Chapter

Implications of Land Use and Cover Changes on Upper River Rwizi Macro-Watershed Health in South Western Uganda

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Abstract

The upper Rwizi river system in South Western Uganda has been severely degraded due to encroachment and unsustainable resource utilization. Little is, however, known about the link between the upper Rwizi macro-watershed health and land use/cover patterns from the spatiotemporal perspective. This study evaluated the relationship between spatiotemporal land use/ cover change and upper river Rwizi macro watershed health. Remotely sensed data was used to analyze the spatiotemporal land use and cover distribution for upper Rwizi macro watershed. The analysis was done using Landsat and Sentinel imagery datasets spanning 1990 to 2020 and 2016 to 2021 respectively. Field verification was undertaken to confirm the land use, cover types, and evaluate the implications of prevailing anthropogenic activities on the watershed health. The land use and cover characteristics in the upper Rwizi macro-watershed exhibits both highly spatial and temporal variations. By 1990, grassland as the dominant land use and cover type spanned 45% of the total study area followed by farmland at 30%. Forests, open water and settlements covered 12%, 10% and 3% respectively. Whereas grassland and forest cover has diminished drastically by 64% and 71% respectively, settlements and farmland have increased tremendously by 79% and 50% respectively between 1990 and 2020. The hillslope hydrological characteristics in the watershed are severely hampered due to increased human activities. It is, therefore, recommended that afforestation in the degraded areas be undertaken to restore the watershed health which could improve on hillslope hydrology.

Keywords: land use-cover changes, watershed health, river Rwizi

1. Introduction

River systems are crucial for the Earth's landscape development [1]. They play significant roles in the provision of water for domestic and industrial purposes as well as a number of resources to communities [2]. Due to their favorable ecological characteristics associated with humid climate and fertile alluvial soils, most river systems have attracted dense populations [3]. The high population densities within river systems have come with increased human activities [4]. The land use dynamics continue to impact on river catchments with negative repercussions on such fragile ecosystems [5]. River catchments are profoundly impacted by land use and cover change driven by anthropogenic activities [6]. The impact of anthropogenic activities on the riverbank morphodynamic is manifested in two ways [7]. First directly, in form of regulation works, artificial cut-offs, gravel and sand exploitation, dam constructions among others. Secondly, it is manifested indirectly in the form of deforestation, social and economic activities in river catchments [5]. Intensive human activities can indirectly impact more dynamic changes of natural processes, which may alter river processes and their subsequent hydro – ecological services [8].

Land Use and Cover Change (LUCC) is a key driver of environmental problems in river valleys and their catchments [9]. Land uses such as forestry, croplands and settlements have transformed most river catchments [10]. Land use and human activities within a watershed can lead to alteration in landscape's hydrological properties [11]. The surface landscape is often fundamentally altered during economic and social development [1]. The quantity, morphology and structure of river systems are usually inadvertently influenced along with land use changes [4]. Estimating historical LUCC trends is essential in assessing the rate at which change occurs; permit exploration of the drivers of that change and related implications [12]. Due to LUCC implications on watershed degradation, impacts like decline in river water quality and quantity often take route [13]. Degraded watersheds have posed serious problems for the environment and people living within river environments [3]. Effective management of watersheds, therefore, requires an understanding of the hydro – ecological resource changes over time and space amidst human activities [14].

The Rwizi river system navigates through Ankole highlands in South Western Uganda providing a source of water and livelihood to people across the region [15]. At least 12 districts including Rakai, Lyantonde, Isingiro, Lwengo, Kiruhura, Mbarara, Bushenyi, Buhweju, Rwampara, Sheema and Rubirizi depend on Rwizi's water for both domestic and commercial use [16]. The Rwizi river system that covers approximately 8,200 km [15] is under serious threat and is on the verge of drying up due to degradation [17]. River Rwizi, which is a lifeline for more than five million people in southwestern Uganda [16] including over 400,000 people in Mbarara City [18], has had up to 80 percent of its water drying up [17]. In recent years, river Rwizi has been branded as a river on the brink of extinction due to climate change, human encroachment and unsustainable resource utilization [15]. Its degradation is not unique but a common challenge to all river systems around the country [19]. Poor land management on the riverbanks and buffer zone is partly responsible for its catchment degradation [20]. The rapid population growth in the region has significantly increased pollution and untreated effluent discharge into the river system [16], while increased demand for water is causing the river to dry up [17]. The destructive agricultural practices, population pressure and unsustainable activities taking place within the river's catchment areas have led to the deterioration of its water quality and quantity [20]. These challenges are now fueling increased socio-economic hardships for local residents that are now manifesting through increased poverty, and continuous water shortages leading to water rationing in the region [15]. These challenges are likely to be exacerbated by the impacts of climate change and continued biodiversity loss [21]. There is, however, particular dearth of information on the implications of LUCC on the ecosystem health of upper Rwizi macro watershed. This, therefore, calls for an urgent need to undertake a spatial –temporal LUCC analysis on the upper Rwizi macro watershed in order to evaluate the major drivers and related implications of this change.

2. Methods and materials

2.1 Study area

The study was conducted in the upper Rwizi macro watershed within the Ankole highlands of South Western Uganda situated between latitude 0°36′06″S to 0° 48′85″S and longitudes 30°28′30″E to 30°59′65″E (**Figure 1**). River Rwizi originates from Buhweju hills with various tributaries from Ankore highlands and pours its water in Lake Victoria via the drainage systems of Lakes including Mburo, Kachera and Kijanebalola [17]. The upper Rwizi macro watershed was selected for a detailed study owing to increased degradation that is associated with spatiotemporal land use and cover distribution. The drainage network and topography served as baseline information for establishment of the study area and was delineated automatically from a 30 m Digital Elevation Model (DEM) in ArcGIS 10.5. Topographically, the landscape is a dissected plateau, variant of Koki land system characterized by long straight ridges [15]. The topography comprises mainly extensive flat-topped ridges and hills encircling down land arenas (**Figure 2**) typical of Ankole landscape [19]. The ridges have comb-like appearance due to many gullies on the landscape [22]. The geology of the area consists of a sedimentary rock system of the Precambrian age commonly referred to as Karagwe-Ankolean rock system. Quartz–mica and mica schists, shale, phyllite as well as swamp deposits and alluvium dominate this rock system. The soils of the highlands comprise acric ferralsols, dystric regosols, eutric regosols, gleyic arenosols, gleysols, histosols and leptoslos [20].

