The use of Landsat Imagery, Geographic Information System and Digital Terrain Modeling for Land use Planning in Lake Nakuru Drainage Basin.

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Abstract

Land use planning is essential for sustainable development of both rural and urban environments. The approaches in land use planning in Kenya which use analogue maps in the preparation of land use plans are inadequate since the maps are two-dimensional, have coarse scales and in many cases out of date. These shortcomings have often resulted in incoherent land use policies, haphazard settlements, land degradation and environmental pollution in many parts of Kenya.

To address this problem, computer-based methods using remote sensing, GIS and digital terrain modelling techniques were used at two sites within the lake Nakuru drainage basin. The first site, Gichobo sub-catchment represents land predominantly under small scale farming. Landsat TM and GIS were employed to generate land use classes for the sub-catchment. The results showed that a total of 180 hectares or 3.6 percent of the sub-catchment was under illegal cultivation within the forest. The second site, Njoro river sub-catchment represents land under large scale farming. At this site, DTMs were generated from a contour map after which images and layers of different features were digitised and draped. The DTM's representation of the sub-catchment facilitated visual location of waterways, communication routes and other physical facilities.

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1. Introduction

Improper land use planning has been identified as one of the main causes of environmental and land degradation in the Lake Nakuru drainage basin, (Karanja et. al., 1986, China, 1993, Chemelil, 1995). Land fragmentation and deforestation have led to serious soil erosion problems, including gullying and siltation of lake Nakuru. The main agricultural activities in the study area include crop and livestock production as reported by ICRA (1997). The dominant food crops are maize, potatoes, vegetables and beans. Wheat and barley are grown as cash crops on medium and large scale farms where their cultivation is economical. The overall impact of improper land use planning is manifested by reduced farm productivity and increasing poverty.

The study covered two sites, both of them within the lake Nakuru drainage basin. The two sites included Gichobo sub-catchment and Njoro river sub-catchment as shown in Figure 1b. Remote sensing, GIS and DTM techniques were applied to ascertain their effectiveness in land use planning. The results showed that the methods are suitable and can be effectively used in land use planning. Five land use classes were generated by GIS operations using layers from landsat TM data and field data at site 1. The analysis of the sub-catchment using remotely sensed data facilitated the detection of illegal cultivation within the sub-catchment. At site 2, DTMs were generated to represent the surface terrain of the area. The hills on the west on Tatton farm at Egerton University are quite distinct as shown in Figures 5 and 6. The use of digital terrain models in land use planning can greatly enhance development planning (Niemann and Howes, 1991). The use of these computer-based technologies can simplify the planning of agriculture, communications, waterways, terraces and other infrastructure within Lake Nakuru drainage basin.

2. The study area

The study area consisted of two sub-catchments within lake Nakuru drainage basin. The first site, Gichobo sub-catchment lies between latitudes 0^0 22’ S and 0^0 27’ S and longitudes 35^0 55’ E and 35^0 59’ E, covering an area of 50 Km^2. The altitude of the area ranges from 2140–2700 m a.m.s.l. Topography is predominantly rolling land with slopes ranging between 8-12 %. The sub-cachment is drained by river Lamuriak which originates from Mau escarpment and empties into lake Nakuru. Soils of the sub-catchment are deep, well drained silt loams on the slopes and poorly drained shallow silt clay loams in the lowlands. The main land use is crop production and livestock keeping. The steep land along the escarpment is covered by natural and planted forest.

The second site, river Njoro sub-catchment lies between latitudes 0^o 18’ S and 0^o 23’ S; and longitudes 35^o 53’ E and 35^o 58’ E, and measures about 100 km^2, with a mean altitude of 2200 m a.m.s.l. It lies in between the Rongai-Njoro plains and the upper slopes of the Mau escarpment and is drained by river Njoro and a small seasonal stream which runs from the area close to Beeston saw mills. The soils in the area are predominantly quaternary and the tertiary volcanic deposits (Kinyanjui, 1979). The quaternary deposits include the black ashes of the Rongai-Njoro plains, pyroclastics and sediments of the Rongai plains and Mau slopes, and cover the Northern part of the area. Tertiary deposits cover the Southern part of the area and include black ashes of Elburgon and welded tuffs. They have a topsoil of clay loam or loam texture with friable consistence and a weak to moderate, subangular blocky structure. The subsoil texture ranges from silty clay loam to clay loam and clay. The soils have pH ranging from 5.6 to 6.4, which makes them slightly to moderately acid. The upland soils have high organic matter.

