Mapping and Analysis of Landcover Changes in the Upper Gucha Catchment using GIS and Remote Sensing

Abel Nyaribo Kaburi and Patroba Achola Odero

ABSTRACT - Geospatial technologies and their capability to capture, store, manipulate and display data, have found great utility in the analyses of any geospatial phenomena with speed and accuracy anywhere on/above or below the Earth surface. One such field of application is watershed conservation and management. This study demonstrates the role of spatial technologies especially GIS (Geospatial Information Systems) and Remote Sensing, in the identification and analysis of human impact on the land cover through land use practices within the upper Gucha watershed. The upper part of the Gucha River has been harnessed for water supply development in Kisii and Nyamira towns and recently Keroka Township. It has a population growth rate of 2.75% per annum, poverty level of 51% and average population density of 874.7 persons per km^2 leading to land fragmentation and clearing of primary vegetation within the catchment to accommodate the population. The methodology involved delineating the catchment using GIS Hydrology tools, by filling the DEM (Digital Elevation Model) and creating a flow direction, from which a flow accumulation was calculated so as to identify water pour points accurately for watershed delineation and channel generation. Preparation and processing of the satellite imageries for the years 1990, 2000 and 2013, was carried out in Erdas Imagine environment for onward change detection analysis. Results include Change Detection Maps of the watershed for visualization and quantification of land cover changes within the watershed over that period as tools for informed decision making by managers during conservation and management of the watershed. Some of the change detection analysis indicates that more forest land grassland is rapidly changing for crop land. The changes for forest land and grass land are 10.5% and 2.6% respectively for the period the study. Notably, 0.085% of the land changed from water bodies to forest land while the change from forest land to water bodies is 0.061%. A number of similar analyses have been presented. This study concludes by appreciating the importance of spatial technologies in not only mapping water resources especially water channels in a watershed, but also in land cover/land use change detections for general management of resources.

Key Words: GIS, Remote Sensing, Land Cover, Conservation, Management.

I. INTRODUCTION.

Environmental and Developmental issues are considered as the most important drivers of human welfare anywhere on the Earth surface. They are the main determinants of human welfare in terms of prosperity and survival. However, history is witness to the fact that many a time developmental issues are given priority than environmental conservation and its quality. This is because human survival is an immediate need and therefore ‘‘an urgent’’ issue and the environment takes time to exhibit ‘‘stress’’ – but indeed threatens on the very human survival that ‘human greed’ tries to address in short term – development. There is a struggle between productivity and conservation, economic development and environmental ‘health’ sustainability.

In many developing and underdeveloped countries, about 80% of the population reside in the rural areas and mostly rely on the natural resources of land and water for day-to-day livelihood [1]. Coupled with population pressures on landscapes through agricultural practices, and other socio-economic activities on non-elastic land resource, there is a lot of pressure on watershed components. Land managers are continually looking for new methods of managing and monitoring the health of the landscape and its components such as watersheds, natural vegetation and wetlands.

Population explosion in rural areas tempered with limited agricultural knowledge implies more land degradation, higher poverty levels and health problems. This situation demands for appropriate management of available resources, both natural and man-made, especially watersheds and wetlands. This can only be achieved through enforcing an all-round appropriate conservation practices to balance between resource exploitation and conservation for sustainable development. For sustainable development to be realized, appropriate management tools in terms of cost and technology must be implemented on both the affected areas so as to search for solutions, and the unaffected areas so as to improve on their general health [2].

The ability of Geospatial Information Systems (GIS) and Remote Sensing technologies in terms of data capture, storage, analysis and display have proved very efficient, effective and fast in terms of accuracy, speed and cost, hence very useful tools for not only general environmental conservation and management, but most importantly for specific issues such as watershed conservation and management, and restoration [3].

Watersheds are hydrologic units that are considered to be efficient and appropriate for assessment of available resources and subsequent planning and implementation of various development programs. A watershed is defined as “Natural Hydrologic entity that covers a specific area of land surface from which the rainfall runoff flows to a defined

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drain, channel, stream or river at any point [4]. Hence, all the basic natural resources such as soil, water and vegetation in the hydrological entity of a watershed area should be managed sustainably.

