Chapter

The Impact of Land Use and Land Cover Changes on the Nkula Dam in the Middle Shire River Catchment, Malawi

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Abstract

Land use and land cover changes over a 26-year period for the middle Shire River catchment, Malawi, in southern Africa, were assessed using geographic information systems (GIS) and remote sensing techniques. The catchment area under study was divided into two sections, western and eastern sides of the Shire River. High rate of deforestation averaging 4.3% per annum was observed and more pronounced in the western side of the river. Rapid population growth and increase in gross domestic product (GDP) are identified as the major drivers of deforestation and forest degradation due to clearing of vast fields for agriculture, land expansion for urban settlement, and cutting down of trees for wood fuel energy. Deforestation in the middle Shire River catchment has resulted into increased soil loss through erosion causing huge accumulation of sediment at the Nkula B Hydroelectric Power Dam downstream and, consequently, causing serious problems with generation of hydroelectricity. Frequent droughts and floods in the area have drastically affected crop production forcing people into cutting down of trees for charcoal as a livelihood strategy. Combined techniques such as GIS, remote sensing, and socioeconomic factors used in this study could be applied in other places where similar challenges occur.

Keywords: LUCC, GIS, remote sensing, soil, Malawi

1. Introduction

Land use and land cover changes have significant environmental consequences at local, regional, and global scales. These changes have intense implications at the regional and global scales for global loss of biodiversity, distresses in hydrological cycles, increase in soil erosion, and sediment loads [1]. At the local level, changes in the use of land and its cover affect watershed runoff, microclimatic resources, processes of land degradation and landscape-level biodiversity, soil erosion, and sediment loads [2]. All these have direct impacts on livelihoods of local societies.

The Shire River in Malawi, southern Africa, is among the areas where land use land cover change (LUCC) has become more prevalent in recent years resulting into severe soil erosion and causing heavy siltation downstream [3–9]. The river is an important source of livelihood to many people, using the water for agriculture, domestic purposes, and the generation of electricity [6, 8, 10]. One of the most important structures across the Shire River is the Nkula B Hydroelectric Power Station situated in the middle section of the river. The dam at Nkula Falls that supplies water into the power station has, in recent times, been threatened with massive siltation, some studies attributing this to increased human population and agricultural activities [5, 6, 8]. The conceptual setting of this study originates from a strong link that exists between land use change and soil erosion [8, 11–15]. Land use and management practices are important factors in determining the extent of soil erosion [8, 15]. Good vegetation cover promotes infiltration of water into the ground and soil retention, while deforestation results into increased runoff than infiltration occurring during periods of more precipitation [16–18]. Increased runoff consequently leads to stronger soil erosion usually in areas with poor vegetation cover [8, 19–20]. Erosion of soil under continuous cultivation is the most serious form of resource degradation occurring in Malawi [3, 8, 19, 21–23]. The rate of soil loss in Malawi is currently estimated at 29 t/ha/year [24], which is higher than the previously reported 20 t/ha/year [21]. In the middle Shire River, estimated soil loss between the year 2000 and 2014 ranged from 0.1 to 21.1 t/ha/year [24, 25]. According to the Malawi Government Report (2015), the middle Shire River catchment has many bright spots (areas experiencing high soil loss but declining trends over time), for example, Neno and Ntcheu in the west and Zomba and Chiradzulu in the eastern side of the river.

The question regarding land use changes over time, and its driving forces in the middle Shire River catchment nevertheless remain unresolved [4, 6]. Such knowledge is critical to the development of policies and action plans necessary for changing current LUCC trends in the area as it has been observed in other places [26–30]. Furthermore, problems of LUCC are global and serious in many developing countries where increasing population has resulted into excessive pressure on natural resources [8, 30].

The study was carried out to understand the impact of land use and land cover changes on the Nkula Dam in the middle Shire River catchment, Malawi. The LUCC drivers analyzed in this study include biophysical changes (e.g., climate change) and human activities (e.g., population, poverty, land policies, and GDP growth) [3, 4, 6]. Climate and socioeconomic data were compiled to analyze the drivers of LUCC in the study area. Geographic information systems (GIS) and remote sensing techniques which are gaining increased recognition globally as rapid methods of acquiring and analyzing up-to-date information over a large geographical area were used in the study [30–33].

2. Study area and methods

2.1 Description of the study area

The Shire River is the largest river in Malawi, originating from Lake Malawi which supports vast agricultural and socioeconomic activities in its catchment (**Figure 1**) [34]. The river is divided into three sections, namely, the upper, middle, and lower Shire [34, 35]. This study focused on the catchment of the middle section of the river which includes the Shire Plain which is bounded by mountains on both sides and the Nkula Dam downstream [34, 36]. The plain is more extensive to the west of the river than it is to the east (**Figure 1**). The middle section of the Shire River has eight administrative districts, supporting a population of about 5 million people (**Figure 1**).