The study area experiences a bimodal rainfall pattern [16] with two wet and dry seasons [17]. The principal rainfall season is from late August to early December, while the minor one is from late February to mid-May [20, 21]. The average annual rainfall is 1000 mm per annum [23] however, mean annual rainfall can go as low as 750 mm in the eastern and as high as 1520 mm in western parts of the region [17]. There is a marked dry season experienced from June to August as well as January to

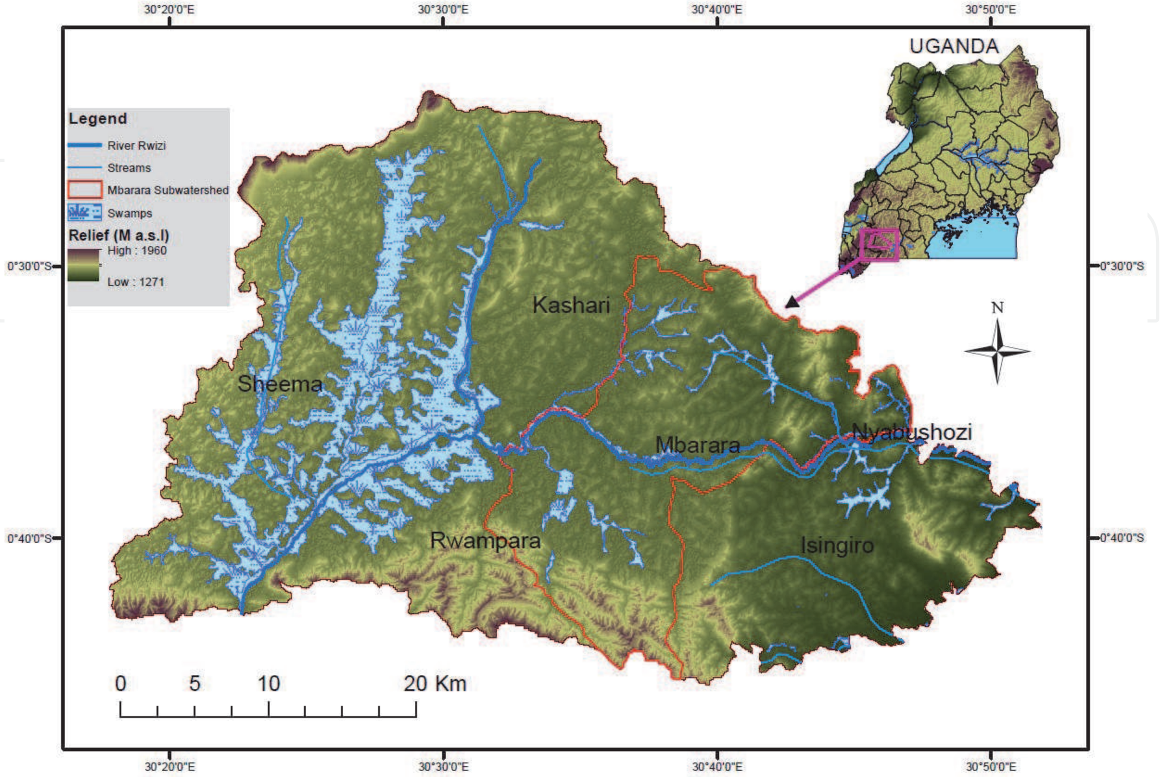

Figure 1.
Location of the study area indicating study sites.

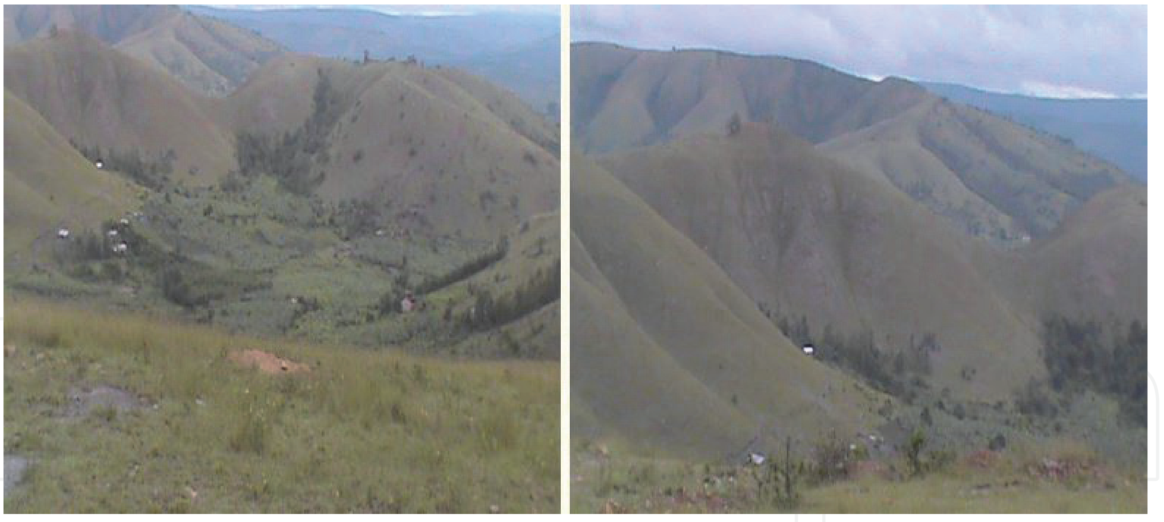

Figure 2.
Mbarara sub watershed landscape dominated by rolling hills. Photo credit, Ayesiga, November 2020.

February [24]. More than a century ago, the highlands in the watershed were covered by natural vegetation from the crest to the valley bottom dominated by *Themeda Triandra* and *Hyparrhenia rufa* grass species [21] as well as tree species including *Vernonia ammygdalina*, *Acacia sieberriana*, *Acacia hockii*, *C. edulis* and *Albizia coriaria* [17, 20]. These have however, been colonized by *Londetia kagerensis* on some hillslopes. The valley bottoms are currently dominated by *I. cylindrica* and *Cymbopogan afronadus*/ lemon grass [19]. The vegetation cover is characterized by medium savannah grass with scanty elephant grass (*P. purpureum*). The population density (361/km^2) of the region is one of the highest in Uganda [23] with its major source of livelihood being agriculture characterized by arable and livestock farming [16].

2.2 Datasets and sources

Remotely sensed data was used to analyze the spatiotemporal land use and land cover distribution for upper Rwizi macro watershed in south western Uganda. The analysis was based on Landsat and Sentinel imagery data sets spanning 1990 to 2020 and 2016 to 2021 respectively. Landsat satellite imagery of 30 m spatial resolution (path 172 and row 060) were downloaded from the open source site- USGS Earth explorer (https://earthexplorer.usgs.gov/). A Key Hole Mark-up Language File (KML) for Rwizi macro-watershed was developed using Google earth and later exported to USGS to delineate the area of interest. Specifications were made about the cloud cover (less than 10%) and dataset requirements. Landsat scenes for 1990 were picked from Landsat 4–5 TM, while scenes for 2000 and 2010 were picked from Landsat 7 ETM$^+$ level 1 archives. Landsat scenes for 2020 were picked from Landsat 8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) satellite. Selected scenes were dropped into the item basket in USGS and downloaded using the Bulk Download Application. The sorted scenes were then prepared in folders in windows files explorer for pre-processing.

2.2.1 Image processing and classification

Landsat images for 1990, 2000, 2010, and 2020 and Sentinel 2 images for 2016 and 2021 were exported to ArcGIS 10.5, geo-registered to WGS 84 datum, and projected into the Universal Transverse Mercator (UTM) zone 36 N coordinate system. Before performing the final analyses, a series of processes were performed on the downloaded images to improve visualization, processing speed as well as reducing noise. The nature of these processes necessitated swinging between two software packages of ArcGIS 10.5 and QGIS 2.18. The satellite scenes were loaded, visualized and inspected in the two software packages. Gap filling was, therefore, done to seal the existing gaps in the images. This was done in QGIS 3.4.2 using the fill NoData tool under the raster analysis tools provided by the GRASS plugin of open source software. The fill NoData tool which employs data from the gap masks provided by USGS to fill stripped zones on the scenes was done for 2010 image. Satellite imagery scenes downloaded contained the 'black NoData borders' which had to be discarded. This process was carried out in ArcGIS 10.5 utilizing the copy raster tool under the data management toolset. Using this tool, the NoData and background data values were set to zero. The first major pre-processing step performed was to create image composites for ease of visualization and interpretation of selected images. Formation of composites was done by stacking the eight bands of Landsat using the composite bands tool provided under the data management toolset of ArcGIS. Image composites for each path/row combination was done for each of the two scenes for the four selected years. Image composites were created by combining individual bands in a pre-determined pattern. This was done to enhance visualization but most importantly to capture different parts of the electromagnetic spectrum since different objects reflect in different parts of the spectrum. The band combination 432 was selected and used for creating the Red-Green-Blue image composites because it is the best band combination for visualizing and analyzing reflected vegetation [25].