The integration of technologies such as GIS and Remote Sensing, in the management of the components of a drainage area of any ecosystem, is important for optimum development of land resource, water resource and plant resources to meet the basic needs of man and other animals (domestic and wild) in a sustainable manner - this is part of a Watershed Management process [5].

Diversity in physical landscape results in different classes of land, which are subjected to different types of utilization/land use. This has resulted in uncontrolled exploitation of resources resulting in unproductive or degraded land. Such degraded lands, which are currently under-utilized and are continuously deteriorating due to lack of water and appropriate soil management practices or on account of natural cause are called Wastelands. Westland can be brought under vegetative cover with reasonable effort through the employment of the right space technologies such as spatial technology-GIS and Remote Sensing.

The main objective of this study is to demonstrate the contributions of spatial technologies, especially GIS and Remote Sensing in the Conservation and Management of the Upper Gucha Catchment by identifying the land covers and land uses within the watershed. The dynamics of the land covers and land uses are carried out through a time series analysis.

II. THE GUCHA CATCHMENT PROBLEM.

Originating from Kiabonyoru area near Nyamira town, the Gucha catchment is located on the southwestern part of Lake Victoria drainage area in western Kenya. Gucha River is among the tributaries of the greater Gucha - Migori River whose total drainage area is 5180 km^2. The total area of the catchment is 2196 km^2 [6]. Considering the Gucha-Migori River system as a whole, the Gucha catchment constitutes approximately 42% of the total catchment area of the Gucha-Migori River system [6]. The catchment covers large parts of Kisii and Nyamira counties with only a small portion occurring in Migori district in the South Nyanza region.

The upper part of the Gucha River has been harnessed for water supply development for Kisii, Ogembo, and Keroka townships and other smaller towns, besides other domestic uses within the watershed. There are several small scale self-help and private water supply projects within the catchment. Population growth rate in this catchment is one of the highest in the country, being 2.75% per annum and poverty level of 51% [7]. The average population density of the larger Kisii district is 874.7 persons per km^2, with Nyaura location in Keumbu division having an extremely high density of 3,135 persons per km^2 [7]-Upper Gucha catchment lies in this location. It is important to note that, though Nyamira Town sits right at the source of the Gucha River it does not harness water from the Gucha catchment, but from the Sondu catchment. This may be attributed to topographical challenges.

It is extremely alarming that there is no primary vegetation to be found in most parts of the Gucha watershed with exception of the river line valley floors. This is due to the fact that the vegetation has been cleared by the inhabitants of the watershed to give way for cultivation of crops and settlement. Most of the current vegetation found in the catchment is of secondary. Recently, even the primary vegetation that occurred within the river valleys has been cleared as a result of swamp reclamation to accommodate the ever swelling population. The vegetation cover of the catchment consists of agricultural crops such as tea, coffee, maize, bananas, millet, beans, pyrethrum to some extent and eucalyptus (blue gum).

Apart from agriculture other activities such as brick making have sprung up within the watershed and may have serious environmental impacts on the watershed if not managed well. Besides being a source of building material, the watershed supplies fire wood not only to the locals but also to all tea factories in the area.

The main resources in the basin are fertile agricultural lands, vegetation (secondary) and water resources (surface water and groundwater). High rates of population expansion within the catchment create competition for resources hence pose a great danger to the water resources and watersheds. The examination of impacts due to population pressure on water resources is vital and will play an important role in devising future water resources planning and management strategies in the catchment [8]. Geospatial tools are critical the examination and identification of these impacts with a view to mitigate on them from an informed perspective.

It should be noted that most studies on this catchment did not demonstrate how the use of spatial technologies especially in the extent to which indigenous vegetation has been cleared with a view to quantifying what has been cleared of primary vegetation and which secondary vegetation has been brought in.

The study area is contained within three districts of the larger Kisii (Kisii, Gucha and Nyamira i.e. Kisii & Nyamira Counties). It comprises of an upland watershed of the Gucha River. The study area lies between longitudes 34˚ 37′ 00″ and 35˚ 01′ 00″ East and latitudes 00˚ 24′ 00″ and 00˚ 59′ 00″ South; The altitude of the area lies between 900 m and 2000 m above the mean sea level. Figure 1 shows the study area.