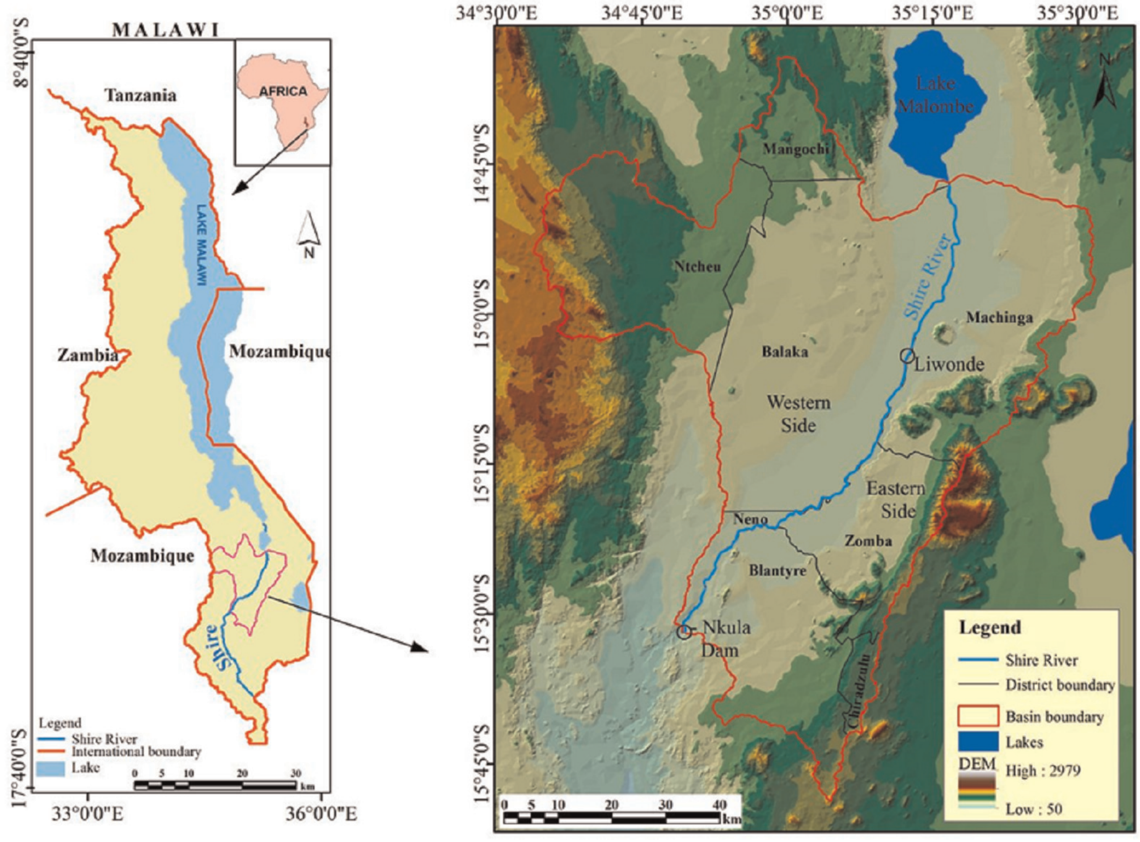

Figure 1.
Map of Malawi (left) showing the middle Shire River and its catchment (right). Eight administrative districts are located in the study area.

Climate in the middle Shire River catchment area varies due to differences in altitude with annual average precipitation ranging from 750 to 2500 mm [35, 37]. Highlands receive more rain which begins in November and ends late in April [6, 37]. Annual average temperature of the area is around 23°C, with highlands in the east experiencing cooler temperatures than plains in the west [6, 35]. The rocks in the study area are mainly composed of Precambrian basement complex and igneous rocks [37]. Amphibolite and granulite facies are dominant in the western and eastern side of the Shire River, respectively, while soils in the river's catchment are dominated by Cambisols [6, 24, 37].

2.2 Data collection procedure

The following procedures were followed in order to answer the study questions: firstly, six Landsat images for the dry seasons (to avoid cloud cover effects) of 1989, 1993, 2000, 2006, 2011, and 2015 were downloaded from the United States Geological Survey (USGS, http://glovis.usgs.gov/) at Level 1 T using different paths and rows (167/070, 167/071, 168/070, and 168/071). All images had a spatial resolution of 30 m which is large enough to visualize changes in land use [38] from Landsat 5, 7, and 8. Secondly, meteorological, topographical, and socioeconomic data from 1989 to 2015 were collected from the Malawi Department of Meteorological Services and Statistics [24, 36]. The third stage was the processing of the Landsat images and, finally, classification of land use which was followed by analysis of different land covers. Statistical analysis was done on data for the topography of the catchment area, temperature, rainfall, population, and GDP in order to determine drivers of LUCC.

2.2.1 Remote sensing image processing

Landsat images were processed using ENVI 5.1 Software to study information on the types of land use and their spatial patterns. To analyze these spatial patterns, the following steps were followed: firstly, relative radiometric correction was done on each band to eliminate errors arising from radiation caused by weather conditions; secondly, multiband combination of Landsat images was done in preparation for research spectral characteristics of various types of land use; thirdly, geometric correction of remote sensing images was done using Malawi DEM, Universal Transverse Mercator Projection, Arc 1960, and UTM Zone 36S, based on 1:50,000 topographic map scale so that it fits with the Landsat images [38, 39]. This helps to eliminate position errors of Landsat images which the terrain, position of the sun, and angle sensor may produce. A mosaic of required images was prepared and a single image generated. Atmospheric Landsat images were then corrected by ENVI 5.1 FLAASH module.

