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Assessing the Extent of Historical, Current, and Future Land Use Systems in Uganda

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Abstract: Sustainable land use systems planning and management requires a wider understanding of the spatial extent and detailed human-ecosystem interactions astride any landscape. This study assessed the extent of historical, current, and future land use systems in Uganda. The specific objectives were to (i) characterize and assess the extent of historical and current land use systems, and (ii) project future land use systems. The land use systems were defined and classified using spatially explicit land use/cover layers for the years 1990 and 2015, while the future prediction (for the year 2040) was determined using land use systems datasets for both years through a Markov chain model. This study reveals a total of 29 classes of land use systems that can be broadly categorized as follows: three of the land use systems are agricultural, five are under bushland, four under forest, five under grasslands, two under impediments, three under wetlands, five under woodland, one under open water and urban settlement respectively. The highest gains in the land amongst the land use systems were experienced in subsistence agricultural land and grasslands protected, while the highest losses were seen in grasslands unprotected and woodland/forest with low livestock densities. By 2040, subsistence agricultural land is likely to increase by about 1% while tropical high forest with livestock activities is expected to decrease by 0.2%, and woodland/forest unprotected by 0.07%. High demand for agricultural and settlement land are mainly responsible for land use systems patchiness. This study envisages more land degradation and disasters such as landslides, floods, droughts, and so forth to occur in the country, causing more deaths and loss of property, if the rate at which land use systems are expanding is not closely monitored and regulated in the near future.

Keywords: land use systems; land change modeler; prediction; Uganda

1. Introduction

Human activities, especially the conversion and degradation of habitats, are causing global biodiversity declines [1]. The notable activities include the cutting down of trees, charcoal burning and poor farming methods, among others, which undermine the functionality of ecosystems [2]. The rapid conversion of natural vegetation, for example, to farmlands, could be attributed to farming techniques and agronomic approaches that aim at modern agricultural intensification [3]. For instance, in the Equateur province of the Democratic Republic of Congo, the agricultural expansion through shifting cultivation is the main proximate cause of deforestation [4]. In the northern portion of the Brazilian Atlantic Forest, generally 76% of the households use fuelwood regularly and consume on average 686 kg/person/year of tree biomass; poorer people, however, consume 961 kg/person/year [5,6].

Anthropogenic land use activities (such as management of croplands, forests, grasslands, and wetlands) and changes in land use/cover (such as conversion of forest lands and grasslands to cropland and pasture, afforestation), cause changes superimposed on natural fluxes [7]. Tower, ground-based, and satellite observations indicate that tropical deforestation results in warmer, drier conditions at the local scale [8]. These conditions lower agricultural productivity, with reduced soil moisture content and pasture, and lead to human migration, resource conflicts, and loss of biodiversity, among others [9–12]. In the Kenyan Eastern Mau Forest Reserve, forest-to-cropland conversions are undermining the ecosystem's capacity for carbon sequestration [13]. In the Ngerengere River in Tanzania, changing land use affects surface runoff and increases floods in the mountainous areas [14].

Geographical information systems and remote sensing (GIS and RS) techniques can be used to explore the temporal and spatial characteristics of land use/cover changes [15]. For example, in Uganda, GIS and RS were applied to assess the impacts of land use/cover change on terrestrial carbon stocks [16]. The information about land use is often stored in geospatial databases, typically acquired and maintained by national mapping agencies. Such databases consist of objects represented by polygons that are assigned class labels indicating the objects' land use [17]. Therefore, land use/cover information can be directly interpreted from appropriate remote sensing images [18].

Presently, the diversity of conversions of natural ecosystems to land use systems is a critical challenge in Uganda. This is driven by the need to meet the livelihoods of smallholders, high demand for forest products, urban expansions, and infrastructural developments (such as the construction of highways, hydropower dams, and industrial parks, among others). As a result, the country has witnessed massive losses of natural vegetation and intensification of human activities. This condition is worsened by the overexploitation of resources, use of unsustainable harvesting and agronomic practices, and changes in climate. Some of the threatened ecosystems include Mt Elgon in Eastern Uganda, the Mabira Central Forest Reserve, the Lubigi wetland system, and Lake Victoria, among others [19–22]. As a result, the country is faced with a number of environmental problems such as frequent occurrences of landslides and floods that cause deaths and loss of property, loss of biodiversity, low agricultural output, and reduced forest and wetland goods and services, among others [23–25]. This study takes note of a number of studies that have been conducted in the country to quantify changes in land use/cover [26–28]. However, there is no study that has redefined and reclassified land use systems and estimated their future scenario at a country level using a Markov chain model [29]. With high population increase causing increased demand for arable and settlement land, fragile ecosystem goods and services are under enormous pressure to meet the needs of the people. This case is evident with a number of fragmented patches of arable land across the country. Therefore, with this patchiness of the landscape, reclassifying land use systems is pertinent for land cover conservation and land use systems management.

The overarching aim of this paper was to critically assess the extent of historical, current, and future land use systems in Uganda. The specific objectives of this study were to (i) characterize and assess the extent of historical and current land use systems, and (ii) project future land use systems. This study identifies areas where conservation is needed because of increasing human activities. This information is also conceptualized within the framework of Uganda Vision 2040 and Second

National Development Plan that calls for the protection of fragile ecosystems which support the economy, for example, through tourism, and attainment of sustainable development goals.

