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Assessment of Land Cover Changes in the Micro-Catchments of the Nyando River Basin within the Lake Victoria Basin, Kenya

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Abstract

The Nyando and Awach river catchments serve as vital headwaters draining into the Winam Gulf of Lake Victoria, an ecosystem increasingly threatened by sediment and nutrient loading. Despite its crucial role in regional hydrological stability, this region has undergone immense, largely unregulated anthropogenic pressure, leading to suspected widespread environmental degradation. The lack of long-term spatial data on the nature and level of land cover conversion constitutes a major barrier to formulating effective conservation strategies. To address this gap, this study quantified the extent, magnitude, and spatial dynamics of Land Cover Change (LCC) to assess the actual scale of environmental degradation. LCC was quantified through a time-series analysis of LANDSAT TM/ETM satellite imagery (1995, 2000, 2006, and 2012). A comparative micro-catchment classification (Uninterfered, Interfered, and Intervened sites) provided the environmental sampling framework. Images were processed using a Hybrid Supervised Classification approach to delineate four key thematic classes: Vegetation, Built-up Land, Water, and Open Land. Change detection matrices were then generated to calculate the absolute change, rate of change and conversion pathways. The results revealed significant vegetation decline in the Nyando catchment, characterized by a net loss of 54.2% of vegetative cover over the 17-year period. This loss corresponded with a marked increase in Open Land (≈41.5%) and Built-up Area (≈14.3%). The dominant conversion pathway, accounting for approximately 40.9% of all change, was the direct transformation of Vegetation to Open Land, signifying widespread, non-conservative agricultural expansion in the highlands. However, the Awach catchments registered comparatively lower net change, largely due to the replacement of indigenous forests with commercial plantations, which concealed ongoing ecological degradation. The significant expansion of exposed Open Land critically increases the risk of soil erosion and intensifies runoff, posing a serious threat to the hydrological stability of the basin and contributing to sediment loading in Lake Victoria. Urgent policy interventions focused on mandating soil conservation practices, regulating settlement expansion and immediate rehabilitation of riparian zones are necessary to reverse these detrimental trends and ensure the sustainable use of basin resources.

Keywords: Land Cover Change, Nyando River Basin, Micro-catchments, Satellite Imagery, Land Degradation, Lake Victoria Basin

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Introduction

Lake Victoria is the world's second largest freshwater lake and the largest in the world (Awange, 2021). It covers an area of about 69,000 km^2, spanning 400 km north-south and 240 km east-west. Lake Victoria touches the equator in its northern reaches, and is a relatively shallow lake for its area, with an average depth of only 40m, and a maximum depth of about 80m (Renaut & Owen, 2023). The lake's shoreline is long (about 3,500km) and convoluted, enclosing many small, shallow bays and inlets, as well as wetlands, all of which differ a great deal from each other and from the lake itself (Muyodi, Bugenyi & Hecky, 2010). The lake has a wide land catchment area of about 193,000km^2, which extends into five countries; Burundi, Kenya, Rwanda, Tanzania, and Uganda and supports a large number of inhabitants (Awange, 2021). The catchment has different reliefs, with highland areas dominating areas far from the lake, and lowlands near the lake. The northern part of the lake, particularly in Uganda, is lower than the lake and that is where the outlet to the Nile River system starts. The highlands in these regions feed most of the lake's tributary rivers. The riparian population had reached roughly 40 million due to high growth rates (Muthoka et al., 2024). This demographic pressure drives intense human activities, including agricultural expansion and industrial activity, which severely threaten river and lake water quality if not carefully managed.

Although Kenya contributes the smallest portion of Lake Victoria's surface, its catchment supplies about 42% of the lake's total inflow. This makes land use activities in Kenya's portion particularly significant for downstream water quality, biodiversity, and livelihoods, especially in Winam Gulf, which lies entirely within Kenya (Awange, 2021). The Lake Victoria drainage basin is one of Kenya's five main basins and is home to nearly half of the country's population. It is endowed with abundant water, fertile soils, and natural resources, but faces rapid land cover change due to agriculture, settlement expansion, and industrialization (Onganya, 2023). To support sustainable management, the basin is divided into the Lake Victoria North and South Catchment Areas. The Kenyan portion covers 42,460 km^2 and includes entire counties such as Migori, Homa Bay, Kisii, Nyamira, Kisumu, Siaya, Busia, Vihiga, Kakamega, Bungoma, Trans Nzoia, Uasin Gishu, Nandi, Kericho, and Bomet, as well as parts of Narok, Nakuru, Elgeyo-Marakwet, and West Pokot. The basin provides water for domestic, agricultural, and industrial use, supports fisheries and biodiversity, and has substantial hydropower potential already harnessed for electricity supply.

Despite these resources, population growth, urbanization, and intensified agriculture have led to declining water quality in the basin. Poorly managed agricultural and industrial activities have increased pollution loads, sedimentation, and nutrient inflows into rivers, causing adverse changes in the lake ecosystem (Ngodhe, 2021). Over the past five decades, effects such as eutrophication, massive algal blooms, spread of waterborne diseases, and invasion of water hyacinth have been reported (Miruka et al., 2021). The spread of hyacinth continues to block waterways and water intakes, while increased suspended solids raise water treatment costs. Since the early 1990s, land use changes have accelerated environmental degradation and undermined the natural resource base. The Kenyan catchment has several rivers, including seven major ones (Sio, Nzoia, Yala, Nyando, Sondu-Miriu, Kuja-Migori, and Mara) as well as smaller but important rivers such as Awach Seme, Kibos, Awach Kano, Awach Kibuon, and Awach Tende. Originating from highland springs and streams, these rivers transport water, sediments, and nutrients downstream into Lake Victoria, directly linking land cover change in the catchments to lake health and ecosystem stability (Masese et al., 2020).

The Nyando River, the primary focus of this study, is a vital freshwater source and the third largest catchment (3,652km2) on the Kenyan side of the Lake Victoria drainage basin. It is characterized by two distinct terrains: the rugged highland areas (Nandi and West Mau Forests), which have high annual rainfall (1000mm–1600mm) and well-drained soils (Gathenya et al, 2011), and the lowland Kano-plains, which feature unstable black cotton soil and are prone to seasonal flooding (Ocholla, 2010). The catchment is subjected to intensive and extensive land use, including tea, maize, and sugarcane farming. River Nyando is consequently known to carry the highest suspended sediment load compared to other rivers in the Lake Victoria basin, largely due to the severe environmental degradation arising from poor land use practices, agro-industrial effluent discharges, and land cover loss (Kenge, 2009).

The degradation issue extends across the basin, notably within the Awach river systems. The South Awach system, including the Awach Kibuon and Awach Tende Rivers, is particularly affected (Mibey, 2022). These rivers originate from the Kisii highlands, an area characterized by high rainfall, steep slopes, and among the highest population densities in the basin (665people/km2 to 875people/km2; KNBS, 2010). The intensive cultivation of small plots without adequate soil conservation, coupled with widespread forest and wetland destruction for settlement and agriculture, accelerates the loss of topsoil. The consequences of this basin-wide environmental degradation particularly the destruction of forests and wetlands, which comprise the remaining natural vegetation are serious. Despite several conservation initiatives, the extent and patterns of land cover change within the micro-catchments of the Nyando Basin remain underexplored. Limited research has specifically quantified the rate and nature of vegetation loss, at a micro-catchment scale over time. This gap undermines the development of targeted interventions to safeguard ecological stability and water resources. Therefore, this study seeks to assess the levels of land cover change in the micro-catchments of the Nyando River Basin within the Lake Victoria Basin, Kenya.