2.2.2 Land use classification

After processing the Landsat images, identification of different land use classes was done where some visual designs like texture, tone, and the effect zones were used [38]. The land in the study area was classified according to its use or description such as cultivated land, water, forest (indigenous and plantations were combined), etc. When identifying the training sites, the spectral signatures separability of all the eight land use classes presented in **Table 1** were verified including control fields in situ that were also set for validation of each classified image [38]. Land use types were classified by supervised classification maximum likelihood method since it's among the broadly used methods in the scientific literature in addition to it being the fastest and easy to use and giving a perfect interpretation of the outcomes [38–44]. In addition, the method is able to accommodate covarying data which is common with satellite image data [41, 45]. Representative zones for each desired class were located in the image with adequate number of pixels covering the known classes to reduce the image noise [38]. Secondly, training area number and percentage were identified in order to classify several training and test areas. These results were compared with supporting ground data so that the new training statistics could be derived. Thirdly, a statistical file known as spectral signature was created by the image processing software for each class because each and every pixel can only be assigned to one spectral class. Lastly, each pixel was allocated to the most likely class based on the maximum likelihood algorithm where each pixel is assigned to the spectral class that has the greatest probability density function for the multispectral values of the pixel. Maximum likelihood algorithm is the most commonly used algorithm in which a pixel is classified into the corresponding class [38, 43, 46]. Land cover types were then classified into the following eight main classes according to Anderson et al. [47]: (1) forest, (2) shrubland, (3) grassland, (4) cultivated land, (5) bare land, (6) water bodies, (7) wetland, and (8) artificial surfaces (**Table 1**).

A total of 165 training sites (sampled portions of the scene, purposely selected, for the derivation of the training statistics) were chosen for each image to ensure that all spectral classes constituting each land use and land cover categories were adequately represented in the training statistics to classify the entire scene [48]. Classification was done using ground checkpoints, digital topographic maps, vegetation cover map, and the researchers' knowledge of the study area [49, 50]. A total of 156 sampling points (GPS + photograph) were collected out of the 165 training sites during the dry season to avoid cloud cover effects which is more common in

No.	Land cover class	Description
1	Forest	Woodland open general (15–65%) with herbaceous layer. Broadleaved deciduous trees, closed >(70–60)%. Vegetative cover is in balance with the abiotic and biotic forces of its biotope
2	Shrubland	Closed to open (thicket) (15–100%) scattered trees
3	Grassland	Herbaceous closed vegetation (15–100%) with some trees, shrub Savannah, and permanent marsh
4	Cultivated land	Areas where the natural vegetation has been removed or modified and replaced by other types of vegetative cover of anthropogenic origin. All vegetation that is planted or cultivated with intent to harvest is included in this class
5	Bare land	Bare rock and/or coarse fragments. Areas that do not have an artificial cover as a result of human activities. These areas include areas with less than 4% vegetative cover
6	Water bodies	This class refers to areas that are naturally covered by water, such as lakes, rivers, snow, or ice
7	Wetlands	Areas that are transitional between pure terrestrial and aquatic systems and where the water table is usually at or near the surface or the land is covered by shallow water
8	Artificial surfaces	Areas that have an artificial cover as a result of human activities, such as construction (cities, towns, and transportation), extraction (open mines and quarries), or waste disposal

Table 1.
Land cover classes considered and their description [71].

rainy season. Land use types at the sampling sites were evaluated according to field surveys (photographs + GPS) where photographs were taken using a camera and coordinates of the spot were taken using GPS. Accuracy of the supervised classification methods was checked by a confusion matrix of accuracy (**Table 2**) [38, 44, 51] to ensure that various measures, such as error-rate, accuracy, specificity, sensitivity, and precision, were checked.

Landsat image classified type results were compared with the field survey results to evaluate their accuracy and then calculated using confusion matrix evaluation table (**Table 2**).

2.2.3 Statistical analysis

LUCC drivers were mainly analyzed using descriptive methods due to inavailability of spatial socioeconomic data from the government database. Pearson correlation coefficients between socioeconomic data and land use types were analyzed in SPSS for Windows version 10.

3. Results

3.1 Land use and land cover changes over the past 26 years

The overall classification accuracy ranged from 82 to 94% (**Table 2**). The western side of the Shire River covers an area of approximately 3353 km^2, while the eastern side is 2770 km^2 comprising 55 and 45% of the total area, respectively. Regions were defined by slope of less than 10o as plain/flat area. According to **Table 3**, total plain/flat area covers 2417 km^2 which is lesser compared to highlands

Actual type	Classified type									
	Forest	Shrubland	Grassland	Cultivated land	Artificial surfaces	Wetland	Water bodies	Bare land	Actual sum	Accuracy
Forest	9	1	1	0	0	0	0	0	11	82%
Shrubland	0	14	1	1	0	0	0	0	16	88%
Grassland	0	1	20	1	0	1	0	1	24	83%
Cultivated land	0	0	1	21	1	0	0	0	23	91%
Artificial surfaces	1	1	1	2	34	0	0	0	39	87%
Wetland	0	0	1	0	0	8	0	0	9	89%
Water bodies	0	1	0	0	0	1	32	0	34	94%
Bare land	0	0	0	0	0	0	0	0	0	0
Classified sum	10	18	25	25	35	10	32	1	156	

Table 2.
Confusion matrix of accuracy evaluation in middle Shire River catchment in 2015.