2.2.2 Classification accuracy assessment

In Ref. [26], overall, producer's and user's accuracies and Kappa coefficient were calculated from the error matrix. The accuracy of the classification was verified by randomly generated reference points using a stratified random algorithm [27]. Following [28, 29], a minimum of 100 random points were generated per class using stratified random sampling approach for accuracy assessment. Field verification for land use and cover classification was conducted between January and August 2020 using draft classified map derived from satellite image for 2020 as a guide. The field verified data were utilized in the maximum likelihood report as an independent data set from which classification accuracy was compared. The land use and cover images for 1990, 2000 and 2010 were validated using Google Earth images taken in November 1990, July 1999 and October 2009 respectively. Higher classification accuracies were obtained for all the downloaded images due to improved sensors. An overall accuracy ranging between 69% (1990) and 85% (2020) was achieved for the Landsat images. The Kappa coefficient accuracies ranged from 0.65 to 0.82 for 1990 and 2020 respectively.

2.2.3 Land-use and cover change detection

Analysis of land use and cover changes was conducted in three temporal periods including, 1990–2000, 2000–2010 and 2010–2020. The satellite images had to be classified into five thematic classes namely settlements, farmlands, open water, forests and grasslands (Appendix 1). Supervised classification was performed in ArcGIS 10.5 using the maximum likelihood algorithm. The USGS Anderson classification scheme and class definitions were used to assign classes. Post-classification assessments were undertaken using majority filter, boundary cleaning and area calculation to clean the images. Post classification change detection technique was applied to identify the dynamic land use and cover elements from the successive years of satellite data. Post classification was used since the respective imagery were captured using different Landsat sensors and, therefore, with spectral differences. Analysis of land use and cover changes was performed based on automatic comparison of image sub-object hierarchies ("For example, see [30]"). The change detection matrix was computed to determine the proportion of each class which experienced change during the observation period. The major land use and cover change trends were identified from maps generated. The level of persistence was established through a cross-tabulation matrix.

2.2.4 Land use and cover change detection from sentinel images

Given the spectral characteristics of Landsat imagery, very high resolution images from Sentinel 2 were also used to evaluate the land use and cover changes within particular sections of the river system which could not be detected from Landsat images. Sentinel 2A images of spatial resolution 10 m spanning 2016 to 2021 of MSIL2A_N0214_R078_T36MTE type for 01/05/2016 and 27/01/2021 respectively were acquired from the European Space Agency (ESA) website ((https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2), through the Sentinels Scientific Data Hub archive. Using the same search specifications as for Landsat, only 2016 and 2021 images were found in the Sentinel 2 hub for Mbarara sub-watershed. Cloud-free Sentinel 2A images covering Mbarara sub-watershed within upper Rwizi macro watershed were selected and downloaded for land use and cover change estimation. Mbarara sub-watershed within upper Rwizi macro-watershed (**Figure 1**) was identified as the most affected section by land use and cover changes over 30 year study period. The European Space Agency's (ESA) satellite constellations Sentinel 2 program was used to combine both high spatial and temporal resolution. The images were subjected to atmospheric correction effects using the Sentinel 2 Correction prototype processing tool in SNAP. The already ortho-rectified Sentinel 2 images were geometrically corrected in Universal Transverse Mercator projection and World Geodetic System (WGS) 84 ellipsoid. The overall accuracy for Sentinel 2 images was 90% for 2016 and 92% for 2021. The Kappa coefficient was 0.87 and 0.90 for 2016 and 2021 respectively. Like for the Landsat images, five thematic classes were generated from the Sentinel images (settlements, farmlands, open water, forests and grasslands) utilizing the USGS Anderson classification scheme.

2.3 Field investigations and surveys

Before the interpretation of land use and cover maps, field investigations were undertaken between January and August 2020 to verify the actual land use and cover characteristics. Field verification was also undertaken to confirm whether the created maps lie within corresponding natural boundary. After field verification exercise, some correction was made in land use map before finalizing with the analysis. Additionally, survey data from local people and key informants living within Rwizi macro-watershed was collected to better understand and interpret the LUCC scenarios that emerged from the remote sensing and GIS analysis. During these field investigations conducted with the help of community members and local government technical officials, various land use activities carried out by communities in the watershed were identified and analyzed for their implications on the river ecosystem health. In course of the surveys, the status of riverbanks and buffer zone degradation as well as highly degraded zones within the watershed were ascertained.

3. Results

3.1 Land use and cover changes between 1990 and 2021

Land use and cover characteristics in the upper Rwizi macro-watershed exhibits both highly spatial and temporal variations. The detected spatial and quantitative changes in land use and land cover between 1990 and 2021 are given in **Figures 3**–7.

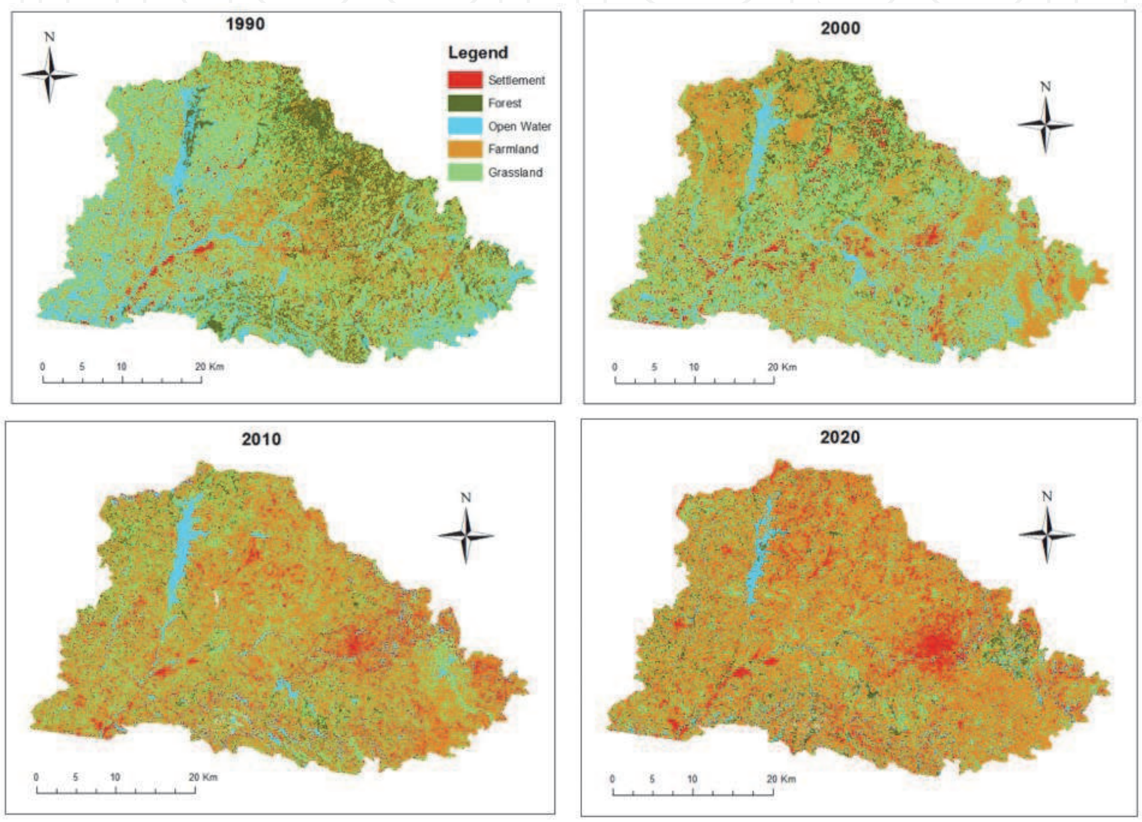

Figure 3.
Land use and land cover distribution between 1990 and 2020 for Upper River Rwizi macro watershed.

