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Analysis of Land Use/Land Cover Changes Using GIS and Remote Sensing Techniques in River Ruiru Watershed, Kiambu County, Kenya

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Abstract Watershed management and water resource planning require accurate measurements of the past and present land use and land cover data to determine hydrological and ecological processes taking place. This study aimed to establish the extent of land use and land cover changes that have occurred in River Ruiru watershed in Kiambu County from 1976 to 2017. The study integrated the use of remote sensing data and GIS techniques to collect and analyse collected data. Three multi-temporal LANDSAT imageries of 1976, 1995 and 2017 were used. Supervised classification-maximum likelihood algorithm in ArcGIS 10.4.1 was employed. Results from the study indicated that built-up areas, annual crops and perennial crops (tea and coffee) increased by 3.068%, 35.848% and 11.493% respectively between 1976 and 2017. However, it was observed that perennial crops increased gradually between 1976 and 1995 but declined by 1.94% between 1995 and 2017. During the same period, between 1976 and 2017, grassland, shrubland and forestland declined by 7.48%, 13.25% and 29.79% respectively. The findings from this study will enable the quantification of change and analysis of the direction of change between various land use/land cover types that have occurred in River Ruiru watershed from 1976 to 2017 hence enabling the assessment of watershed hydrological vulnerabilities resulting from land use/land cover change. The data from this study will provide critical input to decision making on water resources management and planning. This will aid in the management of water resources on a watershed basis thus addressing the potential impacts and deterioration of water resources.

Keywords: *land use change, land cover change, GIS, remote sensing, River Ruiru watershed*

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1. Introduction

It is estimated that land use and land cover change has affected almost a third (32%) of the global land area in six decades between 1960-2019 [1,2]. Moreover, about three quarter of the earth's surface has been altered by humans within the last millennium [3,4]. Consequently, land use/land cover changes associated with human activities and natural factors compromise many ecosystems including watersheds of important rivers [5,6]. These changes have significant impacts on the functioning of socio-economic and environmental systems with important tradeoffs for sustainability, food security, biodiversity and socio-economic vulnerability of people and ecosystems [7-9]. However, despite its significance, understanding how land use and land cover have changed in space and time is limited by shortage of comprehensive data [10,11].Therefore an investigation of these changes provides a baseline requirement for planning and sustainable management of natural resources [12,13].

In Kenya, various river catchments and water towers have been gradually characterized by human settlement, deforestation, wetland reclamation and unsustainable agricultural activities [14,15]. This has accelerated the unprecedented changes in the ecosystem and environmental processes in the country [16,17]. River Ruiru watershed which traverses rural, urban and peri-urban areas is characterized by high population growth, movement of people move from rural to urban environment especially in Ruiru Municipality, higher demands for food security as well as increased agricultural, industrial and quarrying activities. Moreover, the influence of the city of Nairobi has also led to tendency towards land use change from agricultural to commercial and settlement, especially within the urban centres [18]. Therefore, to ensure sustainable development in the watershed, it is necessary to monitor the ongoing process on LULC pattern over a period of time. Information about land use and land cover change is also essential for a better understanding of relationships and interactions between humans and natural environment in the watershed.

River Ruiru watershed is also an important water resource as it includes Ruiru 1 and the proposed Ruiru 2 dams important for inter-basin water transfer to Nairobi City County. This is due to the fact that the towns around the city of Nairobi that share water resources from the Aberdares are among the worst hit by water scarcity resulting from the ever increasing demand. The capacity of water resources in the headwater regions has been declining with time due to a number of factors including catchment degradation and reduced rainfall to recharge the sources [18,19]. River Ruiru is also one of the major perennial tributaries of River Athi which provides water to the population in the vast semi-arid parts of Kenya for various purposes before discharging into the Indian Ocean.