2. Materials and Methods

2.1. Study Area

Uganda, a former British colony, is located along the equator in East Africa. The landlocked country occupies about 241,550.7 km^2, of which 41,027.4 km^2 is open water and swamps while 200,523.5 km^2 is land (Figure 1). Uganda is bordered by Kenya in the East, Tanzania and Rwanda in the south, the Democratic Republic of Congo in the west, and South Sudan in the North. The country is highly engaged in agriculture as the main source of livelihood. Cropland is the largest land cover, followed by grasslands, open water, forests, bushlands, wetlands, and built-up area [30]. The land use/cover utilization types are highly influenced by the amounts of rainfall received. Uganda's climate is considerably modified by elevation above sea level, local water bodies, and local relief. The country experiences both bimodal and unimodal rainfall patterns. Rainfall is evenly distributed throughout the country, except in the northeastern corner. Much of the country receives between 1000–1500 mm of rain per annum, increasing with altitude, but this is variable. In most areas of Uganda, there are wetter and drier seasons. The Central, Western, and Eastern regions have two rainy seasons, from March to May for the first rains, and the second rains from September to November. The Northern region receives one rainy season from April to October, and the period from November to March has minimal rain. Most of the areas in the country receive between 750 mm and 2100 mm of rain annually. The reliability of rainfall generally declines northwards. Amidst the changes being experienced in climate, Uganda's population has also continued to grow rapidly from 9.5 million in 1969 to 34.6 million in 2014 [30]. However, rapid population growth and environmental degradation pose a growing challenge to the continued productivity of the land resources.

Figure 1. Location of the study area in Africa.

2.2. Acquisition of Land Use/Cover Data

This study obtained the spatial land use/cover datasets from the National Forestry Authority for the years 1990 and 2015 and processed them to produce land use systems for Uganda. The authority is the mandated institution required to frequently monitor land use/cover changes in Uganda. This period (1990–2015) was selected because the land use codes and description of land use/cover classes had been defined and classified in detail.

2.2.1. Processing of 1990 Land Use/Cover Data

In 1995, the National Biomass Study (NBS) by the National Forestry Authority generated a national land use/cover map for the year 1990 (Figure 2).

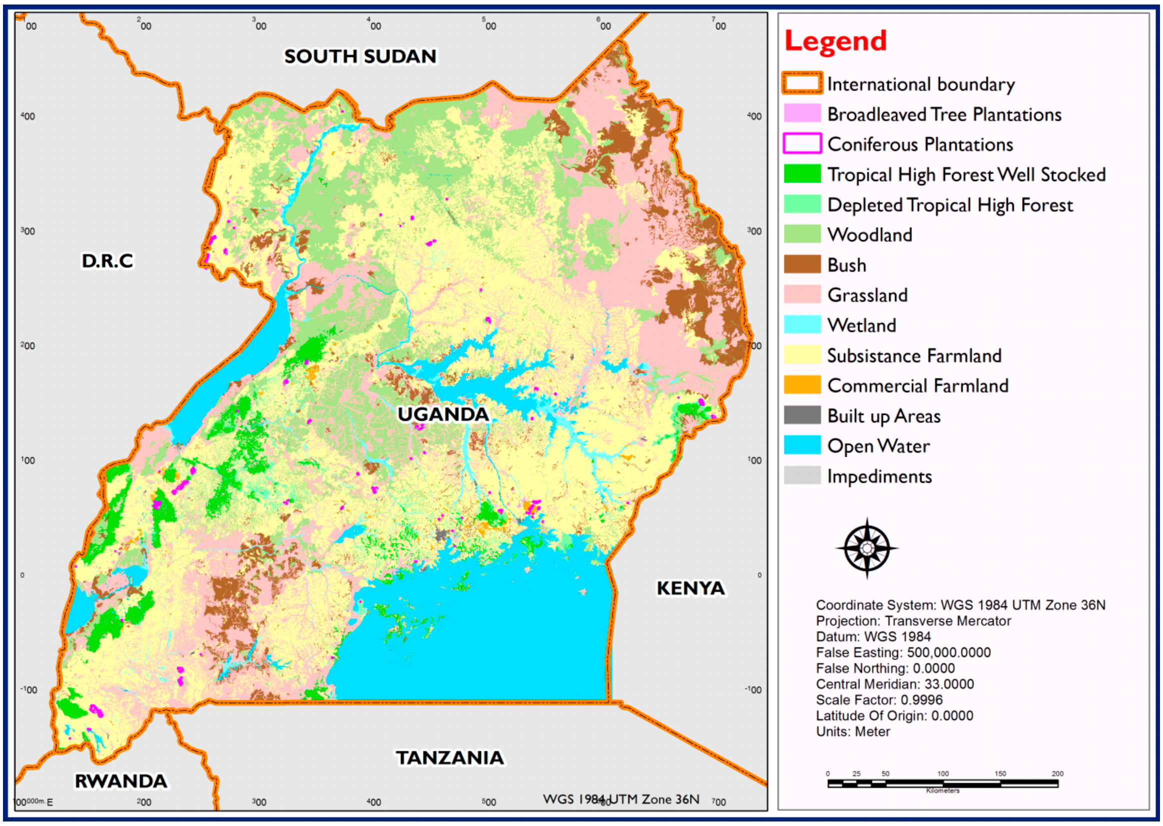

Figure 2. Land use/cover for Uganda for the year 1990.

The NBS generated this layer based on SPOT multispectral (XS): SPOT II satellites' high-resolution images purchased from National Centre for Space Studies (CNES) in France (band swatch 60 × 60 km; covering the 1988–1992 period). The paper hard copies were trimmed to fit the 1:50,000 toposheets of Uganda's Y733 series. The Panchromatic aerial photos were used to fill data gaps identified in the SPOT imagery. The georeferenced images were later manually digitized on a tablet using PC ArcInfo software to characterize the land use/cover types. The captured classes were verified throughout the year and spanned 2 years. The land use/cover types are described in Table 1.

Table 1. Description of the National Biomass Study's land use/cover classes (1990).