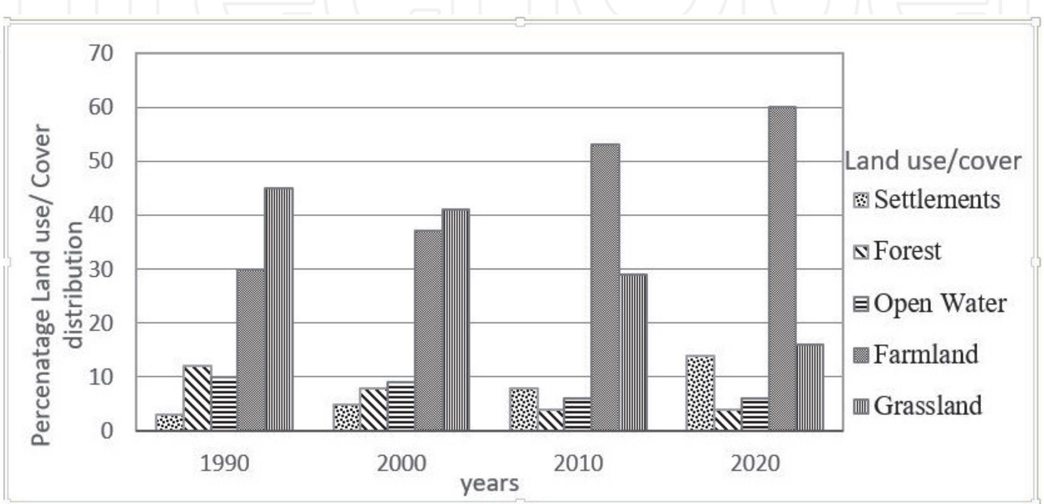

Figure 4.
Land use and cover changes between 1990 and 2020 for upper Rwizi macro watershed.

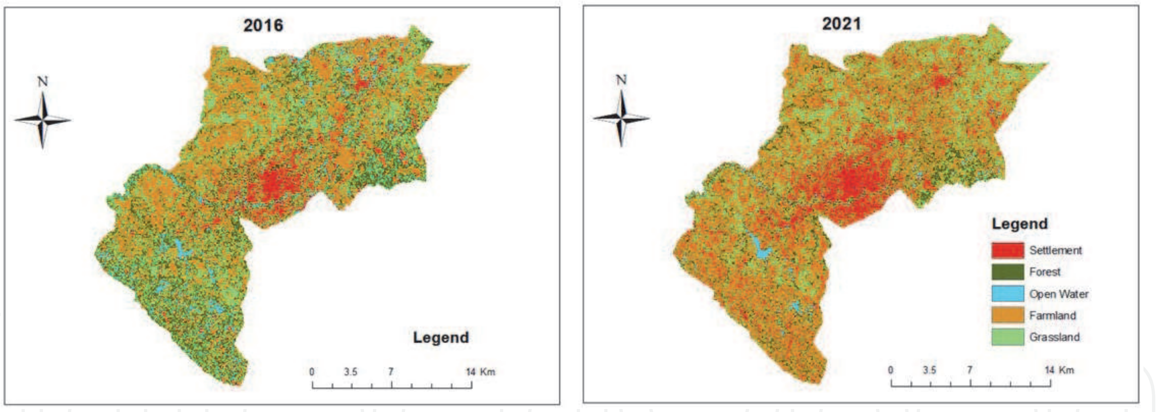

Figure 5.
Land use and cover distribution for Mbarara sub-watershed between 2016 and 2021.

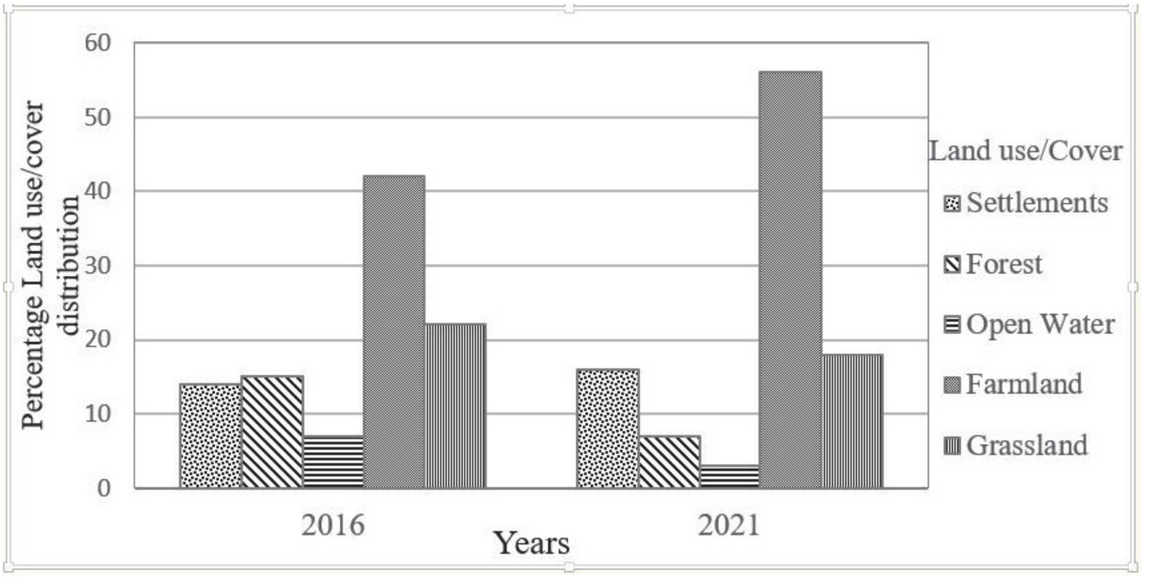

Figure 6.
Land use and cover changes for Mbarara sub-watershed between 2016 and 2021.

Figure 7.
Land use and land cover distribution between 2003 and 2021 based on Google earth images for a section in Mbarara City.

There are five land uses and covers detected as shown in the figures. From **Figures 3** and **4**, it is vividly noticeable that whereas, a decrease in forestland and grasslands is noticeable from 1990, farmland and settlements have expanded drastically.

Figure 4 illustrates the percentage land use and cover distribution in the study area from 1990 to 2020. By 1990, grassland as the dominant land use and cover type spanned 45% of the total study area coverage followed by farmland at 30%. Forest land, open water and settlements covered 12%, 10% and 3% respectively (**Figure 4**). Whereas grassland and forest cover have diminished drastically by 64% and 71% respectively between 1990 and 2020, settlements and farmland have increased tremendously by 79% and 50% respectively over the same period (Appendix 2).

The study area has experienced a drastic conversion of forests and grasslands to settlements and farmlands. For example during the 30 year study period, over 419 km^2 of grasslands and 126km^2 of forest land have been converted to settlements and farmlands (Appendix 2). The reclaimed open water sections along the river valley have been converted to settlements and farmlands covering 63.8 km^2 between 1990 and 2020.