These rapid and intense changes in land use and land cover have created the need to quantify them so that we can understand and leverage this information to the best way possible. It is also critical in formulating alternative future landscape scenarios to improve environmental conditions [20,21]. Remote sensing and Geographic Information System are powerful, cost-effective tools for assessing spatial and temporal land use and land cover changes [22,23]. The use of these geospatial analysis techniques provide accurate, timely and detailed information for detecting and monitoring changes in land use and land cover [24-26]. By integrating remote sensing and GIS techniques, it is possible to analyze and classify the changing pattern of land cover for a long period and understand the changes within the area of interest. These techniques also allow for the study and manipulation of geographic information for large areas easily and effectively [27]. The potential of satellite based data as a basis for generating valuable information for land use/land cover is widely recognized as they serve a great deal in classification of different landscape components at a larger scale [27,28].

2. Materials and Methods

2.1. The Study Area

The study area was River Ruiru watershed which has an area of 484.515 km^2 [29]. The area has a population of 671,646 persons [30]. It lies between longitude 36°40’E and 37°00΄E and latitude 1°10΄S and 0°50΄S. River Ruiru originates from Kikuyu plateau and drains to the southeastern slopes of the Aberdare ranges in Kiambu County.

River Ruiru watershed is hydrologically located within the Athi Basin 3BC sub-basin. The watershed is covered by a well distributed dense lateral river network. It is located in medium rainfall potential area of Athi Basin with moderate and reliable rainfall [31]. The mean temperature is 26°C with temperature ranging from 17.1°C in the upper highlands to 34°C in the lower midlands. Ruiru River is the major river in the watershed with its main tributaries being Makuyu, Gatamaiyu and Komothai [18].

River Ruiru watershed has four dominant land cover types which include trees, settlements, grasslands and croplands [31]. The land cover has high temporal variations with the wet season exhibiting high vegetation cover (high biomass) and the dry season exhibiting very low vegetation cover (low biomass). The upper part is predominantly forested but is currently threatened by encroachments into the forest area. The area has an undulating landscape, with steep valleys where the rivers cross. The land use potential may be described according to the country’s agro-ecological zones which may be categorized as medium to high potential falling under zones UM3, UM2, UH1, UH0, UM1, UM5, UM4 and LH1 as in Figure 1 [32,33].

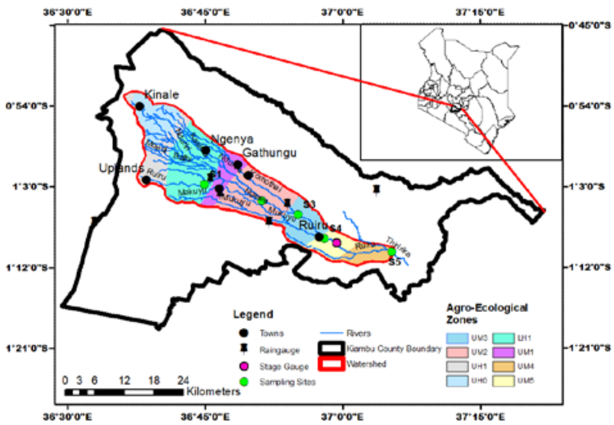

Figure 1. River Ruiru watershed

2.2. Data Collection Techniques

Land use data of four landsat MSS, TM and OLI/TIRS images for 1976, 1984, 1995 and 2017 were obtained from USGS-Earth explorer (http://www.earthexplorer.usgs.gov/) website in Geotiff format as shown in Table 1. Multi-temporal analysis of satellite images is effective for change analysis because of high correlation between imagery spectral variation and land use change [34,35]. To avoid uncertainties, clouds and possible errors emanating from seasonal differences between time points, the selected images were acquired within the dry seasons of the year (December-January-February-March). It has been recommended that by using dry season images, there will be reduced confusion at forest edges between dense forest vegetation and small-scale agricultural plots [36,37]. Landsat imagery was used due to its longest history of service with a relatively high spatial resolution and its wide application for land cover classification across the world [38]. The use of these new data with higher spatial resolutions have the potential of more accurate analysis [39,40].