No.	Land Use/Cover Classes	Description
1	Built-up area	Urban and rural built areas
2	Bushlands	Bush, thickets, scrub (average height <4 m)
3	Commercial farmland	Monocropped, nonseasonal farming, usually with no trees
4	Grassland	Rangeland, pasture land, savannah—may include scattered tree shrubs, thickets, scrub
5	Hardwood plantation	Hard and softwood
6	Impediments	Bare rocks and land
7	Open water	Lakes, rivers, and ponds
8	Small-scale farmland	Mixed farmland, smallholding with or without scattered trees
9	Tropical high forest (well stocked)	Normally stocked
10	Tropical high forest (low stocked)	Degraded/depleted/encroached
11	Wetland	Wetland vegetation, swamps, papyrus, and other sedges
12	Woodland	Trees and shrubs (average height >4 m)
13	Softwood	Scattered woodlots

2.2.2. Processing of 2015 Land Use/Cover Data

This layer was generated based on Landsat 8 images (operational land imager) downloaded from United Stated Geological Survey (USGS) through the Global Visualization Viewer (GLOVIS) portal (covering 180 × 185 km). The dry season images with no clouds were downloaded to a local workstation and analyzed. The images were rectified, coregistered, and atmospherically corrected Top of Atmosphere (TOA) to remove atmospheric errors. The majority filtering method was used to enhance the images for better visualization.

The images were analyzed using a Quantum GIS (QGIS)-based semiautomatic image classification plugin for a hybrid of supervised and unsupervised image classification procedures. The spectral classes extracted, however, were not well represented, and therefore a mean shift segmentation algorithm was adopted and used to segment the land use/cover classes (Figure 3). The parametric supervised segmentation was implemented to refine initial classes following the National Biomass Study (2003) classification system [31]. A field verification exercise was undertaken to validate the classified landscape land use/cover types.

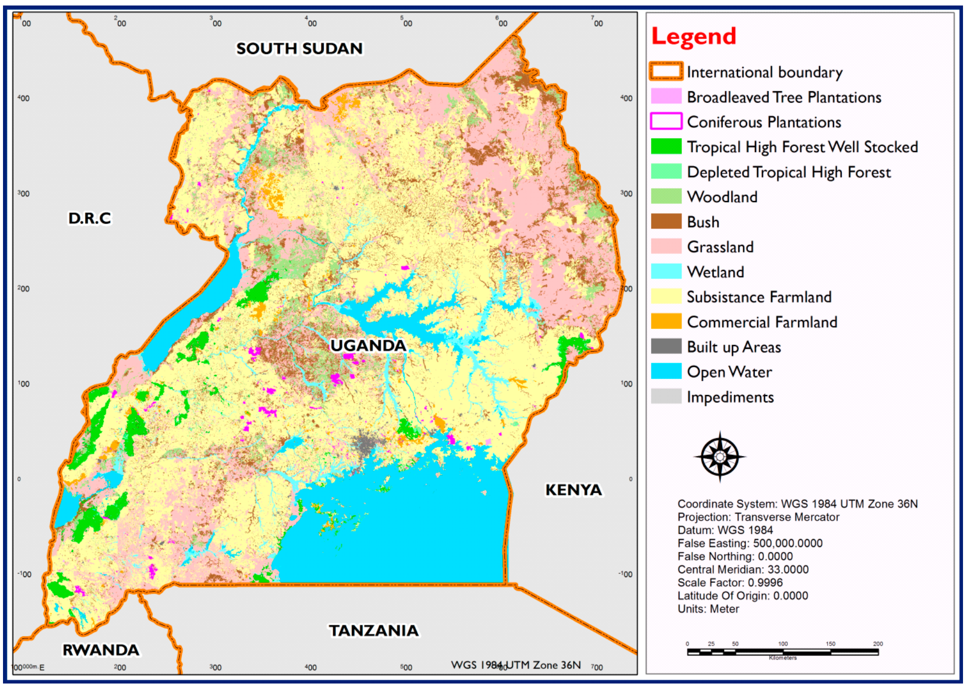

Figure 3. Land use/cover for Uganda for the year 2015.

2.3. Characterization of Land Use Systems

2.3.1. Definition of Land Use System

A land use system is a combination of one land unit and one land utilization type (with one set of land use requirements). According to [32] a single-land-use system is the configuration whose performance is analyzed in the assessment of land suitability. However, the generation of land use systems based on the above definition has proved to be too complex and does not result in readily recognizable land use units. Much simpler schemes have been proposed and applied at a global scale to characterize land use systems and ecosystem attributes. The obtained land use/cover datasets of the years 1990 and 2015 were preprocessed and reclassified in a Geographical Information Systems environment (ArcGIS software version 10.1) in the definition of land use systems for Uganda.

2.3.2. Criteria for the Definition of Land Use Systems

The land use systems were defined based on the following three criterions:

- Similarity in the broad land cover classes;
- Similarity in terms of protection status;
- Presence and density of livestock activities.

2.3.3. Steps of Characterizing Land Use Systems

The 1990 and 2015 land use/cover classes were reclassified into finer land use systems based on their uses. These land use/cover datasets were analyzed into land use systems using the following procedures:

- Step 1: The detailed land use/cover classes were aggregated into 8 classes (forests, grasslands, shrubs, crops and crop mosaics (agricultural land), wetlands, shrubs and bushlands, bare land areas, and open water).
- Step 2: Irrigated land was identified and overlaid with the map generated in step 1 to create a subclass of irrigated agricultural land. Irrigated land is land equipped with infrastructure for irrigation and this was identified from the 2015 irrigation map for Uganda.
- Step 3: The protected area layer was overlaid with the layer generated under step 2 for protected land cover (such as protected forest or grassland). Protected areas are areas gazetted for wildlife conservation and they were identified from the protected areas 2014 map for Uganda.
- Step 4: Livestock intensity was estimated using the Tropical Livestock Unit based on the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) Uganda Census of Agriculture data (2008/2009) and overlaid with the layer generated under step 3 to define grassland, shrubs, and sparse shrub and herbaceous subclasses based on the livestock intensity.
- Step 5: For forests, wetlands, and agricultural lands, if the overlay with livestock indicated a moderate or high livestock density, the land use system was considered as a combination of forestry, wetlands, and crops mixed with grazing, respectively.
- Step 6: In addition to livestock presence, population presence was used to define other forest and wetland subclasses, including unprotected and protected classes for wetlands and forests with agricultural activities and virgin forest.