Methodology

Study Area

The study area covered selected micro-catchments within the upper River Nyando basin, as well as Awach Kano, Awach Kibuon and Awach Tende rivers, where representative stations were selected. River Nyando is one of the main rivers within the Kenyan side of the Lake Victoria drainage basin and drains into Winam Gulf of the lake the same as the Awach River systems (Ogola, Mogwasi & Olale, 2023). The Winam Gulf of Lake Victoria where these rivers discharge has a total catchment area of about 12,000km^2.

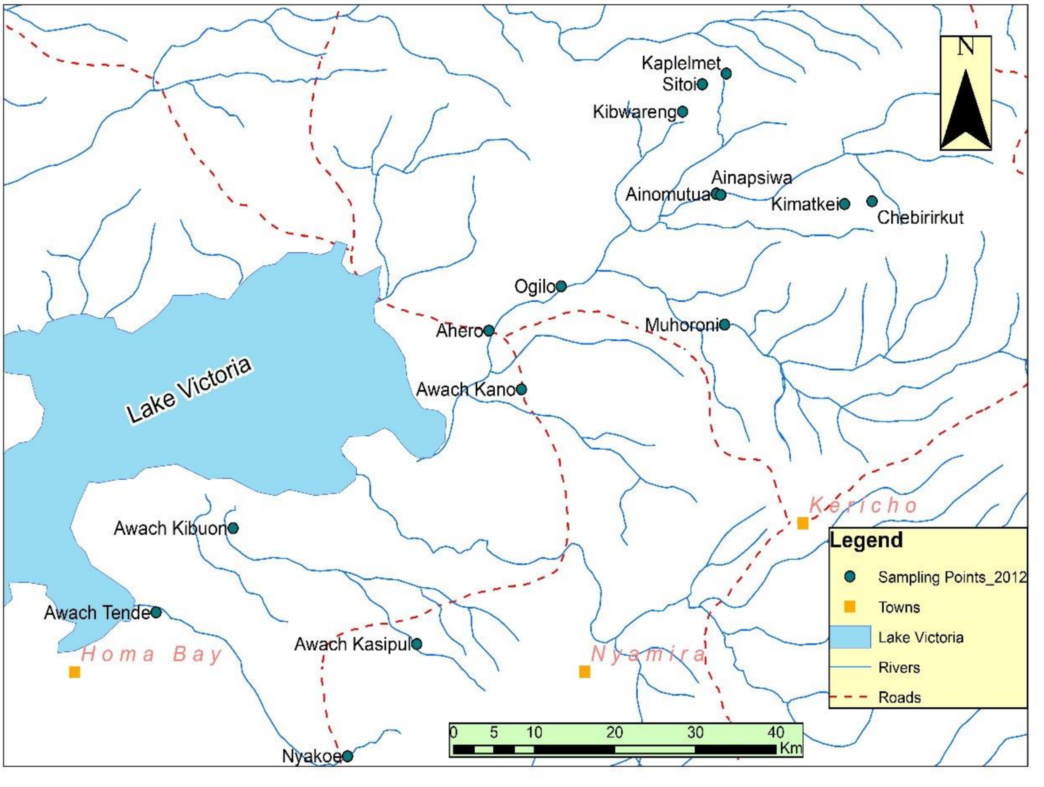


Figure 1: Map of the study area and the sampling stations

The Gulf has a length of about 70km and a width varying from 6 to 30km with a mean depth of about 10m and a maximum depth of 23m. The rivers that discharge into the gulf include Awach Seme, Kibos, Nyando, Awach Kano, Sondu/Miriu, Awach Kibuon and Awach Tende as well as other small streams. All the sampling stations of the micro-catchments of river Nyando as well as the stations on the main tributaries of Nyando River together with the stations along rivers Awach Kano, Awach Kibuon and Awach Tende are indicated in Figure 1.

Micro-Catchment Classification

To establish a clear spatial framework for measuring LCC, five micro-catchment sites were selected based on a classification of their distinct land cover status. This provided a natural experimental gradient of human intervention. Sites were categorized into three groups: Uninterfered Sites served as controls, representing areas where the natural forest or vegetation cover was still intact and disturbance was minimal (e.g., Chebirirkut and Sitoi). The second category, Interfered with but not Intervened Sites, showed substantial land cover loss due to uncontrolled activities, such as clearing vegetation for extensive maize farming, heavy livestock grazing, and poor agricultural practices that left the soil exposed (e.g., Kimatkei and Kibwareng'). Finally, the Interfered with but Intervened Site was selected to evaluate LCC reversal, representing degraded areas undergoing active rehabilitation through reforestation and the implementation of soil conservation structures (e.g., Kaplelmet). This rigorous classification ensured the captured remote sensing data reflected varying degrees of historical and ongoing land use intensity.

Remote Sensing Data Acquisition

The assessment of long-term changes in land cover relied on a comprehensive time-series analysis using LANDSAT TM/ETM satellite imagery covering an approximately 17-year period from 1995 to 2012.

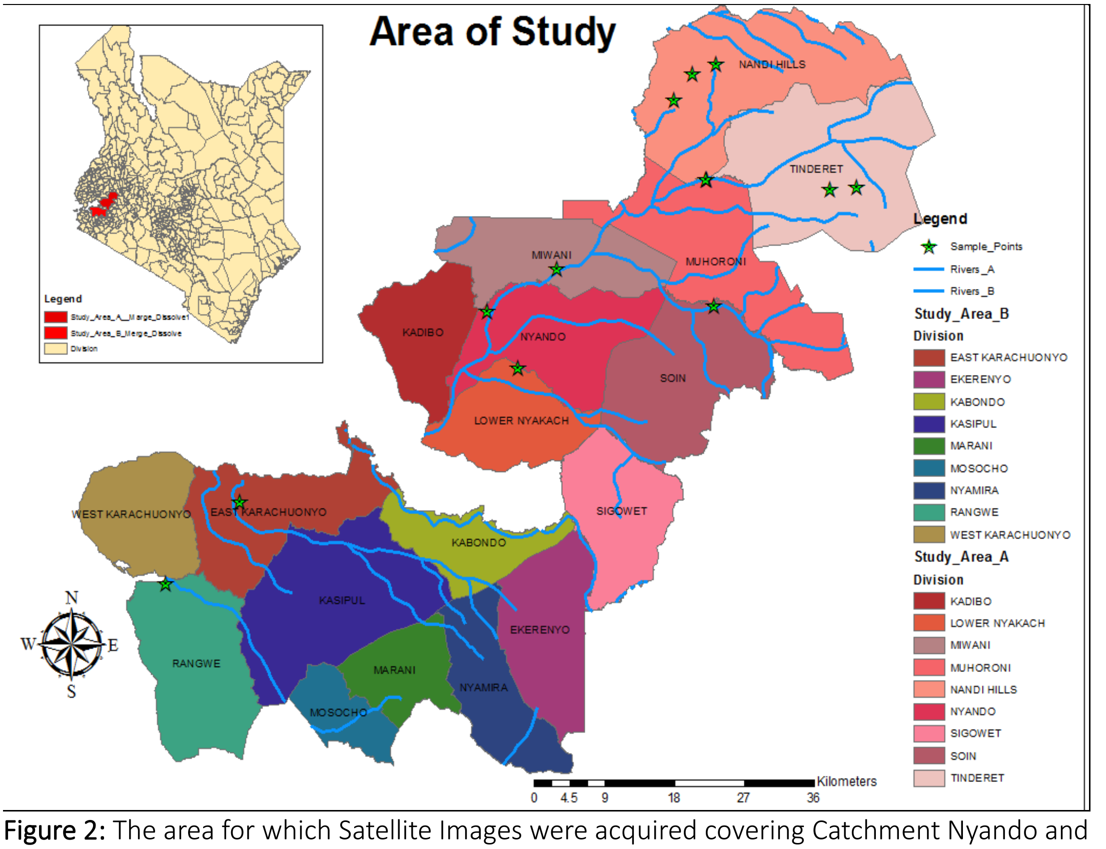


Figure 2: The area for which Satellite Images were acquired covering Catchment Nyando and Awach Rivers