Analysis of land use and cover changes within Mbarara sub-watershed between 2016 and 2021 shows drastic changes in their distribution (**Figures 5** and **6**). During the five year period, forests, open water and grassland reduced by 51%, 54% and 26% respectively within Mbarara sub-watershed. Meanwhile, farmland and settlements increased by 25% and 17% respectively during the same period (Appendix 3). By 2021, farmlands and setllements were the dominant land use and cover types in Mbarara sub-watershed covering 56% and 16% respectively. On the other hand, forests and open water were the least land use and cover types within Mbarara sub-watershed occupying 7% and 3% respectively (**Figure 6** and Appendix 3).

Within the Mbarara sub-watershed, 33km^2 of forest land and 28km^2 of grasslands were converted into settlements and farmlands between 2016 and 2021 (Appendix 3).

The study area has experienced a drastic conversion from natural land covers especially grasslands and forests to human dominated covers including farmlands and settlements over the past 30 years and more (see Google earth images in **Figure 7**).

3.2 Prevailing human activities in the study area

The main human activities in the watershed include crop farming, livestock rearing, fish farming, brick making, sand mining, motor vehicle washing and growing of eucalyptus trees. Forests have been cleared to open up land for farming and settlements. Following field investigations along the Rwizi river valley, it was established that there is increased farming and settlement activities in the study area (**Figure 8**). Reports from the local communities revealed that due to the falling crop yields, many farmers have started encroaching on wetlands along the river valley and forested areas in the search for fertile soils.

The observed farming practices in the study area include both arable and livestock farming. Whereas arable farming is dominant in lowlands and middle slope elements, livestock is commonly practised in the upper slope sections. The major crops grown include both perennial and annuals. The perennial crops include bananas (*Musa paradisiaca*), coffee (*Coffea spp*), tea (*E. abyssinica*), sugarcane (*S. officinarum*) and mangoes (*M. indica*) grown for commercial purposes. The annual crops include Irish potatoes (*Solamum tuberosum*), sweet potatoes (*I. batatas*), maize (*Z. mays*), beans (*P. vulgaris*), peas (*P. sativum*), finger millet (*Eleusin coracana*) and vegetables. In most cases, the crops are inter-cropped. For example farmers inter-crop annual crops in banana gardens especially during the wet season. The dominant cropping systems in the watershed is banana/coffee system.

Figure 8.
Farming activities along Rwizi river buffer zone. Photo credit, Ayesiga, March, 2021.

The study area has experienced increased population growth with a population density of 361/km^2 [23]. The high population growth in the upper river Rwizi macro watershed has led to establishment of several settlements of both rural and urban setting (**Figure 9**). In the study area, settlements are dominant in the valley bottoms and lower slope elements (**Figure 9**). This has led to establishment of roads, buildings and installation of various utilities such as power transmission and telecommunication lines (**Figure 9**).

Due to rapid urban development in the region, there has been an increase in demand for construction materials including sand and bricks. In order to meet the demand for construction materials, local communities have embarked on sand mining (**Figure 10**) and brick making (**Figure 11**) along the riverbanks, wetlands and buffer zones.

3.3 Implication of changing LULC

Changes in the land use and cover characteristics associated with increasing human activities have adversely affected the watershed properties. As already noted, there has been unprecedented conversion of natural land covers into human induced types. Following field investigations, it was established that many slopes flanking the river valley appear to be intensively cultivated leading to the emergence of many bare surfaces (**Figure 12**). Increased farming activities have affected

Figure 9.
Urban settlements along Rwizi river valley and buffer zone. Photo credit, Ayesiga patience. August 2020.

Figure 10.
Sand mining close to river Rwizi near Mbarara City and Rwizi's buffer zone in Nyakayojo. Photo credit, Nseka, December 2020.

Figure 11.
Brick making site near Ruti in Mbarara City and Nyaihanga in Rwampara Distrct. Photo credit, Ayesiga, February 2021.

hillslope hydrological properties. This has resulted into increased runoff due to reduced infiltration as evidenced by many gullies and other erosion features on the landscape (**Figure 12**).

The study established that many urban centres have emerged in the study area over the past 30 years. Settlements dominated by urban sprouting have attracted the development of socio-economic infrastructure (**Figure 13**). The construction of socio-economic infrastructure has created paved surfaces that inhibit infiltration thereby increasing surface runoff, erosion and flooding of the lowlands within the watershed.

Due to increasing urbanization, illegal land acquisitions along the river's buffer zone have occurred in the watershed. Several houses as well as crop gardens have illegally been established along the buffer zone within the upper river Rwizi macro watershed. An interaction with communities revealed that illegal land acquisitions along river Rwizi buffer zone has resulted in the reduction of its width and depth (**Figure 13**). Following field investigation and interaction with local communities, it was established that community members no longer need bridges to cross river Rwizi along several of its sections (**Figure 14**). The act of walking in this river is an indicator of low flow velocity and reduced water quantity.

During field surveys, it was established that the river channel is a few metres away from the gardens, however, due to encroachment on the river's banks, it was

Figure 12.
Intensively cultivated slopes which appear to be degraded. Photo credit: Nseka, July 2020.

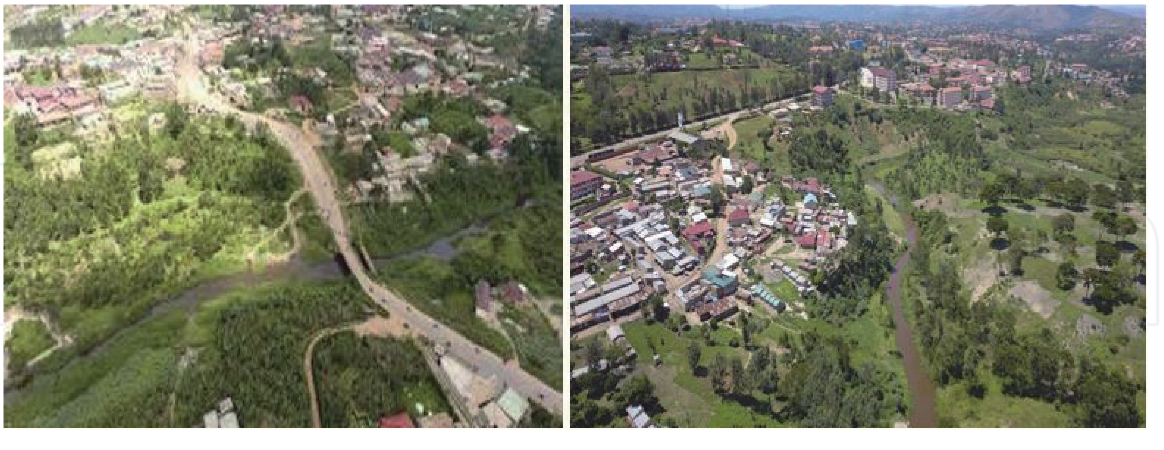

Figure 13.
Socio-economic infrastructure sprouting along the Rwizi river valley. Photo credit, Nseka Denis, September 2020.

hard to realize that there was water flowing. Following an interaction with communities, it was indicated that what used to be papyrus-filled riverbanks has now been cleared and instead, there are water channels from the river flowing to people's gardens. Farmers revealed that they have no alternative to farming other than Rwizi riverbanks, buffer zones and wetlands. Communities living within the upper Rwizi macro watershed confirmed that the water levels in the river system has declined over the years. They, therefore, live in fear that the river will be no more in the

Figure 14.
Shallow section of the river channel where local communities cross without bridges. Photo credit, Ayesiga, September 2020.

coming years if nothing is done to save it. During interactions with local communities, it was further reported that "the formerly wider river is narrowing". Sometimes, during the dry season, since there is hardly any water flowing from the hills, the water levels reduce into a small stream and, if one is not keen enough, they would think it is not a major river. Local communities indicated that sand mining and brick making along the riverbanks and its buffer zone have almost changed its course. Farming and sand mining are among the most destructive activities chocking river Rwizi to extinction. Due to increased human activities along the river valley, compounded with wetland and swamp destruction, the water levels in the river channel and its tributaries have drastically reduced. This is vividly evidenced by the river's water flow gauging station that is no longer used to monitor flow dynamics (**Figure 15**).