2.4. Validation of Land Use Systems

The identified land use systems were validated in the field and consultative workshops for classification accuracies. Two validation workshops were held in Kampala that were attended by key experts in land use systems-related work. The experts were pooled from Makerere University and other institutions of higher learning in Uganda; the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF); Ministry of Water and Environment (MWE); Ministry of Lands, Housing and Urban

Development (MLHUD); National Forestry Authority (NFA); National Environmental Management Authority (NEMA); Ministry of Local Government (MoLG); local urban authorities; and civil society organizations such as Wildlife Conservation Society and the Albertine Rift Program Kampala.

The land use systems were also validated in the field in representative Afromontane (Bulambuli District) and Western mid-altitude landscapes (Hoima district). These landscapes exhibited a wider range of landscape components such as soil, altitude, and population that were harmonized prior to stratification. The landscapes were identified based on a number of factors, such as agroecosystems, biophysical, geographical, socioeconomic, and cultural factors. Other landscapes included Lake Victoria Crescent, Northern Moist farmland, the Southeast Lake Kyoga floodplain, and Southwestern rangeland. The validations were conducted using 3 focus group discussions in each district in addition to field visits to confirm the 2015 land use systems map.

2.5. Projection of Land Use Systems

2.5.1. Description of Land Change Modeler

The prediction of land use systems was carried out in TerrSet Geospatial Monitoring and Modelling Software using the land change modeler (LCM) platform to generate future land use systems for Uganda.

The principle behind the land change modeler is to evaluate the trend of change from one land use system category to another. The influencing factors included the digital terrain model (DEM) and road network to predict the future land use system pattern based on the previous change trend. The Shuttle Radar Topography Mission (SRTM) digital elevation model of 30 m obtained, pre-processed by filling voids and applied in the LCM modeler. The national roads layer was acquired from the Uganda National Roads Authority (2010), verified for completeness, accuracy and incorporated into the model to facilitate the change prediction processes. The location accuracy of the road network was validated using Google Earth Pro (Geoeye image for 2015).

LCM is more accurate because the neural network outputs are able to express the simultaneous change potential to various land use systems more adequately than individual probabilities obtained through the weights of evidence method [33].

2.5.2. Transition Potential

The LCM computes the Cramer's coefficient, which indicates the degree to which each explanatory variable is associated with the distributions of land use system categories. The variables were selected provided they significantly contributed to the explanation of the spatial distribution of the land use systems of interest.

The selected variables were modelled using a multilayer perceptron (MLP). The MLP consists of a set of input units (the input layer), one or more sets of computation nodes (the hidden layers), and one set of computation/output nodes (the output layer). The nodes are linked by a web of connections which are applied as a set of weights. The network is trained by the backpropagation algorithm, which involves spreading the errors from the output layer to the input layers iteratively in order to correct the values of the weights [33].

The MLP is normally organized around transition submodels. A transition submodel consists of a single land use system transition or a group of transitions that are thought to have the same contributing factors (Table 2). The advantage of using MLP is that it is capable of modelling complex relationships between variables.

Table 2. Transitions and submodels (LCM).

Transitions From–To	Submodel Name
Woodland–unprotected to agricultural land	Woodland_to_agriculture
Grassland–unprotected to agricultural land	Grassland_to_agriculture
Bushland–unprotected to agricultural land	Bushland_to_agriculture

Based on the relationship between the transitions and explanatory variables, the maps of change potential are produced for each transition. For example, assuming that a location is more vulnerable if it is prone to several transitions at the same time, the operator 'OR' is used to combine the transition potential in order to produce an overall change potential map.

2.5.3. Future Prediction

The land use systems layers for year 1990 and 2015 were prepared (i.e., ensured they had the same number of classes for land use systems, pixel size, projection among others) and thereafter added to the model to perform the prediction of future land use systems for the year 2040. The period coincides with Uganda Vision 2040, which is conceptualized around strengthening the fundamentals of the economy to harness the abundant opportunities in the country. In the change prediction, the dynamic road development of stochastic highest transition potential was selected with the highest transition potential route. The prediction for future land use systems was based on the Markov chain model [29].

The trend of land use systems was also determined. The trend is hereby referred to as a shift over time among the relationships between the factors that shape the changing nature of human–environment relations. The trend was determined through aggregation of land use systems for the assessed periods (1990–2015; 2015–2040).

3. Results

3.1. Identificaiton and Characterization of Land Use Systems in Uganda

A description of the different land use systems in Uganda is presented in the next section. A total of 29 land use systems were identified and characterized in the country. These land use systems fall into eight broad land use/cover classes, including agricultural land, bushlands, forest, woodland, grasslands, impediments, open water, built-up areas, and wetlands.

3.1.1. Forest Land Use Systems

Four land use systems were identified under forests in Uganda. These include forests consisting of tree plantations, forests with subsistence farming activities, forests with livestock activities, and protected forests. A forest is defined as an ecosystems that is dominated by trees (defined as perennial woody plants taller than 5 m at maturity), where the tree crown cover (or equivalent stocking level) exceeds 10% and the area is larger than 0.5 hectares.

Tree plantation forests are areas of systematically planted, man-managed, primarily exotic tree species (including hybrids). This category includes both young and mature plantations that have been established for commercial timber production, seedling trials, and woodlot/windbreaks of substantial size to be identifiable on satellite imagery. All non-timber-based plantations, such as tea, sisal, and orchards, are excluded. Forest areas with partial or permanent livestock activities and those with farming activities were classified as forest with livestock activities and forest with subsistence activities, respectively. Protected forests included those found in national parks, forest reserves, bird sanctuaries, botanical gardens, and other conservation areas detectable at a mapping scale.