Area/coverage	Plain (≤10°)		Highlands (10–90°)	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Western side	1429	59	1075	29
Eastern side	988	41	2631	71
Total catchment area	2417	100	3706	100

Table 3.
Distribution of plains and highlands in eastern and western side of the middle Shire River.

(with slope ranging from 10o to 90o) covering 3706 km^2. Eastern and western plain/flat areas cover 988 and 1429 km^2, representing 41 and 59% of the total plain/flat area of the study area, respectively (**Table 3**).

The middle Shire River catchment is dominated by shrubland, grassland, cultivated land, and forestland, which accounted for 36, 28, 22, and 12% in 1989, respectively (**Figure 2**).

Findings (**Table 4**) show significant land use and land cover changes in the middle Shire River catchment over the 26-year period.

Artificial and cultivated land increased by 65 and 52%, respectively, in the 26-year period, while forest cover, grass, and shrubland decreased by 35, 27, and 7%, respectively. Other land classes such as wetlands and water bodies show

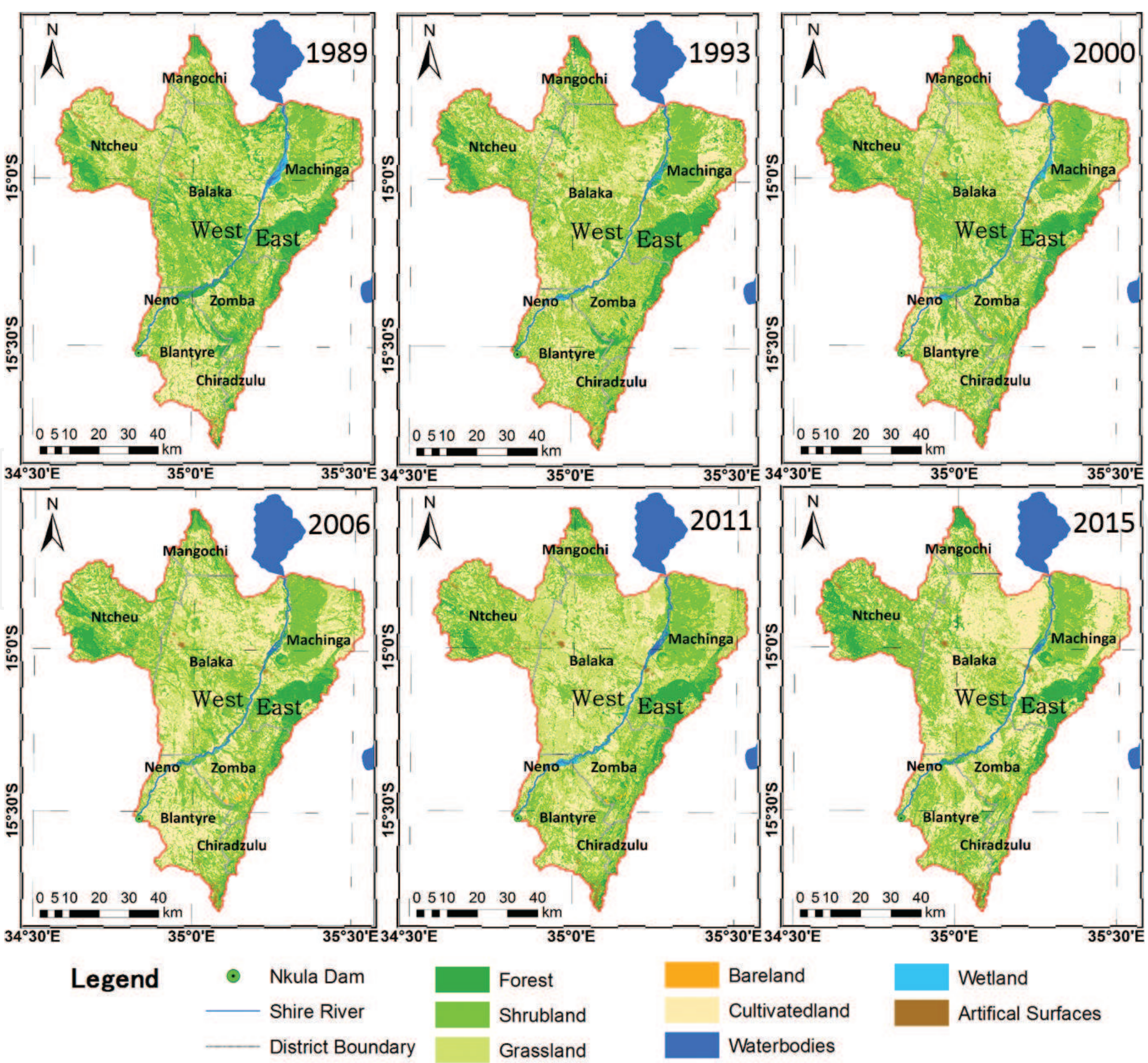

Figure 2.
Land use and land cover changes from 1989 to 2015.