Images were specifically acquired for four key time steps: 1995, 2000, 2006, and 2012. The selection process was highly rigorous, prioritizing images acquired during the dry season (January to early March). This specific temporal window was chosen because it ensured maximum contrast among different land use types, particularly exposing bare or cleared agricultural land and minimizing false change results that could arise from seasonal shifts in vegetation cover or high soil moisture content during rainy periods. This guaranteed that the analysis captured the maximum extent of permanent, human-induced land conversion over nearly two decades. The area for which these satellite images were acquired, covering the full extent of the Nyando and Awach river catchments, is illustrated in Figure 2.

Satellite Image Pre-processing

Before analysis, the acquired images underwent several critical pre-processing steps to ensure geometric and radiometric accuracy. Atmospheric Correction was performed to remove the influence of the atmosphere, such as water vapor and aerosols, which is necessary to produce an estimate of the true surface reflectance a key factor for accurate change detection.

Figure 3: Nyando and Awach Kano Catchment

Pan Sharpening was then applied to fuse the lower-resolution multispectral bands with the higher-resolution panchromatic band, enhancing the spatial resolution from 30m to 15m to better delineate small-scale features within the micro-catchments. The images were subsequently subjected to Geo-referencing in ArcGIS to correct any existing spatial shifts, followed by sub-setting the data. Sub-setting utilized detailed shape-files to precisely define the study boundary, ensuring the analysis was focused strictly on the Nyando and Awach catchment areas. The finalized, processed area of study covering the primary region of LCC analysis (Nyando and Awach Kano catchments) is shown in Figure 3.

Image Classification and Thematic Change Detection

The core LCC analysis was executed using a Hybrid Classification approach, combining initial unsupervised clustering with a rigorous Supervised Classification using the Maximum Likelihood algorithm. This approach utilized training samples to group pixels into four distinct, relevant land cover classes: Built-up Land, Vegetation (representing forest cover, plantations, and dense cultivation), Water, and critically, Open Land (representing cleared agricultural land or bare ground highly susceptible to erosion). An example of the classified output for the base year, showing the spatial distribution of these thematic land covers, is presented in Figure 4.

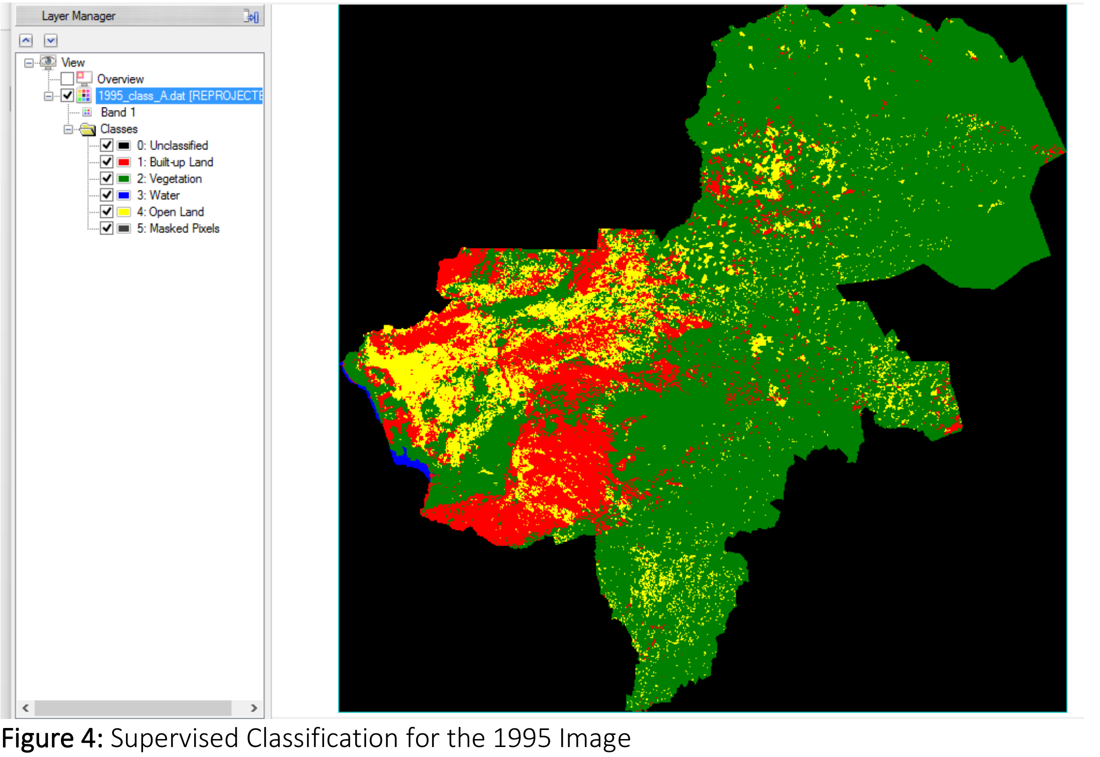


Figure 4: Supervised Classification for the 1995 Image

The classified thematic maps for all four time steps were then used for Thematic Change Detection. This process involved a post-classification comparison that generated a quantified, pixel-by-pixel map and statistical data, precisely measuring the area of increase or decrease for each LCC class between 1995 and 2012. This step quantified the magnitude and location of land cover loss and conversion across the catchment basins, forming the quantitative basis for the study.

Data Analysis and Presentation

The analysis of the quantified LCC data focused on determining the extent, magnitude, and pathways of land cover conversion. The first step involved Areal Extent Calculation, determining the surface area (km2) occupied by each of the four LCC classes for all four time steps to track absolute changes. A detailed Thematic Change Detection Matrix was then generated, quantifying the "From-To" conversions (e.g., the precise area converted from Vegetation to Open Land) across the entire study period. This matrix was essential for understanding the specific dynamics of land degradation. To standardize comparison, the annual Rate of Change (RateLCC) for each class was calculated using the formula:

$$\mathrm{Rate}_{\mathrm{LCC}} = \frac{A_2 - A_1}{T_2 - T_1}$$

Where;
A1 and A2 are the areas of the LCC class at time T1 and T2, respectively.
Complementary visual aids included Bar Charts and Line Graphs showing the total area (km2) of each land cover class at the four time steps, highlighting the significant decline in Vegetation and expansion of Open Land. Finally, comprehensive Transition Tables presented the detailed transition matrices, allowing for an accurate breakdown of the LCC pathways and confirming that the dominant process in the micro-catchments was the widespread conversion of natural land cover to exposed agricultural land.