Both sites receive average annual rainfall of between 600-1100 mm which is trimodally distributed with peaks in April, August and November. The whole of lake Nakuru drainage basin was once covered by rich vegetation of highland evergreen forests. After independence in 1963, land buying companies acquired the large farms formerly owned by white settlers and subdivided them into smaller units which they distributed to their share holders. The new land owners further fragmented the units, clearing off most of the remaining trees to create room for homesteads and farms. At present, only small parts of the natural vegetation still exist, mainly on the upper reaches of the Mau hills and along Njoro River. The acacia trees are however still found scattered all over in the study areas.

3. Methodology

3.1. Gichobo Sub-catchment

A boundary map of the catchment was traced from the Njoro topographic map sheet number 118/4 at a scale of 1: 50,000 onto acetate paper. Drainage, communications and farms were traced, digitised and transcribed into Arc/Info GIS. Detailed field survey was carried out along representative transects in the sub-catchment, and data on field slopes, slope breaks, soil types, soil depths and current land cover and land use were recorded. This data was used to delineate and code different land use categories within the sub-catchment. The coding of different land use categories adopted procedures reported by Anderson et al. (1976). The different land use and land cover classes obtained were also traced onto acetate transluscent paper, digitised and transcribed into Arc/Info GIS. Figure 5 represents the land cover and land use classes in Gichobo sub-catchment as obtained by ground survey.

A quarter scene of Thermatic Mapper (TM) digital data was bought from EOSAT, USA. The raw data was processed using the ERDAS version 7.4, an image processing software. Individual TM bands were displayed and inspected for clarity of the image. In addition, combinations of various bands were displayed and evaluated for quality and details captured by the image. TM bands 4, 5 and 3 were selected because of their superiority in revealing vegetation features on the earth's surface, (Sabins, 1986). A composite image of the 3 TM bands was composed and saved as a 3-dimensional file. Figure 2b shows the colour composite of the selected data.

3.1.1. Image Ratioing

A Normalised Difference Vegetation Index (NDVI) was determined as follows:

NDVI = $[\{(X4 - X3)/ (X4 + X3)\} + 1] \times 127$; where X3 and X4 are bands 3 and 4 respectively. The ratio image created was used to classify the image interactively. On displaying the histogram of the ratio image, it was found out that the pixel values fell into six distinctive groups. Each range of the DN values in a group was assigned a different colour, resulting in the classified ratio image shown in Figure 3.

3.1.2. Supervised Classification of TM digital data

Supervised classification of the composite image was carried out. The maximum likelihood decision rule was used since this criterion is regarded as the most discriminating and mathematically simple (Burrough, 1986). This classification scheme resulted in five land use/land cover classes shown in Figure 4a.

After ground truthing, sample reference pixels for each known class on the ground was available. The programme carried out classification accuracy assessment by comparing the classes generated through supervised classification with reference sample pixels related to ground true land classes. Table 1 shows the results of the classification error matrix generated by the computer.

3.1.3. Combining Landsat TM data and ancillary field data

The supervised classification raster image depicted in Figure 4a was filtered, rectified, vectorised and exported into Arc/Info GIS as vector image. Within the GIS environment, the

TM landsat data and ancillary field data both in vector format could now be combined. By performing a topological overlay clip provided by Arc/Info GIS, it was possible to extract TM landsat data falling within the catchment boundary only and hence produce a new coverage.

3.2. RiverNjoro Sub-catchment

A survey of the sub-catchment was carried out and three survey Ground Control Points (GCPs) within the sub-catchment were located on Kimakia farm (118 T 2-2312 m a.m.s.l.) at co-ordinates $\phi=35^{o}$ 54’ 5’’, $\lambda=0^{o}$ 18’ 40’’, Ngata settlement (118 T 4-2146 m a.m.s.l) at co-ordinates $\phi=35^{o}$ 59’ 8’’, $\lambda=0^{o}$ 17’ 12’’, Ruo (118 T 3-2328 m a.m.s.l) at co-ordinates $\phi=35^{o}$ 58’ 35’’, $\lambda=0^{o}$ 26’ 38’’ and in the Mau forest (point SKP 105-3048 m a.m.s.l) at co-ordinates $\phi=35^{o}$ 53’ 13’’, $\lambda=0^{o}$ 29’ 12’’.