Land cover type	Year											
	1989		1993		2000		2006		2011		2015	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Forest	739	12.07	679	11.08	545	8.90	479	7.82	481	7.86	662	10.80
Shrubland	2201	35.95	1986	32.44	2264	36.97	2043	33.37	1835	31.85	2040	32.97
Grassland	1719	28.07	1838	30.02	1451	23.69	1692	27.63	1617	24.53	1255	20.52
Cultivated land	1367	22.33	1538	25.12	1745	28.50	1814	29.64	2067	33.76	2073	34.09
Artificial surfaces	26	0.43	28	0.45	33	0.54	37	0.60	39	0.64	43	0.71
Wetland	35	0.57	23	0.38	56	0.91	19	0.31	38	0.63	20	0.34
Water bodies	31	0.51	30	0.49	20	0.33	30	0.49	36	0.58	22	0.44
Bare land	4	0.06	2	0.03	9	0.15	9	0.15	9	0.15	8	0.13

Table 4.
Area (km^2) and percentages of different land cover types from the year 1989 to 2015.

fluctuations (**Figure 2** and **Table 4**). Spatially, in 1989, total cultivated land in the western side was 694 km^2 which increased to 1226 km^2 by the year 2015, representing 21 and 37% of the total land in the western side, respectively (**Table 5**).

This suggests an increase of 16% of cultivated land in the western side between 1989 and 2015. In the eastern side, cultivated land increased from 673 to 862 km^2 within the same period, representing 24 and 31%, respectively, of the total land area indicating a 7% change. In 1989, the western side of the Shire River catchment mainly consisted of shrubland, grassland, and forestland which accounted for 35, 33, and 10%, respectively. In the eastern side, shrubland, grassland, and forestland accounted for 37, 22, and 15%, respectively. The western side (Balaka, Neno, and Ntcheu) and eastern side (Zomba) are the main districts where forest, shrubland, and grassland decreased the most. For example, in Balaka District, forest area reduced from 11% in 1989 to 2% in 2011 before increasing to 3% in 2015, while shrubland decreased from 38% in 1989 to 18% in 2011 and then increased to 23% in 2015. Forestland in Neno District decreased from 10% in 1989 to 1% in 2011 and then increased up to 5% in 2015, while shrubland decreased from 35% in 1989 to 19% in 2015 and grassland from 27% in 1989 to 17% in 2015 with some fluctuations in between the years. In Ntcheu District, grassland decreased from 35% in 1989 to 15% in 2015. Forest cover in Zomba district declined from 19% in 1989 to 7% in 2006 and then started to increase from 2011 reaching 12% in 2015. Shrubland decreased from 41% in 1989 to 27% in 2015 in the same district.

3.2 Changes in climate, population, and GDP

Results indicate some fluctuations in the amount of rainfall received in the area within the 26-year period that might be due to climate change as a result of land use and land cover changes due to human activities (**Figure 3**).

Rainfall in the catchment area declined continuously from 1989 to 1993, culminating into the drought of 1992 and 1993 (**Figure 3**) [52, 53]. Malawi is regularly affected by drought and floods [53]. The country (including the study area) was affected by heavy floods in 1989, 1998, 2000, 2001, and 2015, destroying crops and displacing many people (**Figure 3**) [53]. Earlier studies indicate that rainy season in Malawi is dominated by tropical and extratropical influences with links to the El

Location/district		**Year**					
		1989	**1993**	**2000**	**2006**	**2011**	**2015**
Western side	Balaka	335	556	627	655	688	853
	Mangochi	59	51	41	80	47	91
	Neno	25	41	49	38	28	53
	Ntcheu	275	298	219	226	219	228
	Total area	694	946	935	999	982	1226
Eastern side	Blantyre	359	264	362	381	244	278
	Chiradzulu	33	9	19	17	18	23
	Machinga	184	247	264	263	135	368
	Zomba	96	71	165	155	122	194
	Total area	673	591	810	816	520	862

Table 5.
Changes in cultivated land area (km^2) in districts of the middle Shire River catchment.