Results

Levels and Magnitude of Land Cover Change (LCC) for the Micro-Catchments

The analysis of LANDSAT satellite imagery spanning 1995 to 2012 revealed significant, widespread Land Cover Change (LCC) within the Nyando and Awach river catchments, primarily characterized by a dramatic loss of vegetative cover and a simultaneous expansion of open land and built-up areas. The classification scheme defined the land cover thematic units as: Vegetation (Green), Built-up Land (Red), Water (Blue), and Open Land (Yellow). The thematic classification results for the main study area (Sub-area A, encompassing the Nyando catchment) for the four time steps are sequentially presented in Figure 5 (1995), Figure 6 (2000), Figure 7 (2006), and Figure 8 (2012), visually demonstrating the rapid conversion of land use patterns.

Classification results for Location A

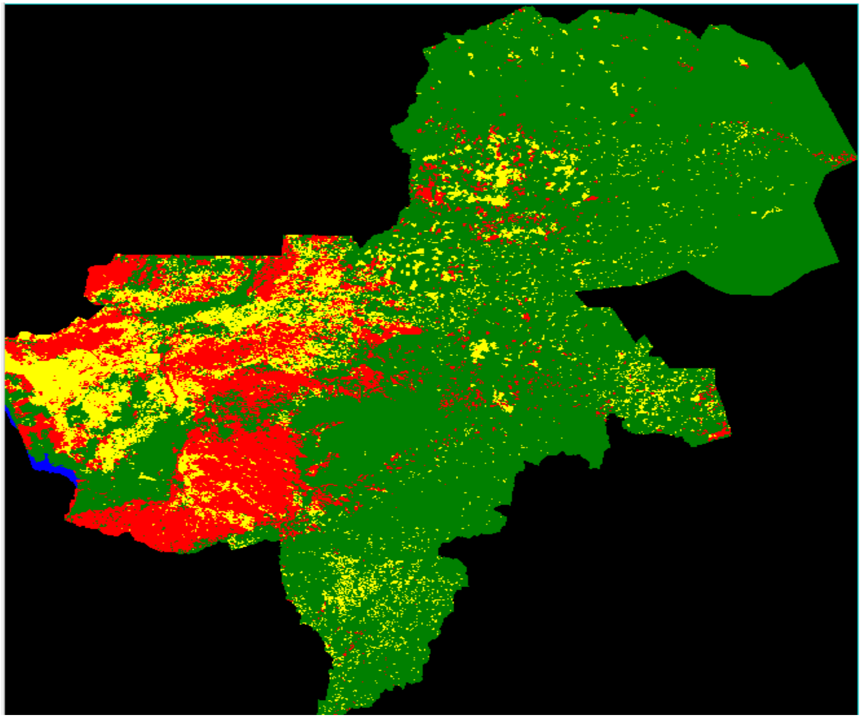
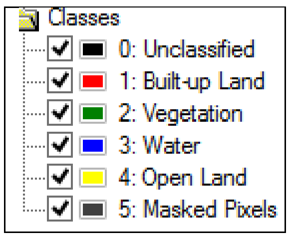


Figure 5: Analysis for Area A, 1995



Theme/ Land Cover	AREA (M²)	PERCENT
Unclassified	610477.51	0.024862
Built-up Land	366577420.80	14.929201
Vegetation	1792342267.25	72.994779
Water	5780738.62	0.235426
Open Land	290128092.43	11.815732

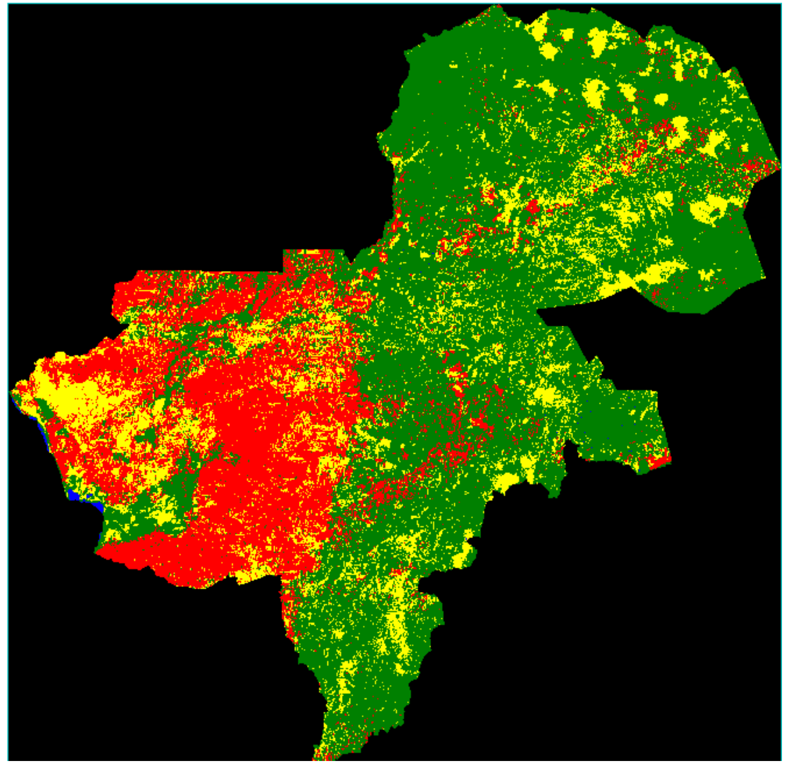
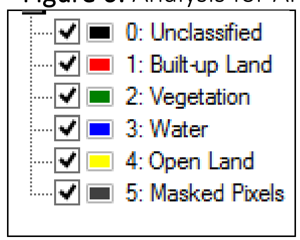


Figure 6: Analysis for Area A, 2000



Land Cover/Theme	AREA (M²)	PERCENT
Unclassified	287100.00	0.011695
Built-up Land	566142975.00	23.062031
Vegetation	1434858975.00	58.449480
Water	3237075.00	0.131863
Open Land	450344250.00	18.344930

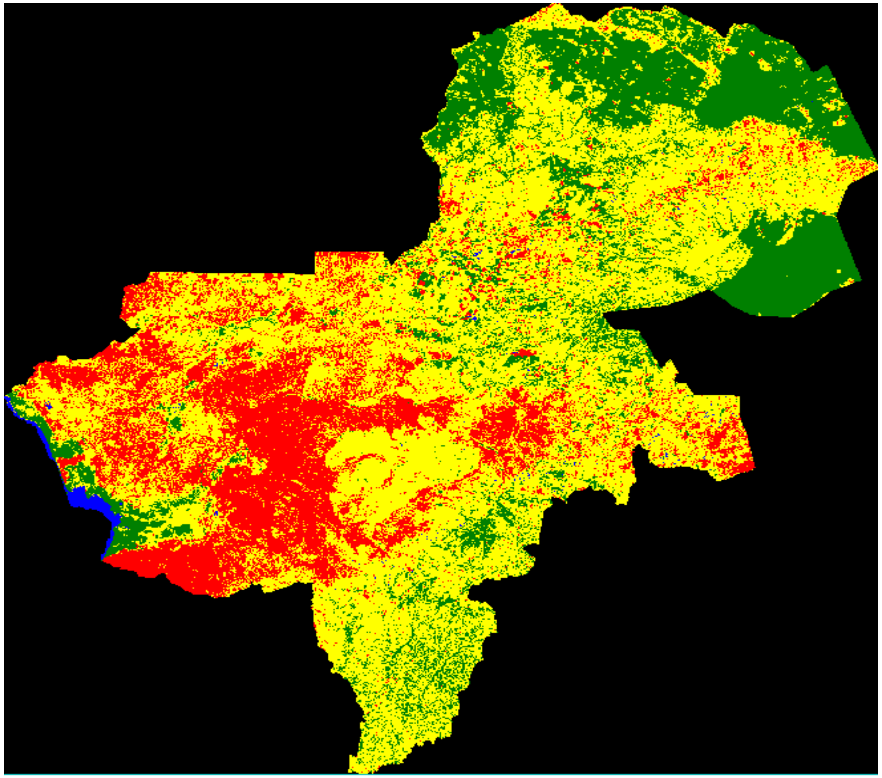


Figure 7: Analysis for Area A, 2006

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	208406.34	0.008489
Built-up Land	516995724.60	21.059407
Vegetation	534187675.82	21.759708
Water	13151383.42	0.535711
Open Land	1390396387.87	56.636685