Data input for the DTMs was created by digitising a contour map (Njoro sheet 118/4) in AutoCAD. All contours were digitised as polylines in one layer. Each contour was manually digitised in point-mode, then assigned its true elevation value using QuickSurf commands. Drainage, communication, farms, forests and built up areas were digitized as different layers. A soil map of Tatton farm and a map showing the fields on the farm were then digitised. Surface operation commands in QuickSurf were used to show elevations and slopes and to manipulate vertical exaggerations suitable for the terrain. Layers of different features were then draped on the DTMs. AutoCad commands of layering, freezing and thawing were used to produce DTMs showing different features as single or combined layers. The contours were then imported into ArcGIS 9 after which a DTM was generated and then layers of images were draped.

4. Results and Discussion

4.1. Land use and land cover classes

From Table 1, it was noted that areas covered by planted forest (F2) were often classified as either natural forest, residential and cropland. Similarly, areas identified on the ground as cropland were often classified as residential. The overall classification accuracy was 52% which was very low. One of the reasons the classification accuracy was low is the fact that some areas on the ground designated as forest land were actually under illegally crop cultivation. Furthermore, there was a lot of biomass around residential areas in the form of vegetables, maize, woodlots and other plants in the gardens. This is probably why all the land identified on the ground as residential was classified as cropland by the image classification procedures. The benefit of the classification was to redefine the sub-classes after examining the causes of the misallocation. It was however clear that the area could be classified into three major land cover classes namely, natural forest, planted forest and cropland. This was in agreement with the interactive classification shown in Figure 3 and Table 2.

Figure 4a and Table 2 summarise the land cover and land use classes generated through supervised classification for Gichobo sub-catchment. The five land classes detected were similarly generalised into three land cover classes, namely natural forest, planted forest and cropland. The differences seen on cropland were as a result of differences in the reflectances of different stages of crop growth.

Closer examination of cropland showed that the land use can be sub-divided into three sub-groups based on slope. Finer categorisation was not visible but was observable during field survey as shown in Figure 4b and Table 3.

4.2. Location and area of land covered by the riverine vegetation

The location and area covered by the natural forest was very clear as shown in both Figures 4a and 4b. However, from Table 2 and 3, the total areas covered by the natural forest do not tally. This is probably because natural forest on TM landsat imagery also includes riverine vegetation which extends into planted forest. Therefore by subtracting the areas covered by natural forest from the corresponding area gives the area covered by riverine vegetation in Gichobo sub-catchment, i.e.

$$N_t - N_g = R$$

Where,

N_t = Area covered by natural forest on TM landsat imagery

N_g = Area covered by natural forest on topographic map

R = Area covered by riverine vegetation in Gichobo sub-catchment

4.3. Detection of the extent of illegal cultivation within the forest

From ground survey as represented in Figure 4b, the eastern boundary of the planted forest was discernable. However it was not possible to ascertain how much forest land had been affected through illegal forest cultivation. But by combining TM landsat imagery ground survey, it was possible to detect the total area of forestland that had been encroached through illegal cultivation, i.e.

$$(N_g + P_g) - (N_t + P_t) = I$$

where,

N_g = area covered by natural forest on topomap

P_g = area covered by planted forest on topomap

N_t = area covered by natural forest on landsat imagery

P_t = area covered by planted forest on landsat imagery

I = area of forest land under illegal cultivation

From the above relationship, it was found that the total area within the designated forest area that has been cultivated is 603.14 hectares.

4.4. Adjusted current land use / land cover classes for Gichobo Catchment

Table 4 shows the detailed land use / land cover classes of Gichobo sub-catchment after correcting for riverine vegetation and illegal forest cultivation. Hence the use of both landsat imagery and ground survey was useful in generating a more refined land use and land cover map for Gichobo sub-catchment. Individual approaches by either method would not have provided detailed information as shown in Table 4 .

4.5. Digital Terrain Model for river Njoro sub-catchment

Figure 5 represents the DTM generated in a South-North orientation. A vertical exaggeration of 3 was found to be suitable to achieve distinguishable landforms such as hills, crests and valleys with a contour vertical interval of 20 metres. The DTMs generated closely represented the terrain of the sub-catchment. The hills on the west of the study area and on Tatton farm at Egerton University were well defined. The micro-topography could not be represented because of the coarse resolution of the map sheet used (scale 1:50,000).