3.1.2. Agricultural Land Use Systems

Three major land use systems were identified under agricultural land, namely subsistence agricultural land, commercial agricultural land without irrigation, and irrigated commercial agricultural land. Agricultural lands are arable and regularly tilled for the production of crops, with or without irrigation. Commercial agricultural lands are characterized by large, uniform, well-managed field units, often mechanized, and more than 10 ha in size [34], with the aim of supplying both regional and national and export markets. Some use supplementary irrigation and others are rain-fed. Subsistence farmlands are generally smaller in size, i.e., less than 10 ha in size (about 2 ha on average) [34]. Subsistence farmlands are generally rain-fed.

3.1.3. Open Water Land Use System

This land use system consists of permanently open water (man-made or natural); static or flowing; salty, brackish, or fresh. This land use system includes lakes, lagoons, ponds, and big reservoirs (big dams).

3.1.4. Grassland Land Use System

Grasslands are defined as those areas where herbaceous plants dominate the vegetation and where woody plants and shrub cover less than 10% of the area. There are five land use systems under grassland areas, three of which involve livestock (grassland with high livestock density, grassland with medium livestock density, and grassland with low livestock density). Other land use systems include grassland protected and grassland unprotected.

3.1.5. Built-Up Areas Land Use System

This land use system essentially comprises of all formal built-up areas, in which people reside on a permanent or near-permanent basis, identifiable by the high density of residential and associated infrastructure. It includes cities, towns, municipalities and rural clusters (trading centres).

3.1.6. Impediments Land Use System

This system comprises land covered by bare bedrock, rocky land, and cobble fields and which has less than 10% vegetated cover during any time of the year. Two land use systems were identified on this type of land, including protected impediments and unprotected impediments.

3.1.7. Wetlands Land Use System

Wetlands are areas of land with a permanent mosaic of water and herbaceous or woody vegetation that covers extensive areas. The vegetation can be present in either salt, brackish, or fresh water, the depth of which does not exceed six meters. Three land use systems were identified under wetlands, including wetlands with livestock activities, wetlands with crop farmland activities, and protected wetlands.

3.1.8. Bushlands Land Use System

Bushlands represent dense, woody, semisucculent, and thorny vegetation types of an average height of 2–3 m which are relatively impenetrable in an unaltered condition. Bushlands are used for grazing and are found in or outside protected areas. Five land use systems, of which three were associated with livestock presence and two were associated with their protection status, were identified.

3.2. The Extent of Historical and Present Land Use Systems

The extent of historical and present land use systems is presented in Table 3. For both periods, a total of 29 classes of land use systems were identified and defined; namely, three (3) of the land use systems are agricultural, five (5) are under bushland, four (4) under forest, five (5) under grasslands, two (2) under impediments, three (3) under wetlands, five (5) under woodland, and one under open water and urban settlement respectively. In 1990, the agricultural land use system was the most dominant (35.06%), followed by grassland (21.17%), woodland (16.45%), and open water (15.28%). The other land use systems include open water—protected, urban—settlement, impediments, and forest- and bushland-related land use systems.

Table 3. Changes in the extent of land use systems coverage between 1990 and 2015.

No.	Land Use Systems	1990		2015	
		Area (km^2)	% Area (km^2)	Area (km^2)	% Area (km^2)
1	Agricultural land—commercial	517.32	0.209	2587.71	1.06
2	Agricultural land—irrigated	28.8	0.012	46.08	0.02
3	Agricultural land—subsistence	98,073.36	39.683	107,426.6	44.16
4	Bushlands—high livestock density	1389.29	0.562	1360.66	0.56
5	Bushlands—low livestock density	111.07	0.045	452.54	0.19
6	Bushlands—moderate livestock density	2111.07	0.854	2642.54	1.09
7	Bushlands—protected	5206.78	2.107	7410.41	3.05
8	Bushlands—unprotected	5459.02	2.209	4236.81	1.74
9	Grasslands—high livestock density	3240.07	1.311	6588.38	2.71
10	Grasslands—low livestock density	7398.23	2.993	5350.85	2.20
11	Grasslands—moderate livestock density	6131.7	2.481	6534.76	2.69
12	Grasslands—protected	6648.12	2.690	27,146.2	11.16
13	Grasslands—unprotected	26,402.33	10.683	6118.32	2.52
14	Impediments—protected	9.7	0.004	34.56	0.01
15	Impediments—unprotected	11.52	0.005	51.9	0.02
16	Open water—protected	37,130.69	15.024	36,980.77	15.20
17	Tropical high forest (encroachment)—subsistence	2186.91	0.885	872.06	0.36
18	Tropical high forest—tree plantations	218.1	0.088	2420.6	1.00
19	Tropical high forest—with livestock activities	6765.05	2.737	942.69	0.39
20	Tropical high forest—protected	2715.46	1.099	3199.14	1.32
21	Urban—settlement	362.1	0.147	1340.09	0.55
22	Wetlands—protected	1963.58	0.795	6028.29	2.48
23	Wetlands—with crop farmland activities	217.43	0.088	347.64	0.14
24	Wetlands—with livestock activities	528.3	0.214	487.72	0.20
25	Woodland/forest—high livestock density	1851.1	0.749	685.19	0.28
26	Woodland/forest—low livestock density	5481.56	2.218	1246.91	0.51
27	Woodland/forest—protected	4092.06	1.656	6822.21	2.80
28	Woodland/forest—unprotected	9612.57	3.889	867.25	0.36
29	Woodland/forest —moderate livestock density	11,281.56	4.565	3024.91	1.24

In 2015, agricultural, grassland, and wetland-related land use systems remained the most dominant. Between the two periods, agricultural and woodland-related land use systems experienced the most significant changes in terms of gains or losses. Agriculture-related land use systems increased by 8.56%, while those related to woodland reduced by 11.86% compared to their original values. Figures 4 and 5 show the spatial distribution of the different land use systems across the country for the years 1990 and 2015, respectively.