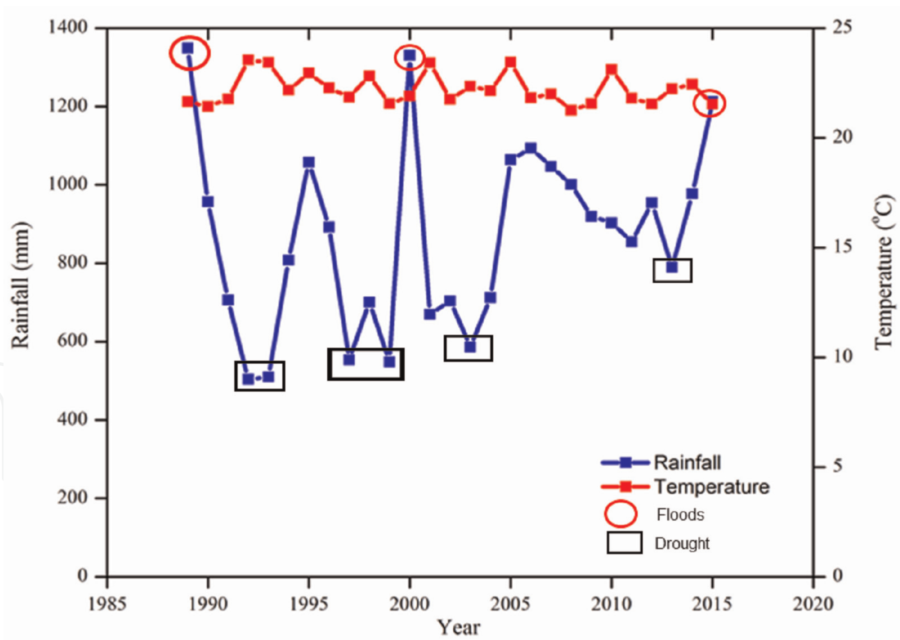

Figure 3.
Annual rainfall and temperature for the middle Shire River catchment from 1989 to 2015. Circles represent flood years, while rectangles represent drought years (Source: Malawi Meteorological Department).

Niño-Southern Oscillation (ENSO) [54, 55]. Actually, this is reported for the whole of Southern Africa [56].

The population of Malawi which includes districts under study on the western (Mangochi, Balaka, Ntcheu, and Neno) and eastern sides of the middle Shire River (Blantyre, Zomba, Machinga, and Chiradzulu) has been increasing steadily since the 1980s (**Figure 4**).

Increased population is more pronounced in urban areas. For example, in 2015, Blantyre and Zomba cities had 3006 and 2240 people per km^2, respectively [34, 53, 57]. There has been a general increase in the GDP over the past 26 years especially between 2006 and 2011 and falling between 1993 and 2003 (**Figure 4**).

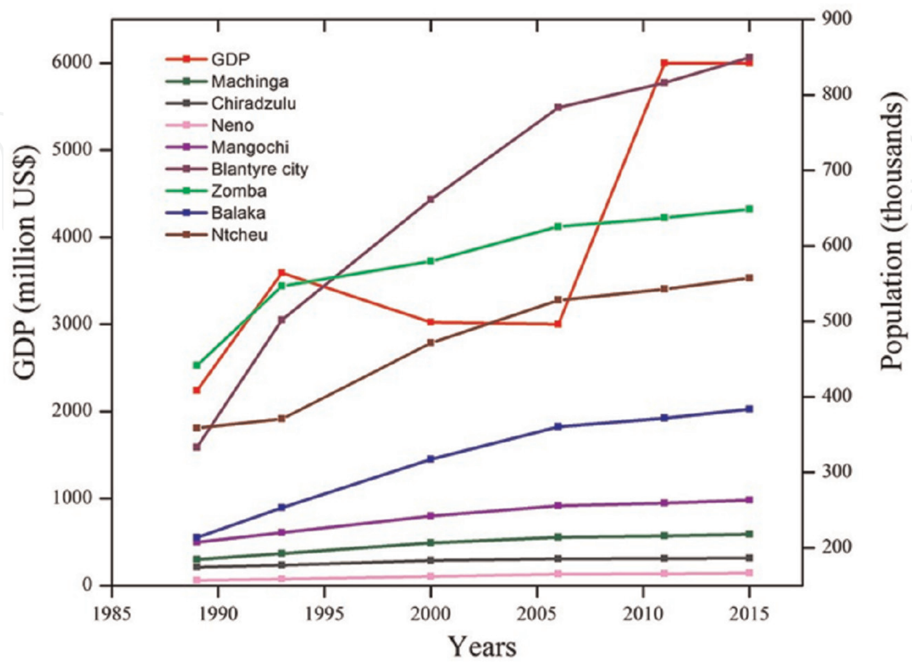

Figure 4.
Population of districts in the middle Shire River catchment area and GDP (US$) for Malawi from 1989 to 2015 [53].

4. Discussion

4.1 Drivers of LUCC in the middle Shire River catchment

Rainfall affects LUCC in the middle Shire River catchment. Drought and floods in the western side of the river, therefore, have resulted into low crop yield. As a survival mechanism, people resort to cutting down of trees to earn income, causing forest degradation [58, 59]. This may, therefore, explain the concurrent low rainfall received against a sharp decline in forest areas between 2006 and 2011 (**Figures 2** and **3**). Results in this study agree with an earlier report for the upper Shire River catchment [60] indicating a direct link between poor rainfall (drought/floods) and cutting down of trees.