4.6. DTM with draped Image

As shown in Figure 6, the valleys of rivers Njoro, Lamriak and Nessuit are clearly distinguished. Menengai hill and lakes Nakuru and Elmentaita are shown clearly. The Lions hill on the east of lake Nakuru and the Mau hills are quite distinct.

4.7. Soil-landscape Model in river Njoro sub-catchment

The DTM with draped soil map of Tatton farm clearly showed the soil boundaries. Although the micro-terrain of the farm could not be generated because of the course scale of the source map, it was possible to get the soil-landscape relationship from the analysis. Mapping soil types by this technique proofed easier because the generated landforms were easier to observe visually and then describe the associated soils. The benefits of this technique can be realised in planning the location of communication routes, telecommunication masts, waterways, water tanks, farm ponds and enforcing environmental conservation laws.

5. Conclusions

Combining remotely sensed data with field data enabled the study to determine that about 180 hectares or 3.6 percent of Gichobo sub-catchment was covered by riverine vegetation. Analysis of combined ground survey data and landasat TM data facilitated the detection of nearly 600 hectares (or about 10 percent) of the total area of Gichobo sub-catchment being under illegal cultivation. Without the benefit of these technologies, area determination using ground survey alone could have been costly and in some cases impossible. Integrating TM landsat data, ancillary ground data and GIS enabled the study to evaluate the type and extent of different land use categories present in the sub-catchment.

The DTMs generated represented the terrain of river Njoro sub-catchment fairly accurately based on the resolution of the source map and facilitated automated processing and draping of communications, soils, forests, rivers and farms within the catchment. The DTMs obtained are suitable for land use planning and soil and water management within the sub-catchment given the advantage that once data is available in the appropriate format, relief representation can be obtained rapidly and economically. Communications, waterways, farm ponds, terrace channels, etc can easily be planned within farms. Elevations and slopes were generated and easily categorised with speed as compared to manual slope mapping which is without doubt very tedious and prone to errors. This capability of DTM can be used widely in planning agriculture by zoning areas for particular crops such as tea and pyrethrum depending on their climatic and altitude requirements. In soil and water management, morphologic facets of landscape may be correlated with specific processes such as shallow mass movements and gully erosion.

The study showed that the use of remotely sensed data, GIS and DTM facilitates automated mapping of landscape and land use, thereby reducing the time spent in the field. The technique allowed rapid updating of the source maps enabling more appropriate decisions to be taken to enhance catchment planning.

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TABLES

Table 1: Classification Error Matrix

Classified Data	Reference Data						
	BG	F2	F4	CL7	RES	CL12	TOTAL
BG	0	0	0	0	0	0	0
F2	0	11	2	0	0	0	13
F4	0	4	12	0	0	0	16
CL7	0	0	0	3	0	0	3
RES	0	3	0	6	0	1	10
CL12	0	3	2	3	0	0	8
TOTAL	0	21	16	12	0	1	50

BG= Background; F2 = Planted forest; F4 = Natural forest; CL7 = Cropland; CL12 = cropland; and RES = Residential.

Table 2: Area tabulations of land use classes for Gichobo sub-catchment obtained by Supervised classification

Cluster Number	Area (ha)	Description
Cluster 1	1326	Planted forest
Cluster 2	582	Natural forest
Cluster 3	346	Cropland
Cluster 4	1486	Cropland
Cluster 5	1158	Cropland
Cluster 0	55	Background
Total	4954	-

Table 3:Area tabulations of land use classes for Gichobo catchment
obtained by ground survey

Category	Land Use / Land cover	Area
422	Planted Forest	2107.94
213	Medium Holder Cropland	945.77
211	Small Holder Sloping Cropland	603.70
212	Small Holder flat cropland	589.39
421	Natural Forest	403.20
11	Residential	240.60
62	Wetland	61.88
12	Mixed Urban and Built-up	41.42
75	Barren land	15.56
Total	-	5009.47

Table 4 :Area tabulations of the current land use and land cover
Classes of Gichobo sub-catchment