The area experiences two rainfall seasons within the year i.e. short rains that run from September to November and long rains that occur in February to June while temperatures range from 16˚ C and 27˚ C.

The main economic activity in the area is small scale farming among others, with tea and coffee as the main cash crops, and maize as the main stay stable food crop. But it is important to note that due to population pressure, people have resorted to other ways such as brick making to sustain their survival thus putting a lot of pressure on the environment especially the watershed if not controlled.

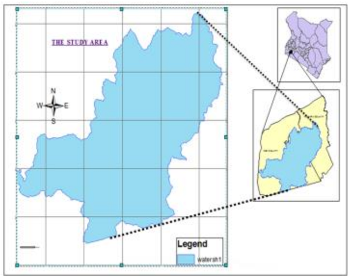

Figure 1(a). The Study Area within the larger Kisii.

III. MATERIALS AND METHODS.

The main objective of this study is to demonstrate how spatial technologies especially GIS and Remote Sensing can be used as tools in the conservation and management of water resources, specifically watersheds. The methodology employed in achieving this objective spans from data collection methods up to the techniques employed in the analysis of results upon which conclusions and recommendations are made as shown in figure 1(b) below. This includes the software used in the whole process.

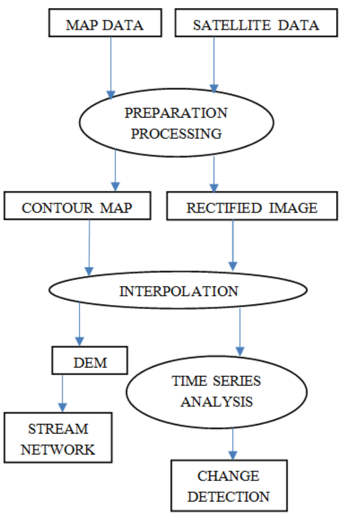

Figure 1(b). Flow Diagram

Topographical maps of Kenya scale 1:50,000 from the Survey of Kenya were used to generate contours of 20 m vertical interval after being geo referenced and made to be on the required and suitable mapping frame. This task was achieved through a digitization process, which is a technique of converting analogue data formats to digital formats. The result was digital contours of the study area. This formed a base map from which a Digital Elevation Model (DEM) of the study area in Figure 2 was generated, from which the contributing channels were extracted as shown in Figure 3.

The contributing river channels were identified from the DEM by performing a DEM filling process so as to remove sinks. A sink is a cell that does not have a defined drainage value associated with it. A flow direction matrix was generated to determine the ultimate destination of water flowing across the surface of the DEM, from which a flow accumulation was calculated and identification of pour points done. The contributing channels were mapped as shown in figure 3.

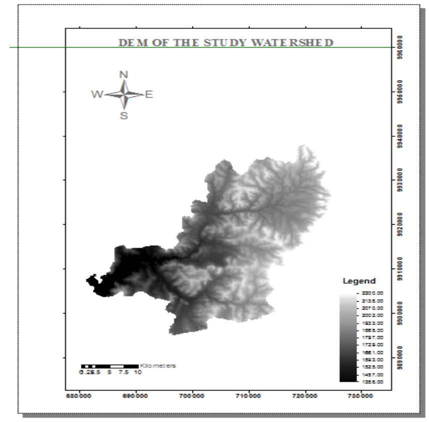

Figure 2. DEM of the Study area

For change detection, remotely sensed data, Landsat TM of 30m resolution images of the study area were acquired from the Regional Centre for Mapping of Resources for Development (RCMRD), Kenya. Land-sat images for the years 1990, 2000 and 2013 were used to carry out a time series analysis of the land cover/land use changes within the study area. These images were processed for corrections and rectification in terms of geometry, environmental distortions besides cloud cover. Further, they were processed and prepared using Remote sensing techniques in terms of subseting and mosaicking so as to identify and ensure good coverage of the area of study. Classification was done in the Erdas environment using nearest neighbour method. The classified images for the years 1990, 2000, and 2013 are shown in figure 4(a), (b) and (c) respectively.