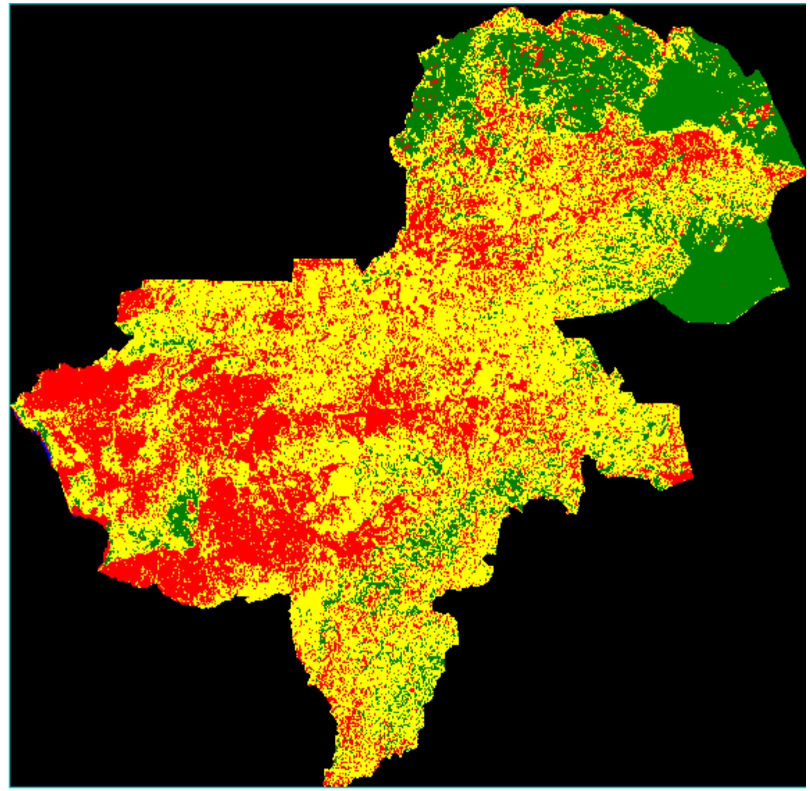


Figure 8: Analysis for Area A, 2012

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	298350.00	0.012154
Built-up Land	718857225.00	29.283197
Vegetation	461244150.00	18.789132
Water	881100.00	0.035892
Open Land	1273564575.00	51.879624

Land Cover Changes

The study area experienced a catastrophic decline in vegetation cover over the 17-year period. In 1995, Vegetation accounted for the vast majority of the land, covering approximately 73.0% of the catchment. By 2012, this figure had plummeted to only 18.8%, representing a net loss of 54.2% of the original vegetative cover, totaling about 1.33 billion m2. The most intense period of LCC occurred between 2000 and 2006, when vegetation saw a substantial decrease of 36.7%. This dramatic reduction in protective cover suggests an extreme increase in land vulnerability to degradation. The changes in the absolute area and percentage cover of vegetation over the study period are detailed in Table 1.

Table 1: Changes in Land Cover between 1995 and 2012

Year	Area, m^2	% Vegetation	% Reduction
1995	1,792,342,267	73.0	
2000	1,434,858,975	58.4	-14.5
2006	534,187,676	21.8	-36.7
2012	461,244,150	18.8	-3.0
Total Increase	**(1,331,098,117)**		**-54.2**

Change in Built-up Land

The built up area has increased with time. In the year 1995, the built up area was about 15% of the catchment, while in the year 2012, the built-up area increased and was about 29%. Within the 17 years covered in the analysis, the built up area increased by about 14%. The change in built up are is shown in Figure 9.

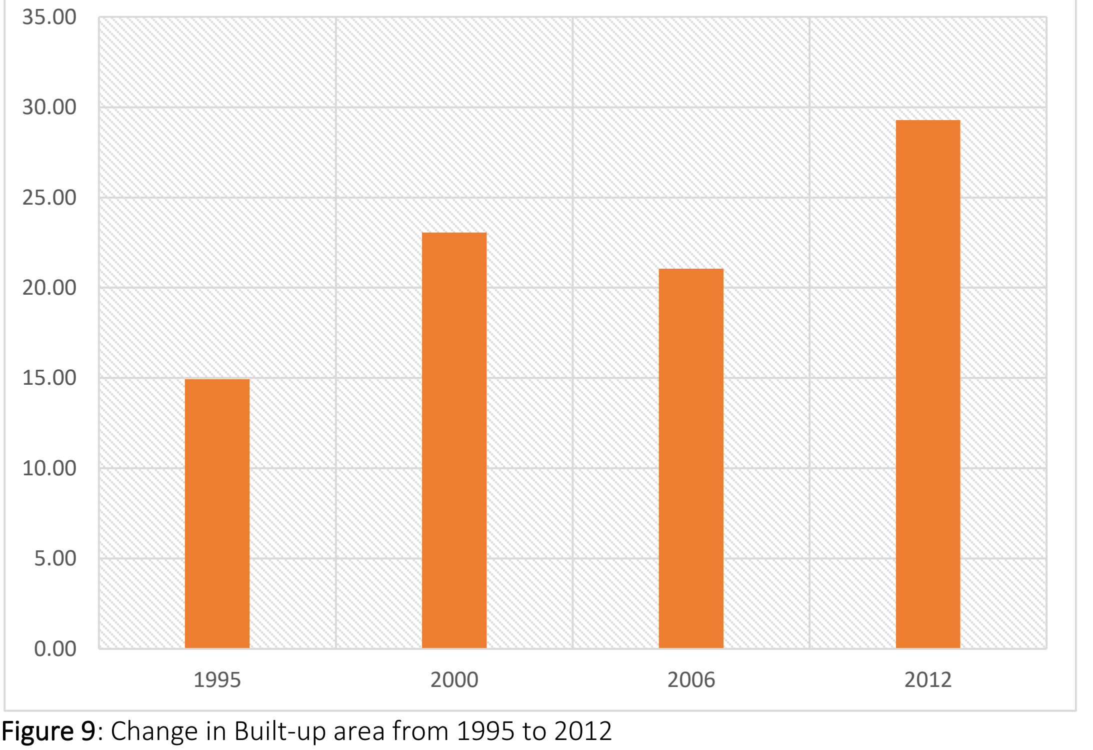


Figure 9: Change in Built-up area from 1995 to 2012

Change in Open (Bare) Land

The open land in the main study area also increased from about 12% in 1995 to about 54% in the year 2012. Within the 17 years considered in this study the open land increased by about 42%. Table 2 shows the changes in open land area.