Category	Land Use	Area (ha)	Area (%)
422	Planted forest	1325.8	26.46
213	Medium holder cropland	945.77	18.88
211	Small holder sloping cropland	603.70	12.05
212	Small holder flat cropland	589.39	11.77
421	Natural forest	403.20	8.05
11	Residential	240.60	4.80
62	Wetland	61.88	1.24
12	Mixed urban and built-up	41.42	0.83
75	Barren land	15.56	0.31
R	Riverine.	179.00	3.57
I	Cultivated forest	603.14	12.04
	Total	5009.46	100.00

FIGURE CAPTIONS

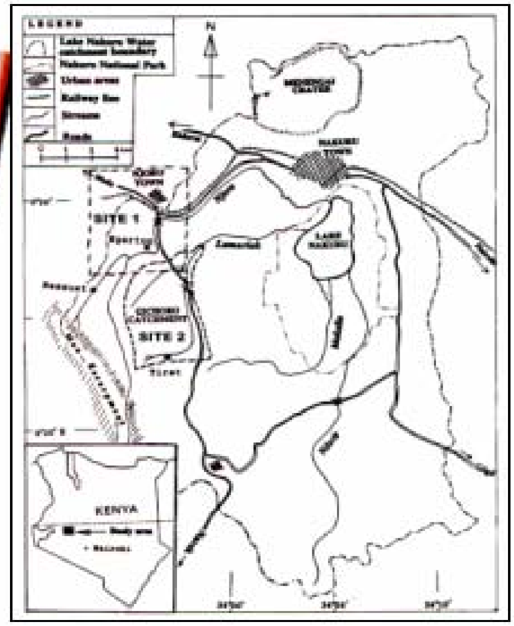


Figure 1a: River Njoro catchment (landsat ETM +)

Figure 1b:The Study sites on a Locational map

Figure 2a: Baseline data (a 1969 air photograph of the study area)

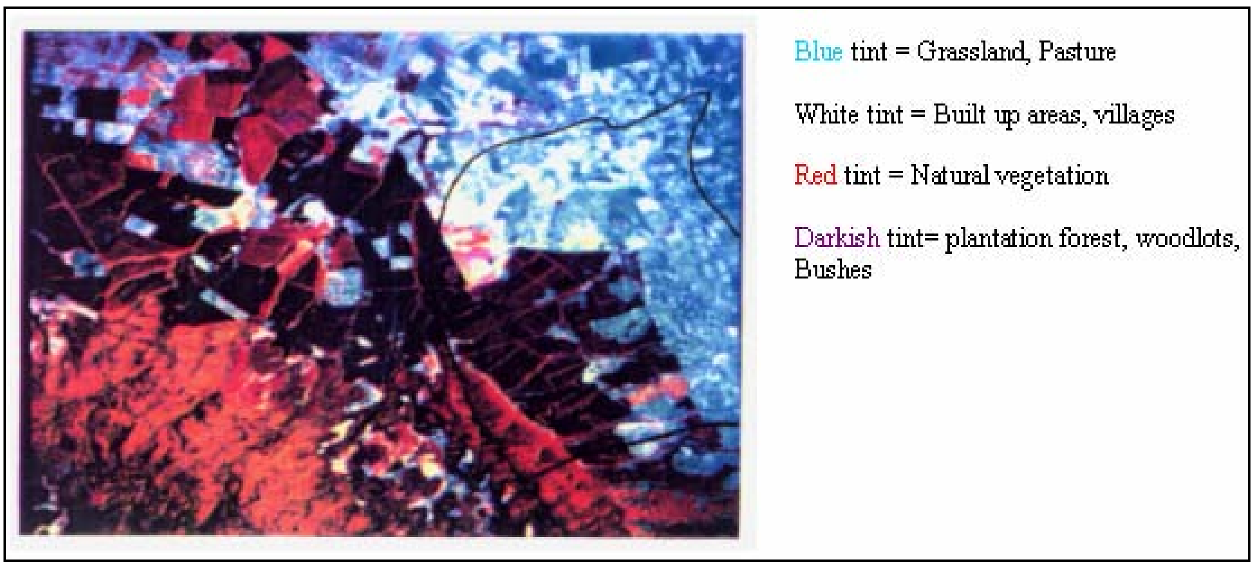


Figure 2b: Assessment data (Landsat image 1989 of the study area)