Following field investigations as well as interaction with local communities and key informants, it was established that the water levels of river Rwizi has dwindled by two and a half meters from the highest level where it used to be as indicated by the original gauging pillars at Nyamitanga which were established in 1970

Figure 15.
The river's water flow gauging station near Nyamitanga in Mbarara town has been rendered useless. Photo credit, Ayesiga patience, October 2020.

(**Figure 15**). Communities living in the watershed revealed that memories of the river with its ample clean water, thick vegetation, wild animals and birds are quickly fading. A close observation of the river channel indicates higher levels of turbidity, with the channel water turning to brown (**Figures 14–16**).

High levels of deposition were also evident in the form of pebbles, silt and clay on the riverbed that has been exposed following low water levels and subsequent reduction in water flow velocity as observed below Rubaya bridge along Buremba road and Ngaromwenda bridge on the Mbarara-Kabale highway (**Figure 16**). The drop in water levels is turning away investors whose project's lifeline depends on good volume of water in the Rwizi river. The drop in water levels is most likely, linked to the degraded hillslopes that no longer have the capacity to recharge the river system.

Due to continuous watershed degradation, many sections of the river channel have been invaded by the waterweed (**Figure 17**). The invasive water hyacinth has congested the river, right from Ndeija sub-county in Rwampara District up to Sango bay in Rakai and the problem has been exacerbated by destructive agricultural practices within the watershed.

The water hyacinth is an indicator of polluted water with many nutrients from the surrounding gardens. Following an interaction with communities, it was revealed that the river's deterioration is due to widespread illegal land grabbing along the fragile riverbanks and buffer zone.

Figure 16.
Dropped water levels along sections of the river Rwizi. Photo credit, Ayesiga patience, December, 2020.

Figure 17.
Sections of the river invaded and covered by water hyacinth near Mbarara City. Photo credit, Nseka, December 2020.

4. Discussion

4.1 Land use and cover changes

The original land cover status for the upper Rwizi macro watershed was generally a natural habitat of diverse flora and fauna experiencing natural hydro-geomorphological processes [21]. The hillslopes were intact, concentrated and promoting the natural movement of water and sediment [15]. The hillslopes flanking the watershed were once well covered by dense vegetation dominated by *Themeda Triandra* and *H. rufa* grass species [21] as well as tree species including *Vernonia ammygdalina*, *Acacia sieberriana*, *Acacia hockii, C. edulis* and *Albizia coriaria* [20] such that surface runoff was limited [17]. The study findings reveal a significant change in the land use and land cover distribution within the upper Rwizi river macro-watershed during the study period. In the study area, it is obvious that trends of land use and cover changes can be observed in the different periods due to evolvement of urban development and farming. Perhaps the most remarkable changes seen in this analysis were in form of settlements and farmlands, which have increased rapidly in the macro watershed. Settlements and farmlands have replaced the pre-existing natural forests, grasslands and open waters. They have directly changed the overall landscape composition of the watershed (**Figures 3**–7 and Appendix 2 and 3). The study findings vividly show that there has been a drastic conversion of natural land cover to human manipulated types. It was observed that most of the watershed has undergone massive transformation over the last three decades. These rapid changes could be attributed to the rapid population growth in the watershed over the past few decades [23]. The high population in the region of over 2,574,000 persons [31] and density of 361/ Km^2 [16] has put tremendous pressure on the land cover, leading to resource overuse and subsequent degradation [17]. This phenomena has also been responsible for the development of urban settlements (**Figures 9** and **13**). As observed by [6], population and economic growth often lead to spatial expansion of cities. This expansion may occur at the expense of increased risk of flooding, soil loss, riverbank erosion, changes in river courses, sediment load deposition and water pollution [1]. These environmental problems are aggravated by land use change from forestry to agricultural and other development activities such as construction of infrastructural facilities [4]. There has been a significant increase in building density accompanied by large-scale construction of socio-economic infrastructure including roads in the study area [32]. This has resulted into acute shortage of farmlands forcing people to encroach on the sensitive riverbanks and buffer zone [15].

Demographic pressure and the decreasing cultivatable land has significantly contributed to encroachments on both wetlands and the river's buffer zone. Increased demand for farmland and settlement land in the study area has led to uncontrolled clearance of forests and grasslands (**Figures 3**–7). The study findings are in keeping with observations made by [19] who noted that most of the natural land cover in the Rwizi catchment have been destroyed due to increasing land use practices. As can be observed on most of the hillslopes in the watershed, there has been complete depletion of vegetation cover (**Figure 12**). Many hillslopes in the watershed are already bare due to degradation. During the field investigations, it was observed that every available space has been intensively cultivated. Gardens appear like a continuous carpet for kilometers from the valley bottoms to uppermost slope sections (**Figure 12**). The river system has, therefore, been modified to meet the needs of human development in different social development stages. Many people have illegally acquired land along Rwizi riverbanks and buffer zones consequently destroying its wetlands. A number of higher order streams have been invaded, cut off and even buried, forcing most of them to transform into narrower streams. Most wetlands, which work as granaries for water and economically release it during the dry periods, have been destroyed to pave way for settlements and farming activities. As observed by [33], this scenario has partly been due to the existence of informal land acquisition policies and the growing land modification in the region.

4.2 Implications of land use and cover changes

The upper river Rwizi macro watershed was under a natural hydrological balance until about 100 years ago, when the dense forests, shrubs, thickets and tall grass began to be depleted [24]. As indicated by [34], the reduction in forest cover greatly affects the landscape's ability to intercept rainfall which greatly affects hillslope hydrological characteristics. Land use and cover changes affect various hillslope hydrological processes including interception, infiltration and evaporation, thereby influencing runoff generation [35]. It has been reported elsewhere that land use and cover changes often lead to natural ecosystem deterioration and landscape degradation [33, 36]. The highlands of the upper river Rwizi macro watershed have been severely degraded as evidenced by bare surfaces in many sections (**Figures 7** and **12**). This has affected rainfall partitioning thus exposing the hillslopes to severe runoff processes [15]. Vegetation cover degradation which is one of the most important parameters in water and soil conservation [36] has resulted into increased runoff coefficients and soil erosion in the upper Rwizi macro watershed [15].