Table 1. Satellite image metadata and date of acquisition

Year	Acquisition date	Sensor ID	Path	Row	Producer	Resolution
1976	11/02/1976	MSS	180	061	USGS	80m
1995	30/01/1995	TM	168	061	USGS	30m
2017	28/12/2017	OLI-TIRS	168	061	USGS	30m

2.3 Land Use Change Analysis

Spatial extent of Ruiru watershed was done through ArcGIS 10.4.1 functions based on 1976, 1995 and 2017 landsat images. Three bands B2, B3 and B4 representing the RGB colours were imported into the ArcMap. A composite of the three bands was formed using the image analysis tool. The study area was extracted through masking in the arctool box then projected into UTM WGS 1984 southern hemisphere zone 37S. Training samples were then created based on different colours of the study area, landsat images and the signature file. Land use classification was done using image classification tool - maximum likelihood classification method. False colour composites (Bands 432) were used for the visual examination and interpretation of the images. Maximum likelihood classification method was used as it is the most widely used per-pixel method which takes into account spectral information of land cover classes [41]. The maximum likelihood decision rule is based on the probability that a given pixel belongs to a specific class [42] and that the statistics for each individual class in each band is evenly distributed.

To prepare land use and land cover maps from satellite images, a classification scheme that defines the land use and land cover was considered. The number of LULC classes are based on the requirement of a specific project for a particular application [43,44]. The images were classified into seven land use types using supervised classification based on land use/land cover classification system [45]. These land use types include built-up areas, annual crops, plantation (tea and coffee), grassland, shrubland, forestland and waterbody.

3. Results and Discussion

Figure 2 indicate that River Ruiru watershed experienced land use/land cover change from 1976 to 2017. Built-up areas increased by 3.07% from 0.69%, 2.16% and 3.76% from 1976, 1995 and 2017 respectively. In the same period, annual crops increased by 35.85% from 10.79%, 38.12% and 46.63%. Perennial crops (Tea and coffee) increased by 11.49% from 4.67% and 18.10% between 1976 and 1995 but declined to 16.16 % between 1995 and 2017. Areas under water bodies slightly increased in the area by 0.1% from 0.21%, 0.29% and 0.31%. In the same period, forestland declined by 29.79% from 56.42% in 1976, to 30.0% in 1995 and to 26.63% in 2017. Similarly, grasslands and shrublands declined by 7.48% and 13.25% respectively from 12.55%, 6.03% to 5.07% and from 14.68%, 5.3% to1.43% between 1976, 1995 and 2017.

The increase in built-up areas, perennial and annual crop farming could be due to population increase in the area and expansion of agricultural land. The observed decline in perennial crops between 1995 and 2017 could have been contributed by the conversion of coffee estates into residential and commercial lands and conversion into annual crops. This conversion was attributed to low coffee prices in the international market. The decline in forestland, shrubland and grassland could be due to increased demand for residential, commercial and agricultural land.

A kappa coefficient of 79 % and an overall accuracy of 82% were achieved for the 2017 land use/land cover classification indicating a high agreement between the classified image and the reference image. Kappa coefficient ranges from 0 to 1 and values higher than 0.7 are considered acceptable while those equal or lower than 0.4 identify a very low correlation between the classified image and the ground truth [46]. According to [47] a kappa value higher than 0.5 can be considered as satisfactory for modelling of land use change. Similarly [48] characterized agreement for the kappa coefficient as follows; values > 0.79 are excellent, values between 0.6 and 0.79 are substantial and values of 0.59 or less indicate moderate or poor agreement. Equally [49] affirms that a K>0.8 is usually considered as a strong agreement and good accuracy while the acceptable threshold for overall accuracy according to USGS classification is 75%. According to (50) such results can be used to study the spatial and temporal patterns of LULC change and evaluate its long-term hydrological impacts.