Both the topographical maps and satellite imageries were prepared and processed using the ArcGIS and Erdas environments respectively to come up with the intended results upon which informed conclusions and recommendations were made.

IV. RESULTS AND DISCUSSIONS.

The upper Gucha watershed exhibits a dendritic drainage pattern which is the most common form of drainage pattern and looks like the branching pattern of tree roots as shown in Figure 3. This type of drainage pattern develops in regions underlain by homogeneous geological material. The subsurface geology has similar resistance to weathering so there is no apparent control over the flow direction of the tributaries. The shape of a drainage pattern is depended on the topography of an area, the type of soil and bedrock, the climate, and vegetation cover which are very important components of a watershed.

By understanding the type of drainage pattern, managers and those concerned with conservation will have easy time in deciding the conservation methods to be applied in conservation processes, thanks to GIS and Remote Sensing in generating water channels from a DEM and change detection analysis.

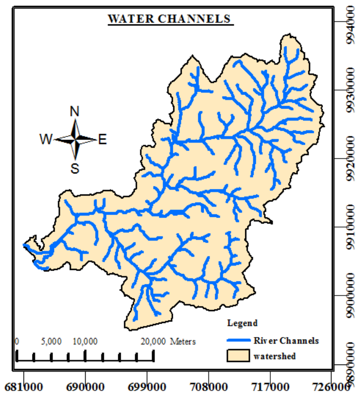

Figure 3. The Catchment and its Stream Network.

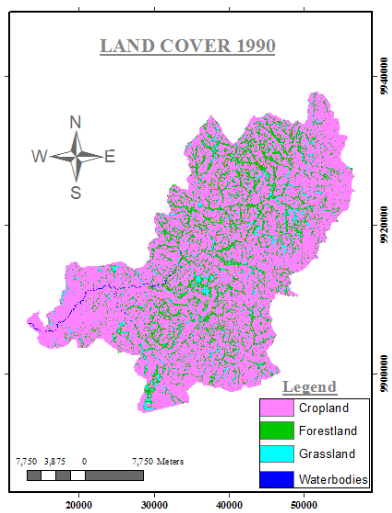

Figure 4(a). Land cover of the study area for 1990

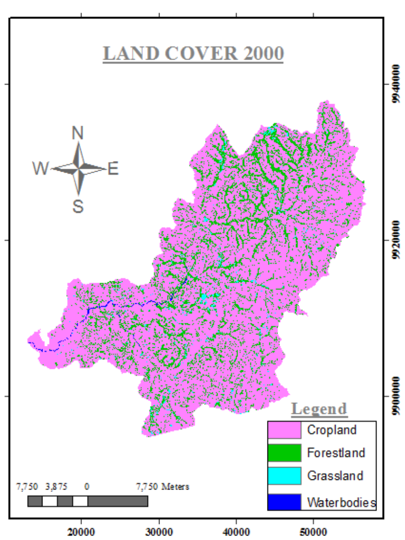

Figure 4(b). Landcover of the study area for 2000

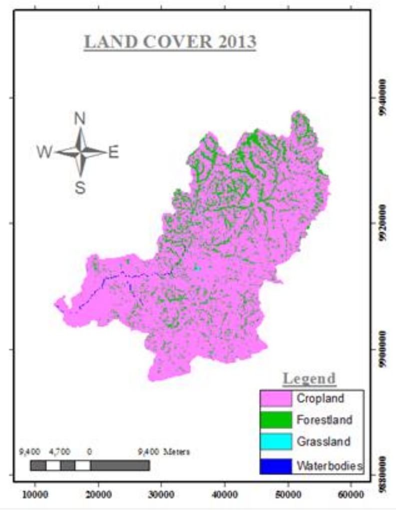

Figure 4(c). Land cover of the study area for 2013

Change detection is the measure of the distinct data framework and thematic change information that can guide to more tangible and reliable insights into underlying process involving land cover and land use changes. Digital change detection is the process that helps in determining the changes associated with land cover properties with reference to a multi-temporal remote sensing data [9]. It helps to identify change within a given area between two or more dates that is characteristic of a normal variation as shown in Figures 4(a), (b) and (c). These Figures represent the land cover of the same area (the upper Gucha catchment), but in different times i.e. 1990, 2000 and 2013. Spatial technology is capable of quantifying the changes as shown in table 1.