Despite an increment in commercial agricultural land, subsistence agricultural land remains the most dominant land use system across the country. It also worthwhile to note that the areas under bushland with moderate livestock activities, unprotected bushland, grassland with low livestock activities, grassland with moderate livestock activities, encroached tropical forest, and woodland which is unprotected or with livestock activities declined by 2015.

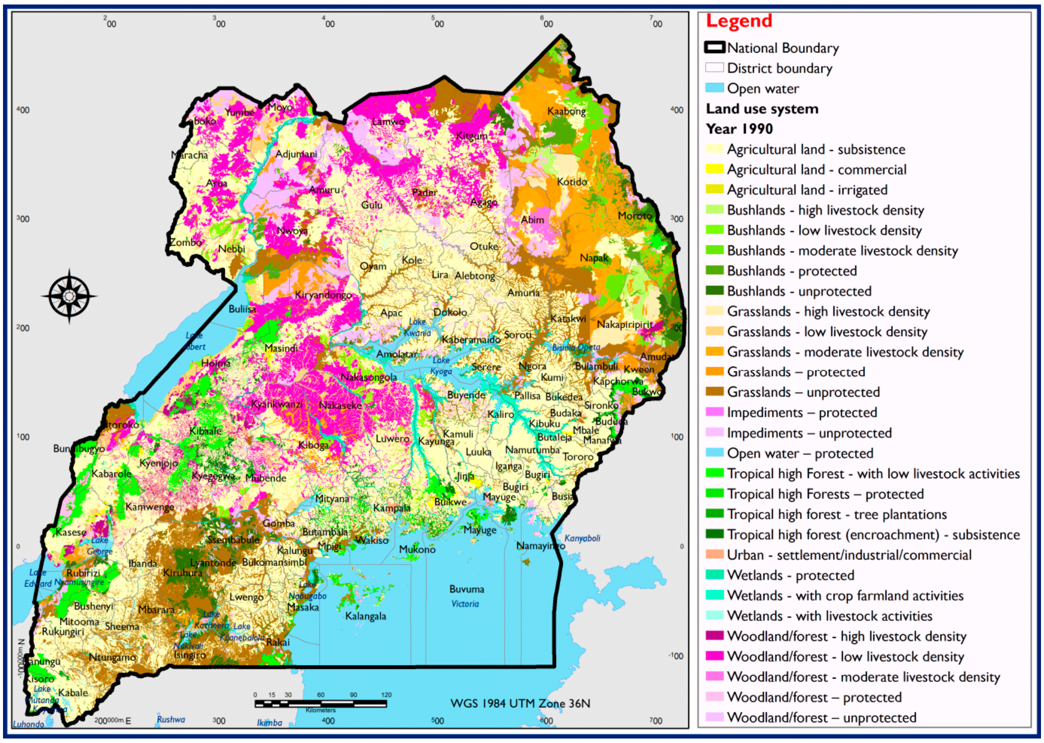

Figure 4. Historical land use systems of Uganda in 1990.

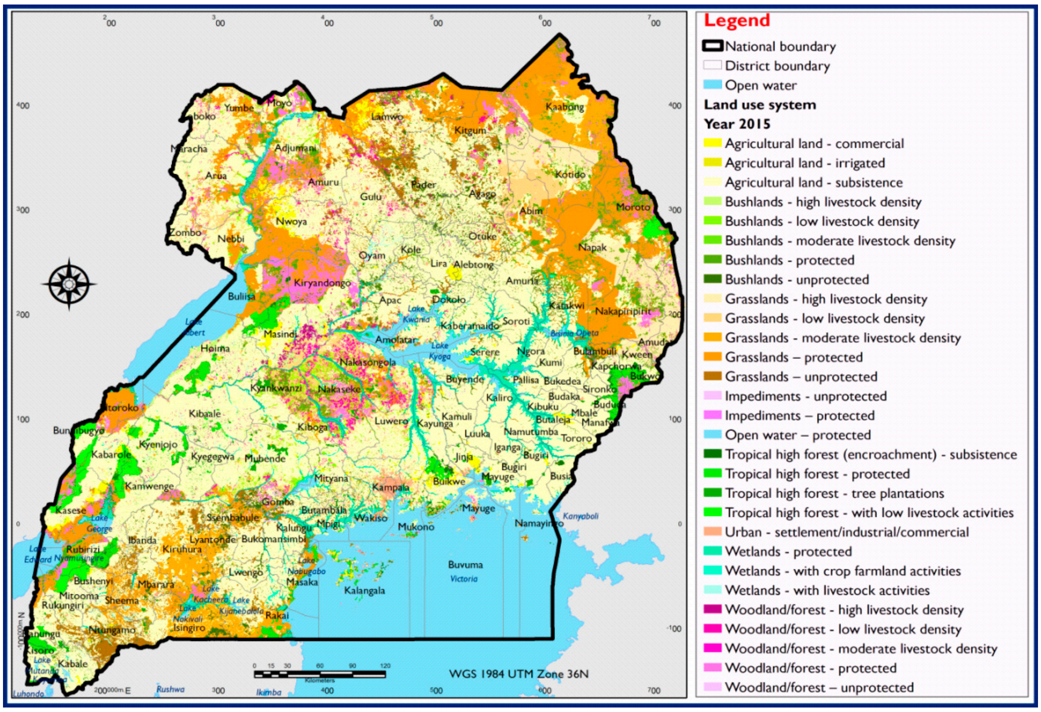

Figure 5. Current land use systems for Uganda, as of 2015.

3.3. Projection of Land Use Systems

Table 4 below shows the projected land use systems for Uganda (Figure 6). By 2040, most of the land use systems' acreages are likely to change in terms gains or losses. Minimum gains or losses of land are likely to be recorded in tropical high forest with livestock activities, woodland/forest with livestock activities, and woodland/forest unprotected. Subsistence agricultural land use is likely to increase by about 1%, tropical high forest with livestock activities is likely to decrease by 0.2%, and woodland/forest unprotected by 0.07%.

