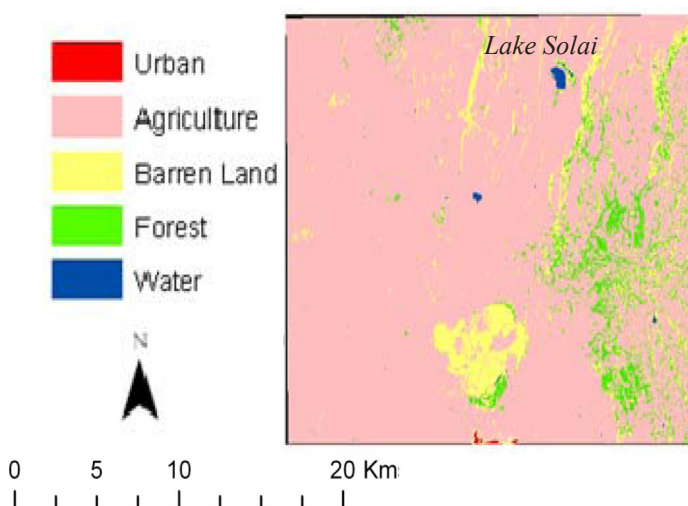


Figure 2. 1989 Classification.

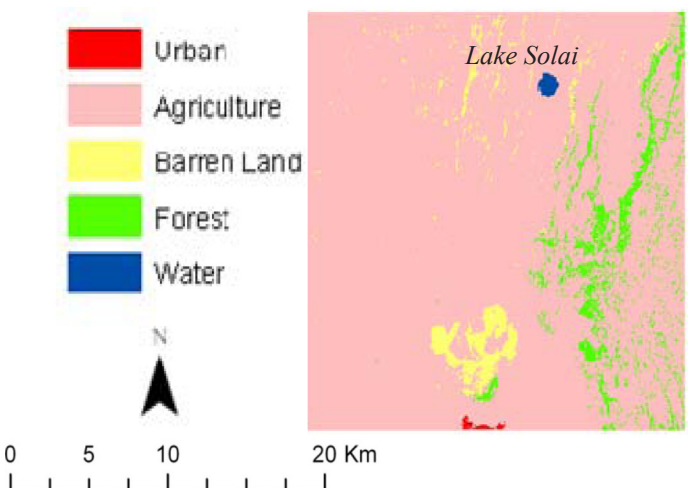


Figure 3. 2000 Classification.

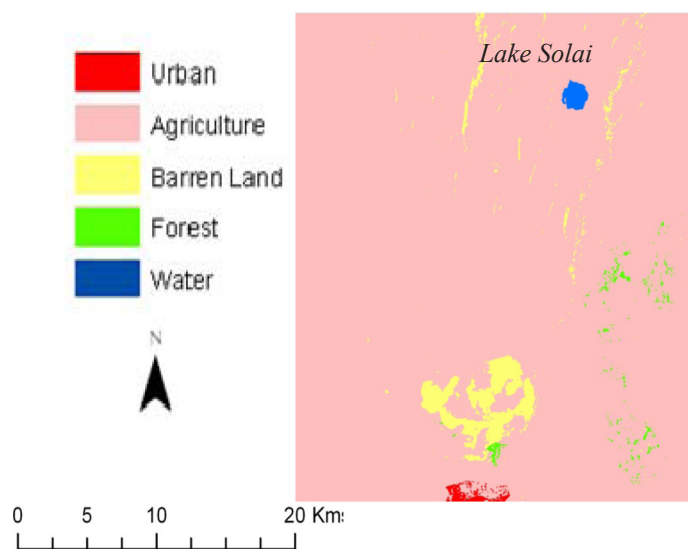


Figure 4. 2010 Classification.

Discussion and Conclusion

In the study area, nearly 67 % of the total land use classes could be identified and extracted using the supervised classification method. This means that about 33% of the land use classes were not confirmed by the method. Manual and field work comparison with the satellite image showed that these were false land use classification of forests and barren land that can hardly be detected visually on the image. There was also spatial pattern concerning the quality of results which could be narrowed to vegetation areas where the feature extraction had more difficulties detecting forest, especially within the Menengai Crater.

Results revealed that substantial land use/land cover changes had taken place with population increase between 1989 and 2000, following increased birth rate and health care access with large population in the part that touches Nakuru municipality. To investigate the changes, image processing algorithms were used to generate change detection information from multi-temporal data sets for 1989, 2000 and 2010 as shown in Figures 2-4.

Statistics of changes in land cover classes were extracted and thematic maps generated in GIS. Accuracy was generated in the form of error matrices after supervised classification with maximum likelihood, achieving an overall accuracy of 67% and Kappa statistic of 0.57.

Rapid urbanization, deforestation and energy generation were noted to be the major factors influencing rapid land use/land cover changes in the study area. Economic developments like geothermal exploration and the rising population were noted to be the major factors influencing land use/land cover changes in the Menengai Landscape. There has been an increase in agricultural land, indicating that barren land has changed into agricultural land following better farming methods. Forest cover has decreased implying destruction of forests through deforestation and changing climatic conditions that inhibit natural growth of vegetation. The reduction in forest cover has hydrological effects that include increased flash runoff and reduced infiltration, hence limiting groundwater recharge. This leads to a decreased in the amount of water that gets to the hot rocks and also a reduced pore water pressure. A

possible major consequence could be a lowering in the amount and pressure of the available geothermal steam in the future.

From Table 1 and Figures 2-4, the greatest losers in land use are forest and barren land, while the highest beneficiaries are agriculture and urban areas. It is also clear that these changes occurred most in the eastern part of the Menengai Landscape, coinciding with the area with high-yield groundwater. Population pressure could have led to more areas being converted into agricultural land, and the adoption of new technologies (augmented by the presence of water) enabled barren land to be turned into productive land. Also, the search for livelihood alternatives easily resulted in the development of urban centers.

More changes are expected in the future. The influences of these changes on the hydrological behavior of the area surrounding the Menengai Caldera are currently unknown. This calls for hydrological and climatic studies based on historical observations coupled with the current land use/cover changes in order to forecast future scenarios. Integration of high spatial resolution images into the research would enable classification to higher level of accuracy and more detailed feature classification.

Since the quest for more energy resources is evident, this work recommends a detailed study of the Menengai Landscape to accurately detect land use/cover changes, and thus help understand the relationships between human, geothermal resource exploration and natural phenomena for decision making. Moreover, an up-

to-date land use/land cover inventory is essential when making arrangements for planning and monitoring land cover in rapidly growing areas.

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