Rapid population growth is one of the drivers of LUCC in the western side of the middle Shire River earlier reported by [60, 61]. Population increase in the western part of the middle Shire River is mainly attributed to the influx of refugees fleeing the civil war from Mozambique from the 1990s. Population growth leads to urbanization, increase in cultivated land, and residential area [3, 8]. The high population density in Malawi with an estimated growth rate of 2.8% is putting increasing pressure on its natural resources, leading to expansion of farming on marginal lands and forests as well as encroachment into protected forest reserves/parks. Results in this study show a transition of land use from forest, shrubland, and grassland to cultivated land and buildup areas (**Tables 4** and **5**). These changes mainly occurred between 1989 and 2011 (**Figure 2** and **Table 4**) probably due to increasing anthropogenic pressure on natural forests. Results also show a drastic change in forest/grassland/shrubland between 1989 and 2011 in three out of the four districts (Balaka, Neno, and Ntcheu) in the western side of the middle River Shire. Large proportion of shrubland, grassland, and forestland (84%) in the western part of the river were converted to cultivated land, buildup areas, and/or bare land. This confirms earlier assertion that increasing population results into a decrease in forest area (**Figure 5**).

The rate of forest decline experienced by Malawi [61] and the Shire River catchment in particular [59], due to heavy dependency on wood for energy, is alarming. Most people around the middle Shire River catchment rely on firewood

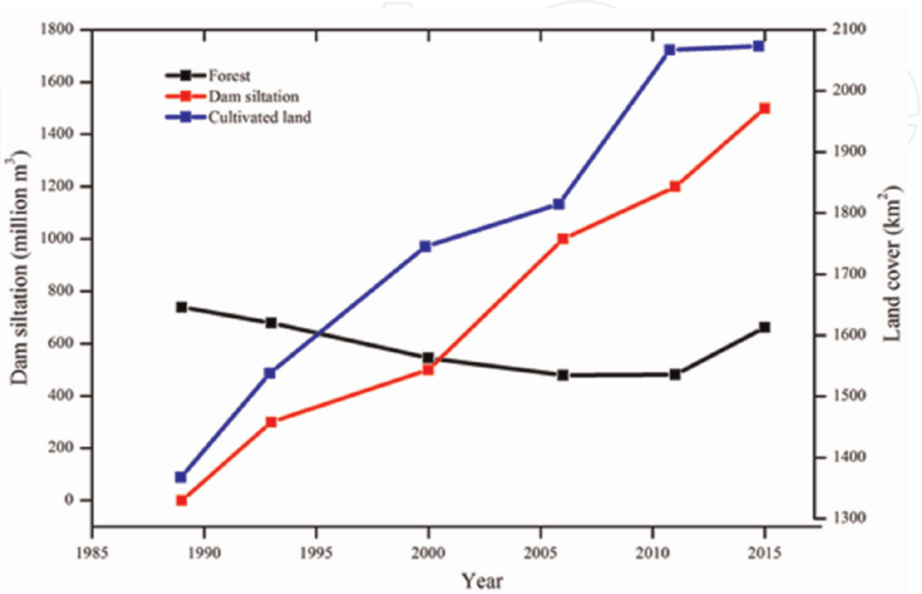

Figure 5.
Changes in forest, cultivated land in the catchment area, and siltation volume in the Nkula Dam from 1989 to 2015.

and charcoal for their daily living [58, 62, 63]. Malawi's forest cover loss is estimated at 2.6% per annum [64]. The middle Shire River catchment lost, on average, about 4.3% of its forest and shrubland annually between 1989 and 2011 (**Table 4**), suggesting a negative relationship between population increase and the decline in forest coverage (**Figures 4** and **5**). Results, nevertheless, showed a recovery in forest cover from 2011 to 2015 (**Tables 4** and **5**), likely attributed to interventions by the government of Malawi and nongovernmental organizations in strengthening natural resource management policies that started around 2008 up to date [5, 65].

Macroeconomic activities such as increase in manufacturing industries and other businesses which contribute to the growth of GDP often require large areas, which also contributed to the transition of forest/shrubland/grassland into buildup areas. Some of such economic activities include opening of new farms which also require clearing of forest areas (**Figures 4** and **5**).

National policies in the past have failed to effectively enforce ban of unabated harvesting of forest resources until recently with the introduction of community-based natural resource management groups and intervention of some nongovernmental organizations in afforestation programs. This may explain the increase in forest cover from 2011 to 2015 as earlier indicated (**Figure 2** and **Table 4**). Globally, large expanses of forests are being converted into bare land for domestic purposes and, principally, due to harvesting of timber [66]. In a study carried out between 1989 and 2002 in the upper section of the Shire River, [60] reported impacts of LUCC on the river's catchment hydrological regime which includes increase in soil erosion. It is reported that agricultural land increased by 18% between 1989 and 2002 [60]. In another LUCC assessment study for Likangala River catchment (a stream from Zomba Mountain which is also a source of several rivers draining into the eastern side of the middle Shire River), woodlands decreased from 135.3 km^2 in 1984 to 15.5 km^2 in 2013 [67]. These results agree with the present study confirming negative impacts of LUCC. Agriculture is the main source of employment to about 92% of the population in Malawi which lives in rural areas [61, 68]. Increase in agricultural activities leads to cultivated land expansion. Cash crops (e.g., tea, coffee, tobacco, and cotton), subsistence crops (e.g., maize and groundnuts), and animal rearing contribute to the increase in agricultural GDP. Results in the present study agree with a report for the region in which land use change (increase in farming activities) contributed to increase in GDP. Similar findings have also been reported correlating land use to increase in income [67]. The increase in cultivated land and artificial surfaces resulted into a decline in forest and shrubland (**Tables 4** and **5**).