Table 4. Projected land use systems of Uganda for the year 2040.

No.	Land Use Systems	2040	
		Area (km^2)	% Area (km^2)
1	Agricultural land—commercial	2875.97	1.191
2	Agricultural land—irrigated	96.08	0.040
3	Agricultural land—subsistence	109,713.8	45.452
4	Bushlands—high livestock density	1333.4	0.552
5	Bushlands—moderate livestock density	1273.4	0.528
6	Bushlands—low livestock density	1079.98	0.447
7	Bushlands—protected	7363.73	3.051
8	Bushlands—unprotected	4219.81	1.748
9	Grasslands—high livestock density	6578.74	2.725
10	Grasslands—low livestock density	5339.8	2.212
11	Grasslands—moderate livestock density	6529.63	2.705
12	Grasslands—protected	27,089.86	11.223
13	Grasslands—unprotected	5966.88	2.472
14	Impediments—protected	28.8	0.012
15	Impediments—unprotected	51.9	0.022
16	Open water—protected	36,984.29	15.322
17	Tropical high forest (encroachment)—subsistence	869.87	0.360
18	Tropical high forest—tree plantations	2407.54	0.997
19	Tropical high forest—with livestock activities	421.69	0.175
20	Tropical high forest—protected	3207.35	1.329
21	Urban—settlement	1432.26	0.593
22	Wetlands—protected	6013.49	2.491
23	Wetlands—with crop farmland activities	647.64	0.268
24	Wetlands—with livestock activities	487.98	0.202
25	Woodland/forest—high livestock density	235.59	0.098
26	Woodland/forest—low livestock density	1953.95	0.809
27	Woodland/forest—protected	6788.46	2.812
28	Woodland/forest—unprotected	287.27	0.119
29	Woodland/forest—moderate livestock density	102.5	0.042

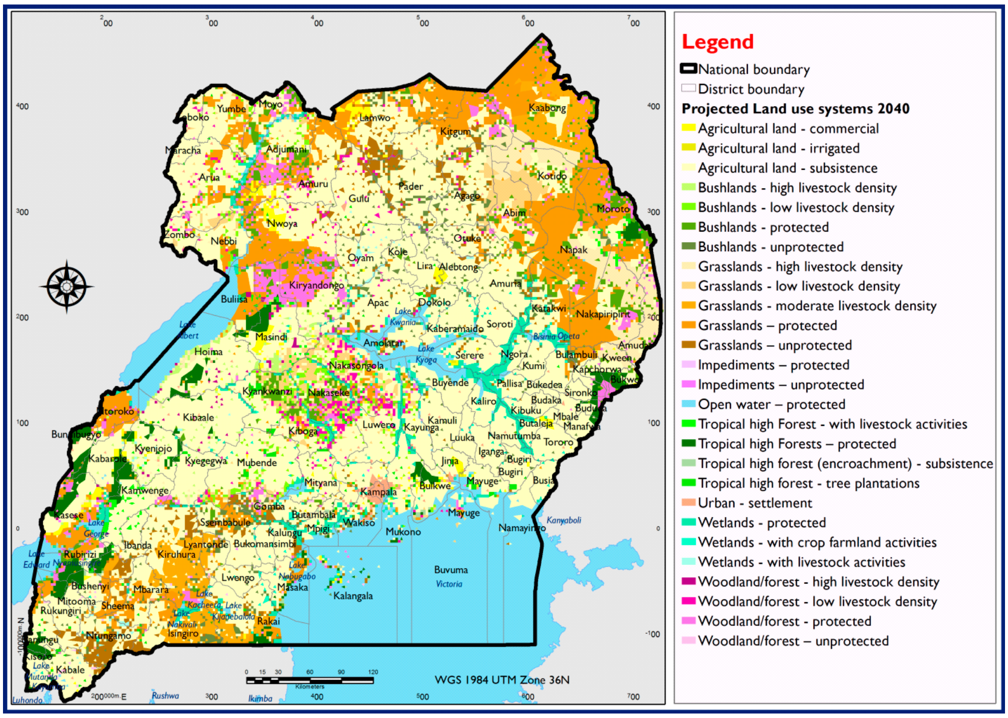

Figure 6. Projected land use systems of Uganda for the year 2040.

Subsistence agricultural land is projected to increase in Western mid-altitude farmland, in the Zombo Afromontane region, in the Southwestern rangeland, in the Lake Victoria crescent, and in the southeast Lake Kyoga floodplains. Figure 6 shows the predicted distribution of land use systems in 2040. Patches of woodlands are likely to emerge in the highlands of Kabale and around the Western arm of the East African Rift Valley system. Patches of tropical forest and tree plantations are also likely to emerge in the Northern moist farmland.

There are normally ambiguities in the acceptability of the results of land use/cover predictions, especially at a large scale and when the result predicts a future scenario based on disturbed variables. The prediction of land use systems model was built on an MLP built module at 1000 iterations. A fairly good model prediction accuracy (53%) was obtained for the conversions of current land use systems to the future.

4. Discussion

Agricultural land use systems dominate land use changes over the study period (between 1990 and 2015), even in the projection for the year 2040. This result was expected and it is consistent with several other studies that have been conducted for Uganda (for an example, see [35]). Using global land use change models, this is also a consistent observation that has been registered across several parts of the world; for example, by the authors of [36], who showed that extensions of the agricultural frontier were a dominant phenomenon observed across the sub-Saharan region. This result, along with previous studies, reaffirms the dominance of agriculture in the livelihoods of a larger population across the African continent and many developing countries. It is not surprising that several attempts to establish woodlots across the region would increase their dominance next to agricultural land use systems.