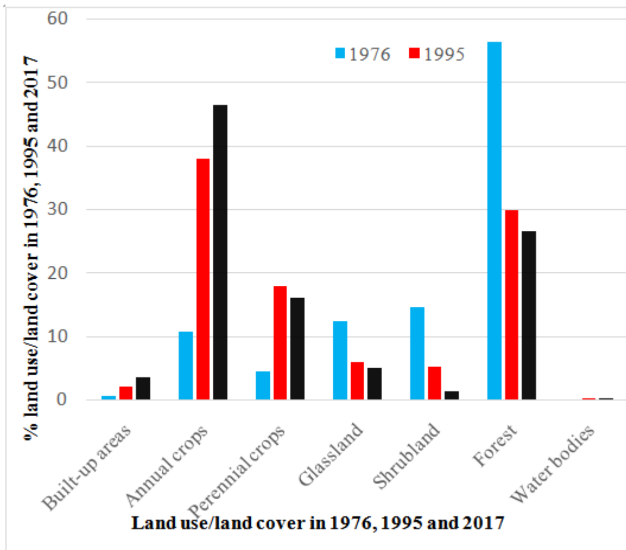

Figure 2. Land use/land cover in 1976, 1995 and 2017

These results are consistent with study findings by [51] in his study on the influence of geomo-hydrometric characteristics and land use/land cover change on water resources management in River Gucha-Migori catchment who observed that between 1986 to 2008 towns and large cultivated areas increased from 21.5 km^2 and 37.1 km^2 to 39.0 km^2 and 56.5 km^2 respectively while closed forests, open grasslands, closed shrubs and open shrubs decreased from 40.7 km^2, 41.2km^2, 211.9 km^2 and 1313.8km^2 to 28.0 km^2, 25.0 km^2, 74.5 km^2 and 268.6 km^2 respectively. Correspondingly [52] in a study on land use cover change and classification in Chaohu lake catchment observed that built-up areas increased from 3.5% in 1979 to 25.1% in 2015. Similarly, the agricultural land use increased from the area coverage of 29.8% in 1979 to 45.2% in 2015 while forested/vegetated land of the catchment substantially decreased during this period, from 59.8% in 1979 to 22.9% in 2015. Further [53] in their study on the effect of rainfall variability and land use and land cover change in a small tropical river basin observed that between 2000 and 2016 forest and shrub cover increased by 5%, built up areas increased by 35%, tea increased marginally by 5% while coffee decreased by 38%.

Findings from the current study are also comparable with the findings by [54] who assessed land use/land cover change in Makueni County and found out that evergreen forests decreased the most from 39% coverage in 2000 to 17% coverage in 2016. Similarly, [55] while evaluating land use/land cover change in Bhimtal Lake catchment observed that during the last 20 years (1995-2015), the settlement area increased from 9.70% to 18.38%, agricultural area has increased from 44.32% to 47.63% while the forest area decreased from 43.58% to 31.47% in their study area. Consequently, [56] in their study on land use change mapping and analysis in Sinily watershed concluded that land use and land cover shift in the watershed was evidenced by the decline in the area of vegetation and water class by 38.2% and 74.3% respectively and augmentation of area covered by classes of settlements by 80.1%, agricultural by 163.7% and barren land by 63.3%.

4. Conclusion

The findings from the study indicated that built-up areas, perennial and annual crop farming increased by 3.07%, 11.49% and 35.85% respectively in River Ruiru watershed for the last 41 years from 1976 to 2017. However, it was observed that between 1995 and 2017 perennial crop farming declined by 1.94%. In the same period, forestland, shrubland and grassland declined by 29.79%, 13.25% and 7.48% respectively due to increased demand for residential, commercial and agricultural land. Remote sensing and GIS techniques provided powerful and effective tools for analyzing land use and land cover change. By comparing each classified map with the successive, it was possible to determine land use and land cover change in River Ruiru watershed. In conclusion, River Ruiru watershed has experienced land use/land cover changes.

Statement of Competing Interests

The author has no competing interests.

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