Table 2: Changes open land between 1995 and 2012

Year	Area, m2	% Open Land	% Reduction
1995	290,128,092	11.8	
2000	450,344,250	18.7	6.9
2006	1,390,396,388	54.1	34.6
2012	1,273,564,575	53.3	0.7
Total Increase	**983,436,483**		**42.3**

The results from satellite analysis showed that as vegetation decreased with time, built up area and open land increased in size as seen in Figure 10 below.

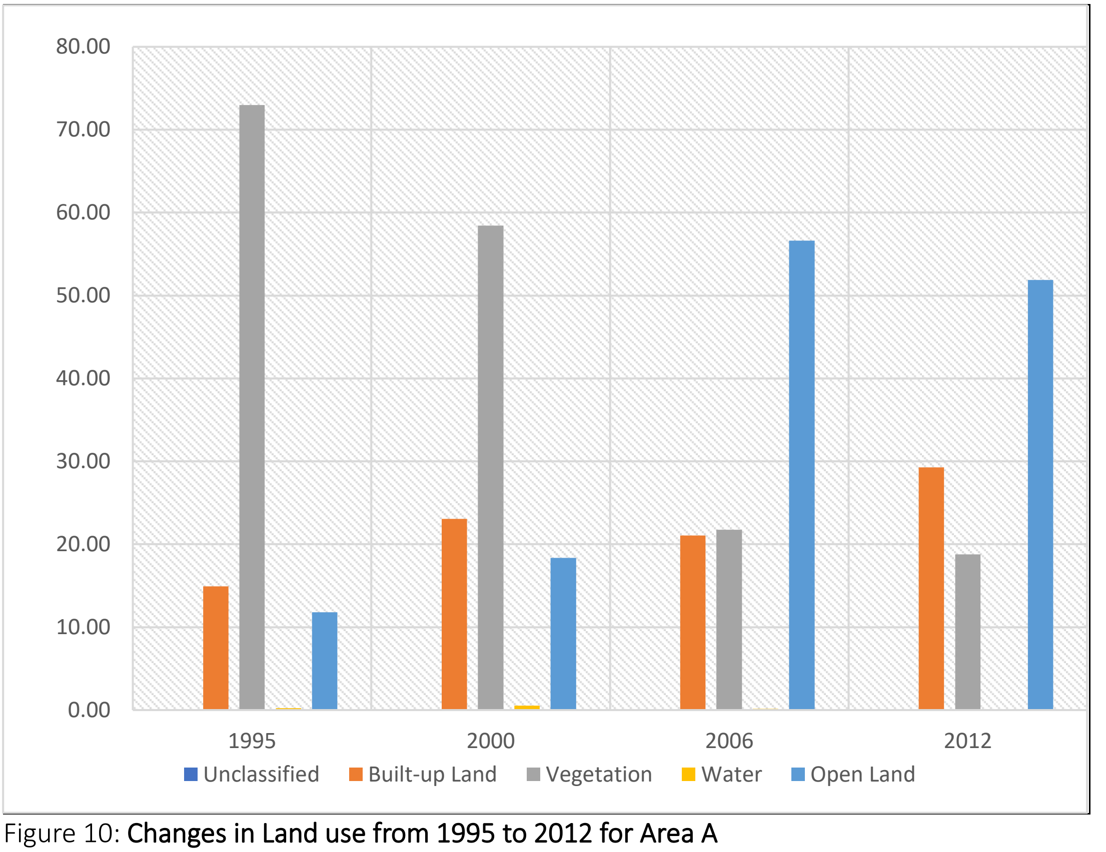


Figure 10: **Changes in Land use from 1995 to 2012 for Area A**

Within the 17 years from 1995 to 2012, there was a decrease of vegetation cover of about 54%, while there was an increase of about 40% for open area, and about 14% for built-up area. The area covered by water also decreased by about 0.2% due to these changes.

Thematic Change

From the analysis, thematic changes from one use to another, was therefore detected as reported in Table 3 below.

Table 3: Thematic changes in area and percentages

From 1995	To 2012	Area (m^2)	Percentage
No change	No change	848446200.00	34.556576
Built-up Land	Vegetation	4032000.00	0.164220
Built-up Land	Water	15750.00	0.000641
Built-up Land	Open Land	116615925.00	4.749679
Vegetation	Built-up Land	342533925.00	13.951149
Vegetation	Water	59625.00	0.002428
Vegetation	Open Land	1005219225.00	40.941824
Water	Built-up Land	3216825.00	0.131019
Water	Vegetation	296550.00	0.012078
Water	Open Land	1466550.00	0.059731
Open Land	Built-up Land	124134075.00	5.055888
Open Land	Vegetation	9196425.00	0.374563
Open Land	Water	4500.00	0.000183

During the period, loss of built up area to other uses was only about 5%, while the gain of built up areas from the same uses was almost four times at about 19%. Most of the gain for built-up area was from change of land covered with vegetation to built-up land, which accounted for about 14%.

Destruction of vegetation to create open land alone accounted for about 41% loss of vegetation cover. Only about 0.6% of other land uses changed to land covered with vegetation, thus putting the net loss of vegetation at about 54%, that is from a total loss of about 55% and a gain of less than 1%.

During the 17 years, there was also decrease in lake level as noted by the loss of surface water cover, which was about 67 times more than the gain although the loss was a small percentage of the total catchment area, Table 4 below.

Table 4: Percentage thematic changes in land use

Land Use	Total % Loss	Total % Gain	Net Gain
Built-up Land	4.91454	19.13806	14.22352
Vegetation	54.8954	0.550861	-54.344539
Open Land	5.430634	45.75123	40.320596
Water	0.202828	0.003252	-0.199576

Land Cover Change in Area B

Results for Area B (Awach Kibuon and Awach Tende catchments) show less dramatic changes compared to Area A. Vegetation decreased slightly from 58% in 1995 to 55% in 2012 (a 4% decline), while built-up land expanded from 16% to 25% (a 9% increase). Open land reduced marginally by 6% during the same period (Table 5).

Table 5: Land use / cover changes for area B

Year	% Coverage			
	Vegetation	Built-up Land	Open Land	Water
1995	58.30	15.69	25.29	0.67
2000	51.14	20.51	27.60	0.73
2006	53.33	23.77	22.38	0.51
2012	54.53	25.07	19.64	0.74
Change	**-3.77**	**9.38**	**-5.65**	**0.07**

Classification results for Area B

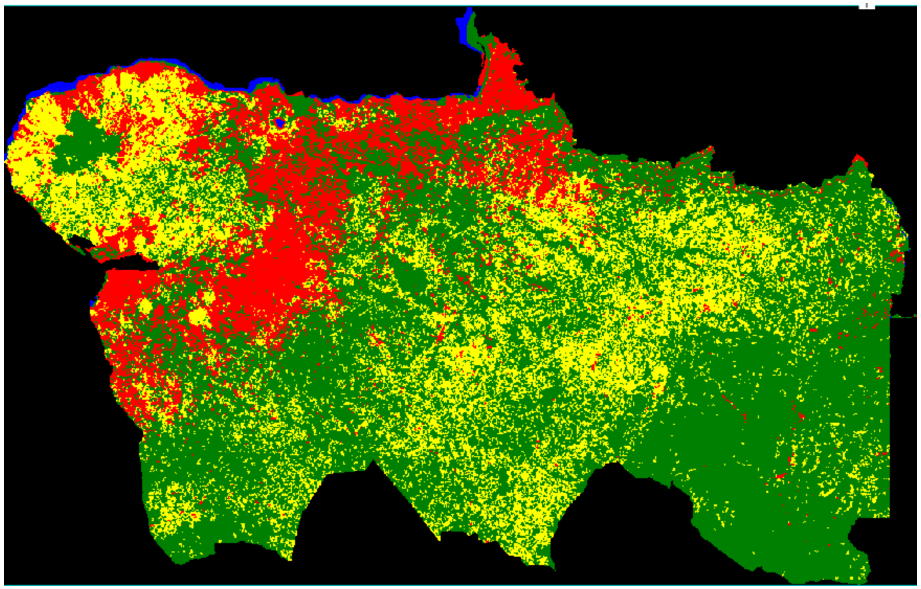


Figure 11: Analysis for Area B, 1995

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	810091.12	0.044877
Built-up Land	283249031.38	15.691352
Vegetation	1052465012.04	58.304167
Water	12065434.48	0.668398
Open Land	456538711.00	25.291206