In Ref. [5] reported a change in the occurrence of the highest runoff and erosion processes incidences in the highlands of South Western Uganda (location of study area) during the year. During the 1960s and earlier when the status of vegetation cover on the valley side slopes was still modest to abundant, the main runoff and erosion risk used to be during the period of March/April [15]. The pattern has, however, changed due to encroachment and the decimation of vegetation cover on valley side and upper slopes in the highlands [19]. The period of worst erosion problem has changed to September/October. This is due to heavy runoff from intense storms that are experienced after the aggressive dry season (June to August) that rage down the almost bare slopes [24]. The change in the main runoff and erosion risk is due to bush burning which is dominant during the prolonged dry season. Bush burning is practiced to provide fresh and greener pastures for the animals and prepare the land for cultivation [21]. Bush burning exposes the land surface to severe runoff and erosion during the subsequent September to November (SON) wet season in the region [17]. This explains why runoff and erosion processes are very intensive at the onset of the SON rainy season. Runoff and erosion processes, however, reduce as the rainfall season proceeds. This is associated with new vegetation that emerges due to increased moisture [15]. The emerging vegetation encourages infiltration while reducing runoff processes [37].

The change in land use and land cover has had significant negative impacts on the soil and river's water quality within the watershed. This is due to the application of excessive amounts of chemical fertilizers and pesticides, which inevitably runoff into the river system. It was reported during community interactions that whenever it rains, water runs on bare slopes, carrying topsoil, pollutants and silt with it. Heavy metals, fertilizers and herbicide have contaminated the waters, thus damaging ecosystems dependent on Rwizi river waters [24]. The silt is affecting the quality of the water in the river system [17]. The expansion of settlements threaten the river ecosystem health, particularly increased sewage disposal and solid waste dumping in rivers. People have built in the river's catchment, thus interfering with the water flow. Increasing urbanization taking place is affecting the hydrological characteristics of a watershed by reducing infiltration of rainwater into the ground and increasing the volume and speed of surface runoff. The replacement of forest cover with paved surfaces or other land use types increases water yield due to reduction in water losses resulting from soil compaction [38]. This increases stream discharge, which is an important element in fluvial processes of erosion and sediment transportation [2]. The processes of erosion and sediment transport result from an interrelated set of natural, human and hydrologic factors within a watershed [10]. The increasing artificial surfaces could be the potential source of pollution within the watershed. Several studies have also shown significant impacts of land use and land cover changes as a contributing source for water pollution [3, 5, 9]. Conversion of the existing land cover increases exposure to other problems in a watershed [7]. This is further confirmed by [11] who maintains that clearance of forest cover accelerates geomorphic processes leading to high sediment yield, rapid channel degradation and mass wasting. In Ref. [13], confirms that destruction of wetlands that can hold water and allow it to flow naturally leads to fast-flowing water in the river system. Due to encroachment within the river Rwizi watershed, the wetland and forest cover along the river valley can no longer hold water and release it in the dry periods. The study established that rainwater flows out of the river system very fast. This situation could contribute to other possible environmental problems such as microclimate change, increased run-off, pollution and degradation of ecological values as well as services within the watershed. Such scenarios could translate into increased hardships for local residents that manifest through decreasing access to clean water, flooding, erosion and intensified salination.

5. Conclusion

The upper river Rwizi macro watershed has experienced a drastic decimation of natural land cover categories especially forests and grasslands to human manipulated types dominated by settlements and farming due to increased population amidst informal land acquisition practices. The dominant human activities in the watershed include crop farming, livestock rearing, fish farming, construction, brick making and sand mining. Changes in the land use and cover characteristics associated with increasing human activities have adversely affected the upper Rwizi macro watershed properties. The watershed ecosystem health is worrying due land cover degradation. Due to increased human activities along the river valley compounded with wetland and swamp destruction, the water levels in the river channel and its tributaries have drastically reduced. The drop in the water levels is also due to the hillslopes inability to recharge the river system. The hillslope hydrological characteristics in the watershed are severely hampered. It is, therefore, recommended that afforestation be undertaken in the degraded areas of the watershed. The responsible agencies should also put more efforts into proper implementation and monitoring of already established laws and regulations like the National Environment Regulations, 2000 for wetlands, riverbanks and lake shores management. This will help to restore vegetation cover which could improve on hillslope hydrological balance. Restoration of the vegetation cover will counteract runoff and erosion processes which are on the increase. There is also an urgent need to provide alternative livelihood to river dependent communities in the watershed. With Mbarara's transformation into a city, there is need to reduce the scale of illegal settlements and development activities encroaching into the adjacent river valley wetlands. This study, therefore, recommends a change in land acquisition policies particularly in wetland and forested areas by revising the overlapping mandates of national agencies and district land boards that issue land titles in these fragile sensitive ecosystems. This should be coupled with a strict adherence of watershed developers to Environmental Impact Assessment standards.

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Conflict of interest

No conflict of interest by the authors.

List of appendices

Appendix 1: Land use and cover description

Class	Land-use/cover classes	Description
1	Settlements	Built-up areas, residential, commercials, rural & urban non-residential, roads and other structures
2	Forests	Tropical, deciduous, coniferous, and plantation forests
3	Open water	Seasonal and permanent wetlands, swamps, bog, streams and rivers
4	Farmlands	Cultivated gardens, fallow lands, plantations
5	Grasslands	Short and tall grasses, thickets, shrubs

Appendix 2: Land Cover changes based on Landsat imagery (1990–2020)

Class	Land Use/ cover class	1990		2000		2010		2020		Overall change	
		Sq.km	% age	Sq.km	% age	Sq.km	% age	Sq.km	% age	Sq. km	% age
1	Settlements	43.33	3	65.2	5	123.11	8	210.15	14	166.82	79.3
2	Forest	177.4	12	130.3	8	51.16	4	61.71	4	126.24	71.2
3	Open Water	144.5	10	126.31	9	93.12	6	80.72	6	63.8	44.1
4	Farmland	443.4	30	534.82	37	780.72	53	875.67	60	432.3	50
5	Grassland	658.04	45	610.02	41	418.46	29	238.32	16	419.72	64
Total		1466.57	100	1466.57	100	1466.57	100	1466.57	100		

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Appendix 3: Land cover changes based on Sentinel imagery data (2016 to 2021)

Class	Land Use/cover class	2016		2021		Overall change over 5 years	
		sq,km	%age	sq.km	%age	Sq.km	%age
1	Settlements	59.79	14	72.11	16	12.32	17
2	Forest	65.64	15	32.45	7	33.2	51
3	Open Water	24.67	7	11.36	3	13.31	54
4	Farmland	184.23	42	245.43	56	61.2	25
5	Grassland	106.44	22	78.42	18	28.02	26
Total		440.77	100	440.77	100		

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References

[1] Deng X.J, Xu Y.P, Han L.F, Song S, Liu Y, Li G, Wang Y.F. 2015. Impacts of Urbanization on River Systems in the Taihu Region, China. Water 2015, 7, 1340–1358.

[2] Han L.F, Xu Y.P, Lei C.C, Liu Y, Deng X.J, Hu C.S, Xu G.L. 2016. Degrading river network due to urbanization in Yangtze River Delta. J. Geogr. Sci. 2016, 26, 694–706.

[3] Lei Wu, Youpeng Xu, Jia Yuan, Yu Xu, Qiang Wang, Xing Xu & Haiyan Wen. 2018. Impacts of Land Use Change on River Systems for a River Network Plain

[4] Uddin K, Abdul Matin M, Maharjan S. Assessment of Land Cover Change and Its Impact on Changes in Soil Erosion Risk in Nepal. Sustainability. 2018; **10**(12):4715. https://doi.org/10.3390/su10124715.

[5] Wu L, Xu Y.P, Xu Y, Yuan J, Xiang J, Xu X, Xu Y. 2018. Impact of rapid urbanization on river system in river network plain. Acta Geogr. Sin. 2018, 73, 104–114.

[6] Deng X.J, Xu Y.P, Han L.F, Li G, Wang Y.F, Xiang J, Xu G.L. 2016. Spatial-temporal changes of river systems in Jiaxing under the background of urbanization. Acta Geogr. Sin. 2016, 71, 75–85.