At a rate of population growth of 3.4% over the region, agricultural land uses are likely to increase by about 1% and this would severely affect the tropical high forest; an observation that has consistently been observed across many parts of the country by scholars, such as in [37]. At this rate of change, the amount of forest cover available in the future will diminish tremendously and therefore is not likely to support the livelihoods of people unless remedial and deterrent measures are put in place. The study revealed that most conversions of land use were directed into agricultural lands, followed by grasslands and bushlands. This suggests that these changes are the results of natural and human-related factors. This is in line with the Millennium Ecosystem Assessment (2005) and a previous report [38], which categorize the contributing factors of ecosystem change into natural or human-induced factors.

These factors are associated with population increase and its associated demands for land resources, inadequate enforcement of environmental laws, the economic values of major crops, culture, low education level for the majority of the people, land tenure, the small size of household land holdings, and political interventions. The contributing factors must, however, be understood and interpreted carefully given the multiple spatial and temporal scales, and social and methodological perspectives in which related studies have been conducted. There is indeed a clear distinction between contributing factors across scales. Moreover, interactions between contributing factors add to the complexity of land use change processes. For example, microlevel studies [35,38] have observed that land use change was occasioned by the prevailing governance shortfalls (policy–institutional dysfunctionality), demographic pressures, the unmonitored influx of immigrant settlers, and the erosion of institutional controls.

The projected unregulated increase in agricultural land is expected to be made at the expense of tropical high forest and unprotected woodland/forest. This was also observed by the authors of [39], who concluded that over 90% of private forests near Budongo Forest Reserve were affected by sugarcane growing. Because of the rising rural populations and high population density hotspots in Uganda [40], the need for agricultural land has increased across the country and this creates multiple threats for ecosystems in general and land use systems in particular. In fact, areas of high population densities in Uganda are typically agricultural production zones. With a national annual population growth rate that is estimated at 3.4%, the need for agricultural land among smallholder farmers should be expected to rise substantially. The growing importance attached to land for commercial agriculture and other large-scale land developments have increased the competition for land and stimulated market-based transactions. These interplays are responsible for large-scale land use changes across the country. The discovery of oil and proposals by sugar companies for large-scale land acquisition may further exacerbate the land use changes; the authors of [41] observed the same across the Albertine subregion, Northern Uganda, and the Busoga subregion. Although this was not explored in greater detail, we can also speculate that the increases in agricultural systems projected by the year 2040 may arise out of the need to satisfy the demands of the growing urban population. Indeed, the authors of [42] reported that the remaining forest is under increasing pressure from the rising urban demand for wood products.

The importance of the institutional and policy environment cannot be underestimated across the whole country. There is a myriad of policies and institutional frameworks which influence land uses across the country; a comprehensive Land Sector Strategic Plan in 2001 and a National Land Use Policy in 2013 followed the Land Act. More broadly, land and land uses are central to macro-scale policy frameworks, including the Uganda Vision 2040 and the National Development Plan II (2015/16–2019/20). However, their influence on land use change can only be speculative. Some studies (for example, see [43] have observed that land cover/use change and the systematic tenfold increase expansion of cropland is attributable to policy changes and interventions by the Government of Uganda and development partners to promote food security in the Afromontane subregion. On the other hand, evidence reported by [44] from the case studies in Kalangala and Amuru Districts demonstrates the incapacity of existing land governance institutions to cope with the scale of change, particularly in areas with existing or proposed commercial land investments. Similar challenges are evident in other areas with large-scale land acquisitions, even when they are not agribusiness-related. In the Albertine Rift, for example, the rush for land stimulated by oil development is overstretching the capacity of local institutions to cope and therefore increasing tenure insecurity.

This study also takes note of the fact that Uganda is prone to natural disasters such as landslides, floods, droughts, hailstorms and so forth that have devastated property and life, resulting in adverse effects such as loss of revenue, migration, and loss of household incomes [45,46]. These are primarily triggered by natural and human activities that have destabilized the natural systems, such as erratic rainfall, unsustainable farming practices, and unplanned settlements, among others. Therefore, this study envisages more disasters to occur in the country, meaning that more deaths and loss of property will occur if the rate at which land use systems are expanding is not monitored and controlled/regulated in the near future.

5. Conclusions

This study reveals a total of 29 classes of land use systems, categorized as follows: three (3) of the land use systems are agricultural, five (5) are under bushland, four (4) under forest, five (5) under grasslands, two (2) under impediments, three (3) under wetlands, five (5) under woodland, and one each under open water and urban settlement. The highest gains in the land among the land use systems were experienced in agricultural land—subsistence and grasslands—protected, while the highest losses were seen in the grasslands—unprotected, woodland/forest—low livestock density, and woodland/forest—unprotected. The grassland areas are highly prone to human encroachments with the aim to establish smallholder farms. By 2040, most of the land use systems' acreages are likely to change in terms gains or losses. Minimum gains or losses of land are likely to be recorded in only tropical high forest with livestock activities, woodland/forest with livestock activities, and woodland/forest unprotected. This is given the assumption that the current state of affairs stays the same. The changes in land use systems are highly driven by population pressure, weak enforcement of environmental laws, and the high economic value of major cash crops. This study will inform the local and national stakeholders on the state of natural resources and their problems and driving forces so that conservation efforts are incorporated in the subnational development plans before they diminish. However, this study takes note of the spatial resolution limitations of the data and inadequate validation of land use systems in all of the seven landscapes in Uganda.

The classification of land systems and their contributing factors clearly brings forward the major causes of land cover conversion to the decision-makers so that adequate plans can be made, especially in terms of allocating more funds towards conservation-related programs and also to enact effective environmental laws. These are fundamental in the national and subnational development planning of the country. This study, therefore, recommends a holistic involvement of all stakeholders and the increment of conservation and land use planning awareness programs throughout the country if the projected detrimental land use systems are to be controlled.

This study recommends that a detailed study to analyze and characterize the extent of influence of the perceived contributing factors of changes in land use systems in Uganda be conducted.

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