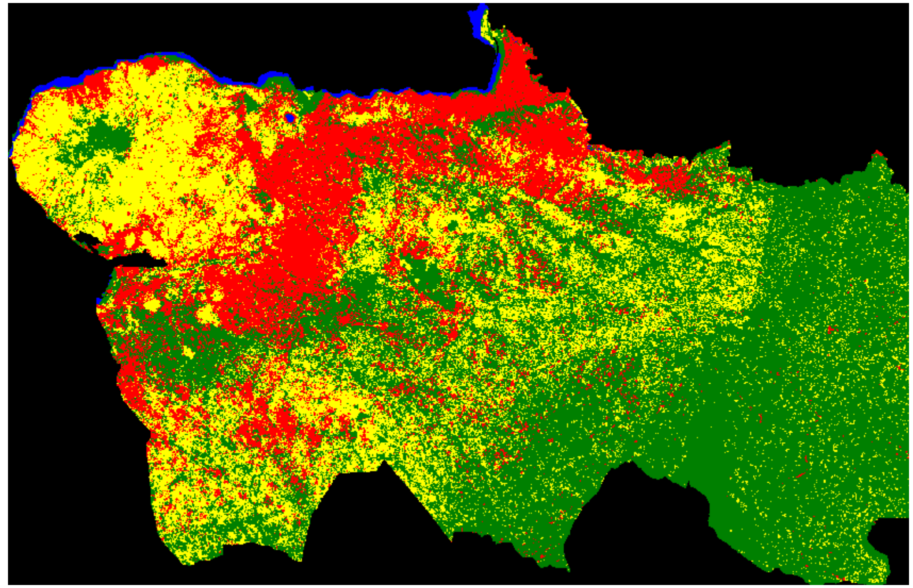


Figure 12: Analysis for Area B, 2000

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	239173.23	0.013253
Built-up Land	370202651.24	20.513370
Vegetation	922977792.30	51.143300
Water	13197870.61	0.731310
Open Land	498072069.39	27.598767

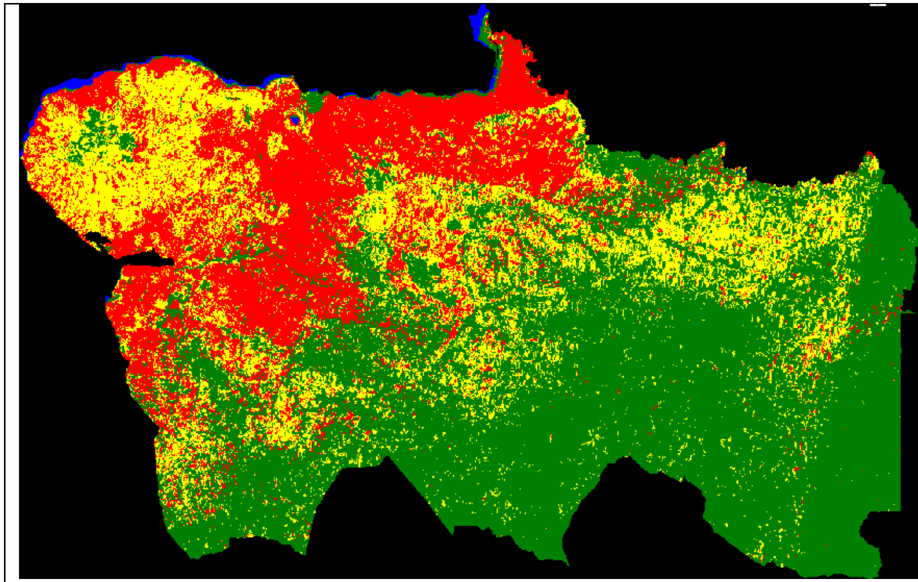


Figure 13: Analysis for Area B, 2006

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	173025.00	0.009588
Built-up Land	428918625.00	23.767018
Vegetation	962426025.00	53.329456
Water	9187650.00	0.509101
Open Land	403974675.00	22.384837

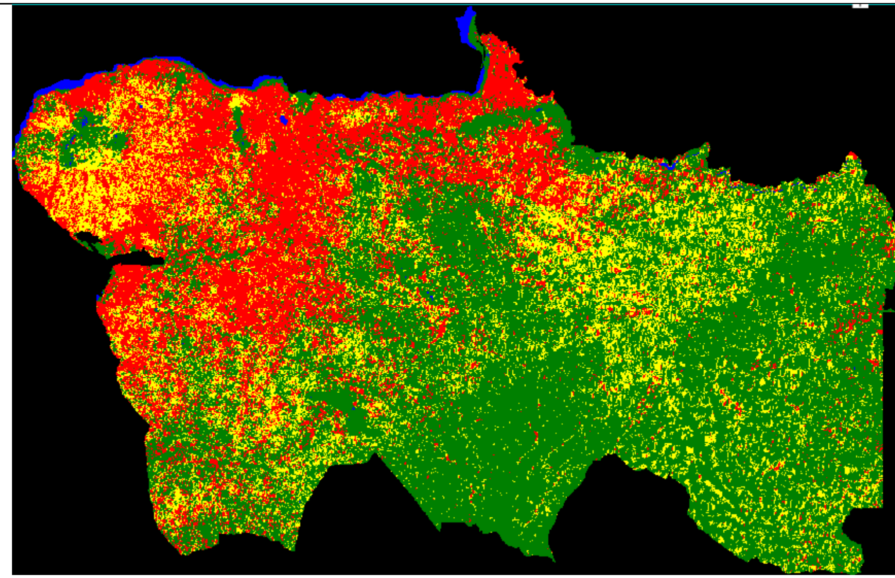


Figure 14: Analysis for Area B, 2012

Classes
- 0: Unclassified
- 1: Built-up Land
- 2: Vegetation
- 3: Water
- 4: Open Land
- 5: Masked Pixels

Land Cover/Theme	AREA (M^2)	PERCENT
Unclassified	259650.00	0.014388
Built-up Land	452436750.00	25.070192
Vegetation	984121200.00	54.531618
Water	13374000.00	0.741073
Open Land	354488400.00	19.642729

Figures 11–14 show the spatial distribution of land cover categories across Area B over the study years. Ground-truthing confirmed that tea plantations and eucalyptus tree stands in the upper catchments were detected as vegetation, which may account for the relatively modest decline in vegetative cover.The results show that from 1995 to 2012, there was a decrease of vegetation cover of about 4%, and open land of about 6% while there was an increase of about 9% for built-up area, Table 5.