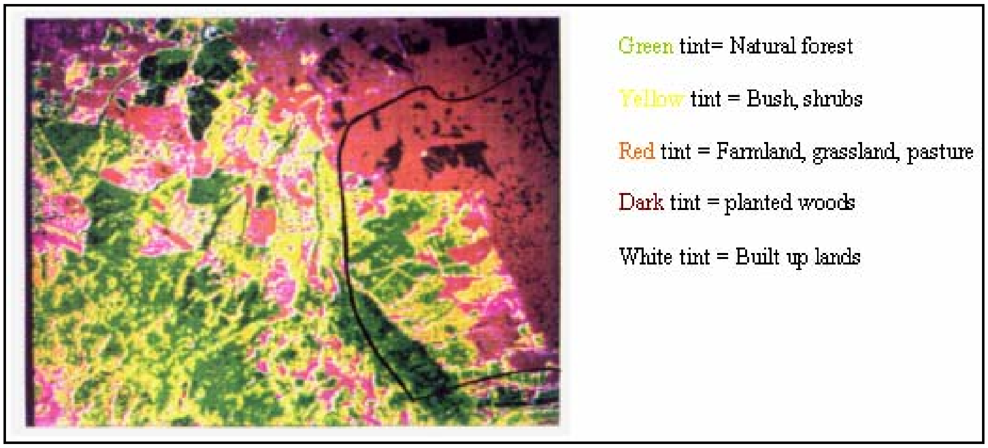
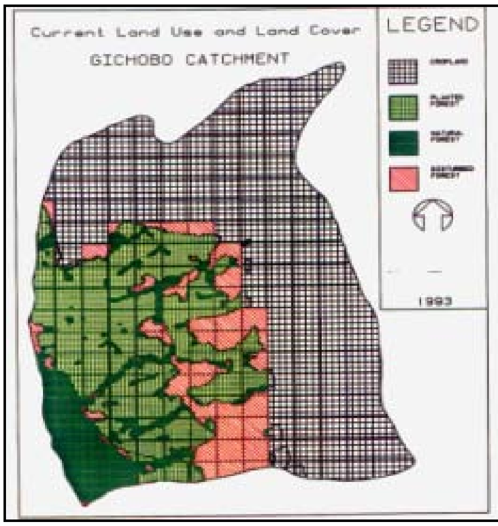