[7] Abdulai A. Tahiru, Dzigbodi A. Doke, Bernard N. Baatuuwie. 2020. Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana Applied Water Science 10:198 https://doi.org/10.1007/s13201-020-01272-6.

[8] Hai D, Umeda S. & Yuhi M. 2019. Morphological Changes of the Lower Tedori River, Japan, over 50 Years. Water, 11, 1-16.

[9] Ahmed A & Dinye R. 2012. Impact of land use activities on Subin and Aboabo Rivers in Kumasi Metropolis. J Water Resour Environ Eng 4(7):241–251

[10] Chalise D, Kumar L. 2020. Land use change affects water erosion in the Nepal Himalayas. PLoS ONE 15(4): e0231692. https://doi.org/10.1371/journal.pone.0231692

[11] Chalise D, Kumar L, Kristiansen P. 2019. Land Degradation by Soil Erosion in Nepal: A Review. Soil Systems. 3(1): 12. https://doi.org/10.3390/soilsystems3010012.

[12] Wan Yusryza, Wan Ibrahim & Ahmad Nazri Muhamad Ludin. 2016. Spatiotemporal land use and land cover change in Major river basins in comprehensive development AREA, Journal of the Malaysian Institute of Planners SPECIAL ISSUE IV (2016). 225 – 242

[13] Adhikari S, Shrestha S.M, Singh R, Upadhaya S, Stapp J.R. 2016. Land Use Change at Sub-Watershed Level. Hydrol Current Res 7: 256. doi: 10.4172/2157-7587.1000256

[14] Julian J.P, Wilgruber N.A, de Beurs K.M, Mayer P.M, Jawarneh R.N. 2015. Long-term impacts of land cover changes on stream channel loss. Sci. Total Environ. 2015, 537, 399–410.

[15] NEMA (National Environment Management Authority). 2018. State of environment report for Uganda for 2017/18. National Environment Management Authority, Kampala, Uganda. Available at: http://www.nemaug.org [Accessed: 2020-11-17]

[16] UBOS (Uganda Bureau of Statistics). 2020. Statistical abstracts 2020. Ministry of Finance, Planning and Economic Development, Uganda.

Available at: http://www.ubos.org [Accessed: 2021-03-10]

[17] NEMA (National Environment Management Authority). 2020. State of environment report for Uganda for 2019/20. National Environment Management Authority, Kampala, Uganda. Available at: http://www.nemaug.org [Accessed: 2021-04-08]

[18] UBOS (Uganda Bureau of Statistics). 2019. Statistical abstracts 2019. Ministry of Finance, Planning and Economic Development, Uganda. Available at: http://www.ubos.org [Accessed: 2020-10-13]

[19] Wanyama J. 2012. Effect of Land-Use/Cover Change on Land Degradation in the Lake Victoria Basin: Case of Upper Rwizi Catchment, South Western Uganda [PhD disseration], Katholieke Universiteit Leuven.

[20] Bamutaze Y, Wanyama J, Diekrugger, B, Meadows, M., and Opedes H.2017. Dynamics of surface runoff and soil loss from a toposequence under varied land use practices in Rwizi catchment, Lake Victoria Basin. Journal of soil and water conservation, 72 (5): 480-492.

[21] NEMA (National Environment Management Authority). 2016. State of environment report for Uganda for 2015/16. National Environment Management Authority, Kampala, Uganda. Available at: http://www.nemaug.org [Accessed: 2020-07-12]

[22] NEMA (National Environment Management Authority). 2016. State of environment report for Uganda for 2015/16. National Environment Management Authority, Kampala, Uganda. Available at: http://www.nemaug.org [Accessed: 2020-12-10]

[23] UBOS (Uganda Bureau of Statistics). 2018. Statistical abstracts 2018. Ministry of Finance, Planning and Economic Development, Uganda. Available at: http://www.ubos.org [Accessed: 2020-10-20]

[24] NEMA (National Environment Management Authority). 2017. State of environment report for Uganda for 2016/17. National Environment Management Authority, Kampala, Uganda. Available at: http://www.nemaug.org [Accessed: 2020-10-17]

[25] Horning N. 2004. Justification for using photo interpretation methods to interprete Satellite imagery: Version 1.0 American Museum of Natural History, Center for Biodiversity and Conservation. Available at: http://biodiversityinformatics.amnh.org [Accessed: 2020-12-21]

[26] James, B.C. and Randolph, H.W. 2011. Introduction to remote sensing. The Guilford Press, New York, U.S.A, 335-375.

[27] Jensen J.R. 2005. Introductory Digital Image Processing: A Remote Sensing Perspective. Pearson Education, Inc., New Jersey, U.S.A., 107-312.

[28] Skirvin S.M, Kepner W.G, Marsh S. E, Drake S.E, Maingi J.K, Edmonds C.M, Watts C.J & Williams D.R. 2004. Assessing the accuracy of satellite – derived land – Cover classification using historical aerial photography, Digital orthophoto quadrangles and air borne video data. In R. Lunetta and J.C. Lyon (Eds.), Remote Sensing and GIS Accuracy Assessment, CRC Press, Bocca Raton, Florida, pp. 115 –131.

[29] Congalton R.G & Green K. 2009. Assessing the accuracy of remotely sensed data: Principles and practices (2nd Edition), Taylor and Francis Group, LLC, New York.

[30] Yang H, Adler R, Huffman G. 2007. Use of satellite remote sensing in the mapping of global landslide susceptibility. Natural Hazards 43(2):

245–256. doi: 10.1007/s11069-006-9104-z

[31] UBOS (Uganda Bureau of Statistics). 2017. Statistical abstracts 2017. Ministry of Finance, Planning and Economic Development, Uganda. Available at: http://www.ubos.org [Accessed: 2020-10-12]

[32] UBOS (Uganda Bureau of Statistics). 2016. Statistical abstracts 2016. Ministry of Finance, Planning and Economic Development, Uganda. Available at: http://www.ubos.org [Accessed: 2020-11-17]

[33] Wasswa H, Kakembo V & Mugagga F. 2019. A spatial and temporal assessment of wetland loss to development projects: the case of the Kampala–Mukono Corridor wetlands in Uganda. International Journal of Environmental Studies. 76(2):195–212. Routledge, Taylor and Francis Group Publishers. DOI: 10.1080/00207233.2018.1494931

[34] Josephat M. 2018. Deforestation in Uganda: population increase, forests loss and climate change. Petroleum Production and Geoscience- Makerere University, Department of Wildlife and Natural Resources- Uganda Wildlife. Research & Training Institute, Uganda. ISSN: 2529-8046

[35] Promper C, Puissant A, Malet J.P & Glade T. 2014. Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios, Applied Geography 11–19

[36] Mango L.M, Melesse A.M, McClain M.E, Gann D, Setegn S.G. 2011. Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modelling study to support better resource management. Hydrology of Earth System. Science. 15 (7), 2245–2258.

[37] Bagoora F.D.K. 1993. An assessment of some causes and effects of soil erosion hazard in Kabale highlands, South Western Uganda, and people's attitude towards conservation. In Abdellatif (Ed) Resource Use and Conservation, Vol 8: Faculty of Social Sciences; Mohammed V. University, Rabat Morocco. Mountain Research and Development.

[38] Mao D & Cherkauer KA. 2009. Impacts of land-use change on hydrologic responses in the Great Lakes region. Journal of Hydrology. 374 (1–2), 71–82.