Furthermore, the country loses about 1.7% of its GDP on average annually due to the combined effects of droughts and floods [69]. Heavy rains received during the 1989 season in the country (**Figure 3**) were associated with devastating floods that drastically affected the GDP due to crop failure and loss of property as well as human life in the same period but increased in the subsequent year (**Figure 4**). Although the devastating rainfall in the 1989 season played a role in influencing the GDP, other factors could also be at play due to the fact that drivers of economic growth are diverse and vary in the magnitude of influence. For example, in 1989, Malawi's economy was associated with high fuel prices due to the war in Mozambique. All fuel transportation routes from the Indian Ocean ports in Mozambique were blocked, and consequently, there was a collapse in commodity prices [68]. Poor sales of tobacco which is the country's major foreign exchange earner also affected the GDP in 1989 [68]. Increased GDP between 2005 and 2009 has been attributed to stabilization and enhanced income growth, which increased income per capita due to the new economic policies and a stable political environment in 2004 [68].

4.2 Consequences of forest decline

These study findings show a decline in forests and then an increase over the past 26 years (**Figures 2** and **5** and **Table 4**). Clearing of forests from the catchment of the middle Shire River has subjected the bare soil to erosion which finds its way into the Shire River downstream to the Nkula Dam as a sink. This, thus, may explain the heavy siltation at the Dam which has reduced the volume of water causing problems with normal generation of electricity (**Figures 4** and **5**). The volume of the Dam at Nkula Falls, which was 3 million m^3 at its construction in the 1980s, has recently dropped to nearly half of its original size due to massive siltation which consequently resulted in low production of hydroelectricity, now failing to meet the country's demand for power. Nkula B Hydroelectric Power Station is the main electricity generation plant in Malawi producing about 124 MW of electricity [70]. The electricity-providing company—the Electricity Supply Commission of Malawi (ESCOM)—is now implementing involuntary power load shedding programs resulting into national frequent blackouts. Consumers now resort to excessive use of firewood/charcoal in place of electricity for cooking and other domestic chores creating a heavy dependency on forest resources.

High soil losses in Ntcheu and Neno Districts could be due to increased population as a result of the refugees' long time settlement in these areas resulting into removal of forests. The expansion of cultivated land could thus be the cause for increased soil erosion and sediment transport downstream, which consequently accumulate in the Nkula Dam in the middle Shire River (**Figure 5**). These findings agree with a recent study [6] which confirmed that most of the sediments going into the Shire River and finally depositing at the Nkula Dam originate from the western side of the Shire River. Several studies elsewhere [20, 66] also report the same, linking increased population to deforestation and soil. Loss of forests coupled with agriculture are cause for rapid land use change resulting into increased soil erosion and siltation in the middle Shire River catchment [4, 6, 8] (**Figure 5**). Malawi, and the middle Shire River in particular, is therefore locked up in a cycle where anthropogenic activities in the river's catchment meant for a survival alternative to lack of electricity have become a cause for soil erosion and siltation in the river, consequently hampering the generation of the needed electricity.

5. Conclusions

Findings in this study show significant land use and land cover changes that have occurred in the middle Shire River catchment over the past 26 years which have also affected the Nkula Dam. Forestland and shrubland have declined, while cultivated land and artificial surfaces have increased in the area, and deforestation appears to be more pronounced in the western side of the middle Shire River. Severe siltation downstream in the Nkula Dam appears to be strongly linked to increased soil erosion as a result of land use and land cover change. Notable drivers for LUCC include rapid population growth and GDP, macroeconomic activities occurring especially in the western part of the river such as manufacturing industries, and poor national policies that have failed to effectively enforce ban of uncontrolled harvesting of forest resources.

To solve these problems, there is a need to review and amend weak policies that encourage noncompliance to regulations of managing forests. For example, all policies that may encourage or result in soil erosion such as river bank cultivation must be amended. Powers should be invested in local authorities to take part in protecting the environment and/or in planting trees, and the government should be able to provide seedlings for the operation. This should be done in a competition manner that the village which will perform well should be given some incentives. There is also need to increase fertilizer use so that land expansion for farming is curbed and yields are improved. In addition to that, population growth can be controlled through increase use of family planning. Encouraging children to go to school to avoid early marriages might also help to reduce poverty which will help to avoid cutting down of trees careless. Deliberate programs should be instituted by the government to curb further effects of climate variability such as droughts and floods. Such programs may include good agricultural practices that conserve soil and protect it from water erosion, discourage river bank cultivation, intensify afforestation programs, and ban the burning of charcoal. Findings in this study and the combination of methods used (application of GIS, remote sensing, and analysis of socioeconomic factors) can possibly be applied in areas where similar environmental problems have occurred. It is preferable to include a conclusion(s) section which will summarize the content of the book chapter.

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Conflict of interest

No potential conflict of interest was reported by the authors.

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