Comparative Land Cover Change in Nyando and Awach Rivers Catchments

Table 6 compares the land cover changes in Area A (Nyando Catchment) and Area B (Awach Kibuon and Awach Tende). The Nyando Catchment experienced severe vegetation loss of 54%, accompanied by substantial increases in open land (40%) and built-up areas (14%). In contrast, the Awach catchments registered only minor vegetation decline (4%), with built-up areas expanding by 9% and open land decreasing by 6%.

Table 6: Land use / cover changes for area A and area B

	Nyando Catchment Area A			Awach Kibuon and Awach Tende Catchment Area B		
Year	Open Land	Built-up Land	Vegetation	Open Land	Built-up Land	Vegetation
1995	11.82	14.93	72.99	25.29	15.69	58.30
2000	18.34	23.06	58.45	27.60	20.51	51.14
2006	56.64	21.06	21.76	22.38	23.77	53.33
2012	51.88	29.28	18.79	19.64	25.07	54.53
Change	40.06	14.35	-54.21	**-5.65**	**9.38**	**-3.77**

Discussion

Level and Drivers of Land Cover Change (LCC)

The analysis of the Nyando micro-catchments (Area A) revealed a profound and ecologically significant scale of land cover conversion. The substantial decline in vegetation cover (≈54%) and the corresponding increases in Open Land (≈42%) and Built-up Areas (≈14%) (Table 1 and Table 2) are consistent with earlier studies documenting widespread vegetation loss in western Kenya. This magnitude of destruction highlights an unsustainable trend driven primarily by anthropogenic activities (Kundu & Olang, 2011; Olang et al., 2014). The most acute period of degradation occurred between 2000 and 2006, resulting in a substantial loss of approximately 38% of vegetation cover in just six years, indicating a rapid change in the intensity and extent of human activities. This acceleration is typically linked to factors such as population growth, land subdivision, and the intensification of subsistence agriculture (Kumar & Koech, 2020; Shilibwa et al., 2024).

Conversion Pathways and Erosion Susceptibility

The LCC observed is characterized by two critical pathways: the conversion of vegetation to farmland and to human settlement. The clearing of land for poor agricultural practices, felling of trees for timber, firewood, and charcoal burning leaves the soil bare, which is then mapped as Open Land. This open land is highly susceptible to erosion; the loss of topsoil occurs through sheet erosion by wind and rain-water (Kumar & Koech, 2020). The eroded particles and associated nutrients are subsequently transported by surface run-off into streams and rivers, confirming the environmental stress. Spatially, this destruction exhibited a clear gradient: vegetation loss to open farmland was concentrated in the upper catchment highlands, while the greatest conversion to Built-up Areas occurred in the lower reaches and plains, supporting expansion of urban centres and infrastructure. Furthermore, the analysis indicated a preference for clearing vegetated land for new settlement development over utilizing existing open or fallow land, thereby directly intensifying deforestation pressure.

Masked Degradation in the Awach Catchments

In contrast to Nyando (Area A), the Awach Kibuon and Awach Tende catchments (Area B) showed a surprisingly slight net reduction in vegetation (≈4%) and a decrease in open land (≈6%) (Table 5 and Table 6). While this might initially suggest stability, ground-truthing indicated that the upper Awach catchments had undergone earlier, intense conversion where indigenous forest was replaced by highly managed plantation forests (e.g., tea and eucalyptus). These stable commercial plantations register as Vegetation in satellite classifications, potentially masking the underlying ecological degradation caused by the functional shift from native forest to commercial monoculture. As demonstrated by Omwoyo et al. (2024), areas with managed plantation cover can retain a consistent spectral signature even as soil health and hydrological function beneath the canopy are altered. Thus, the modest change in Area B likely represents a catchment that reached a state of stable, high-intensity land use prior to the 1995 baseline, rather than a system that was spared from LCC.

Hydrological and Environmental Implications

The observed LCC has critical implications for the basin's hydrology. The loss of vegetative cover directly affects infiltration and runoff, a mechanism shown to intensify flood events in the Nyando basin (Kundu & Olang, 2011). Moreover, the expansion of settlements and agriculture into sensitive areas, particularly wetlands, exacerbates these issues. As noted by Odaro (2023), the conversion of significant hectares of Nyando wetlands to irrigation and farmland reduces their crucial filtering effects, contributing directly to major sediment plumes and eutrophication in the Winam Gulf of Lake Victoria. Finally, the satellite analysis revealed a recession of the lake level along the Winam Gulf shores, exposing land that was rapidly converted to built-up areas or left as open land. This encroachment upon the lake margin, often without regard for the potential for future lake level recovery, signifies a lack of sustainable catchment planning and further compounds the vulnerability of the entire ecosystem.

Conclusion

The satellite imagery analysis spanning the period 1995 to 2012 conclusively demonstrates that the Nyando and Awach river catchments have suffered from severe and widespread environmental degradation driven by anthropogenic activities. The study provides irrefutable quantitative evidence that the hypothesis of low Land Cover Change (LCC) is soundly rejected. Specifically, the Nyando catchment experienced a catastrophic net loss of approximately 54% of its vegetative cover, which was converted predominantly into Open Land (≈42% increase) and Built-up Areas (≈14%

increase). This conversion signifies a direct replacement of protective, native ecosystems with unstable, erosive surfaces. The dominance of the Vegetation that is Open Land conversion pathway, particularly in the upper catchment highlands, indicates that intensive and unsustainable agricultural practices, coupled with unchecked expansion of settlements in the lower reaches, are the primary drivers of this degradation. The magnitude and rapid acceleration of LCC recorded, particularly between 2000 and 2006, establish the catchment as a critical environmental concern demanding immediate policy attention.

Recommendations

Based on the demonstrated magnitude and spatial dynamics of LCC, the following recommendations are directed at the relevant governing bodies, including National and County Governments, Environmental Management Agencies (e.g., NEMA), and Agricultural Authorities:

The County Governments and Land Use Planning Departments must enforce strict regulations to control the conversion of land. Specifically, policies should be established to discourage the clearing of existing Vegetation for new settlements or infrastructure, as this was shown to be the dominant pathway for built-up expansion. Instead, development should be channeled toward already existing Open Land or marginally productive areas. Furthermore, the practice of converting wetlands in the lower catchment and the exposed shoreline of the Winam Gulf must be halted immediately, and permanent non-development buffer zones must be surveyed and strictly maintained to mitigate shoreline encroachment and loss of crucial filtering habitats.

The Ministry of Agriculture and Local Agricultural Authorities must urgently address the severe increase in Open Land in the upper catchment, which constitutes the primary source of soil erosion. This requires mandating and incentivizing sustainable land management practices. These measures include the widespread adoption of bench terraces on steep slopes, the integration of agroforestry, and the use of continuous cover cropping to ensure that soil is not left exposed during the critical rain seasons. Technical assistance programs should be focused on changing farming practices from extensive clearing to intensive, soil-conservative methods.

Finally, Environmental and Forestry Agencies must coordinate a targeted restoration and afforestation campaign. This campaign should prioritize the steepest slopes and riparian buffer zones that have experienced the greatest loss of Vegetation. Given that indigenous vegetation offers superior ecological benefits, restoration efforts should focus on native species rather than large-scale, functional replacements such as eucalyptus, especially in headwater areas where hydrological stability is paramount. Long-term monitoring, using the satellite image classification methodology established in this study, should be institutionalized to regularly assess the success of these reversal efforts and track changes in land cover every five years.

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