Table 1 shows different land covers within the upper Gucha catchment and how they have been changing over that given period. It is clear from the results that most land covers are rapidly changing to crop land, but most outstanding is that more forest land and grassland or open spaces are rapidly changing to crop land. The changes for forest land and Grass land are at 10.5% and 2.6% respectively for the period 1990 to 2013. However, curiously in total almost 0.06% of land changed from forest land to water bodies while 0.085% of land changed from water bodies to forest. This study may explain this phenomenon probably in terms of the brick making activities within the watershed, where, as the mining of soil to make bricks water collects in the resultant holes forming a dam like features. These dams are usually closed after the clay soil has been exhausted and then trees planted on them.

V. CONCLUSIONS AND RECOMMENDATIONS

This study presents the topograpical characteristics and the analysis of the impact of human activities on watersheds using GIS and Remote Sensing with a focus on the Upper Gucha Catchment.

Table 1. Land Cover change in hectares.

	1990 to 2000		2000 to 2013		1990 to 2013	
CHANGE	**Area (ha)**	**Area (%)**	**Area(ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Forestland to Water bodies	47.16	0.053	108.18	0.122	53.91	0.061
Forestland to Cropland	7,590.69	8.589	8,633.61	9.769	9,326.52	10.553
Grassland to Cropland	2,049.03	2.318	998.19	1.129	2,305.08	2.608
No Change	69,230.79	78.335	73,549.26	83.221	70,094.25	79.312
Cropland to Grassland	1,308.15	1.480	0.000	0.000	0.000	0.000
Cropland to Forestland	8,043.84	9.102	4,532.40	5.128	5,872.41	6.645
Water bodies to Forestland	108.72	0.123	50.31	0.057	74.7	0.085
Grassland to Forestland	0.000	0.000	506.52	0.573	651.51	0.737

The paper outlines an overview of environmental issues pertaining to watersheds, the relevance of GIS and Remote Sensing, the current trends and the state of the ecosystem within the watershed with regard to agriculture and urbanization. This is followed by an outline on the need to adopt an integrated water resource management system in the Upper Gucha catchment by employing the spatial technologies, with some emphasis on the growing threats posed by ecological degradation due to population pressures and widespread presence of environmental stressors. The others include the rise in socioeconomic activities especially the need for more agricultural land at the expense of forest land and open lands, impacting on the stability of natural ecosystems.

Several conclusions can be drawn from this study. Despite the increase in the demand for agricultural space at the expense of other environmental drivers, the use of GIS, Remote Sensing and descriptive statistics point to a mix of gains and declines in some of the environmental components. Agricultural activities form the large part of land cover of the Gucha catchment region [9]. Though there exists competition between agricultural activity and other components over space, the study finds 'no danger' in terms of land cover issues in the watershed as pertains to the general climatic change (since agriculture is land cover). Indeed this may explain why this region has been having almost consistent seasons in this era of climatic change. However, agriculture has got its own challenges especially in terms of inputs and methods practiced. This call for concerted efforts to identify vulnerable spots especially slopes, swamps and vallies so that they can be rehabilitated and conserved. This can only be achieved by raising the spectra of responsibilities for planners and those charged with watershed management in the counties of Nyamira, Kisii and neighbouring counties along which the watershed traverses.

Spatial technology and its ability to locate environmentally vulnerable spots in time and space, analyzing the spatial diffusion of ecological stressors known to influence watershed impairment in the Upper Gucha catchment in various ways will continue to be easy, fast and effective. Accordingly, GIS and Remote Sensing techniques as used here provides decision support mechanism for managers in the assessment of environmental risks prompted by human activities along not only in the Upper Gucha but also in other watersheds. From the analysis on the Upper Gucha, the negative environmental impacts ravaging the watersheds by human activities appear predicated on pressures from demography, intense farming and the proliferation of urban development, besides externalities from municipal and industrial activities.

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