Figure 3:Ratio image classified interactively using the histogram of DN values



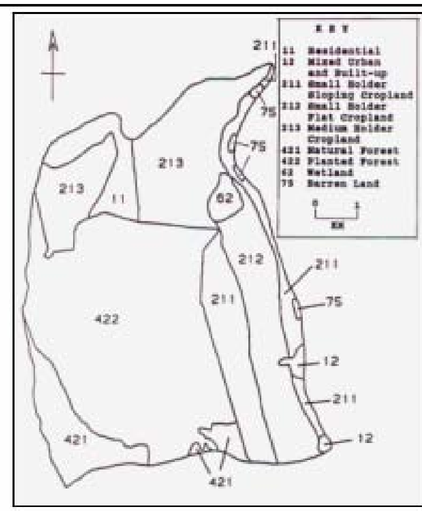


Figure 4a: Supervised Classification

Figure 4b: Ground survey

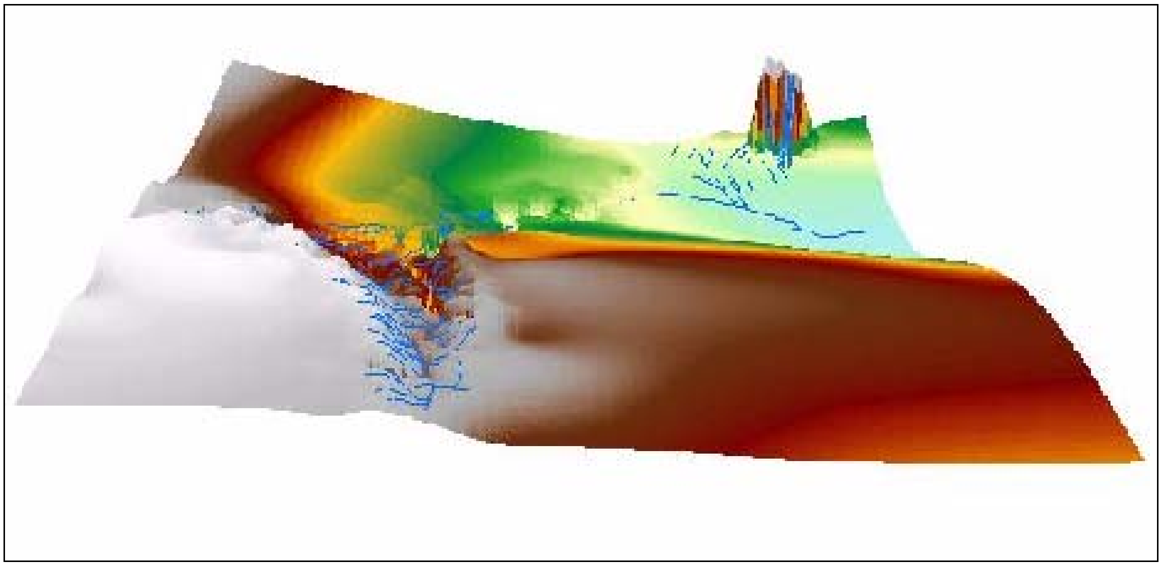


Figure 5: DTM of River Njoro sub-catchment in a South-North direction

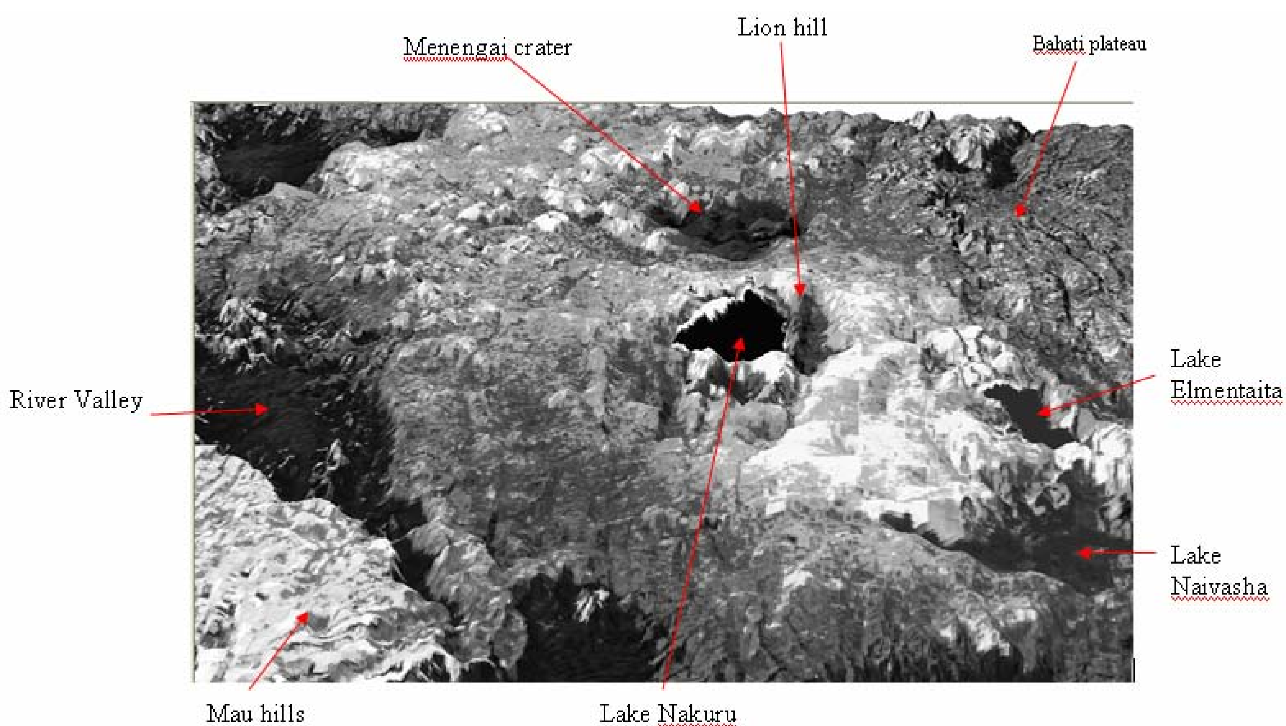


Figure 6: DTM with a draped landsat image