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Land Use and Land Cover Dynamics in the Urban Watershed of Kimemi River (Butembo/D.R.C)

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Abstract

Changes in land use and land cover (LULC) influence hydrological processes in a watershed. This study analyses the dynamics of LULC in the Kimemi watershed from 1987 to 2021. GIS and remote sensing tools as well as landscape pattern analysis were used to achieve this purpose. The results reveal that the LULC change is globally marked by an increase in the bare land and building at the expense of the low vegetation (grassland). Between 1987 and 2011, the bare land and buildings (Tg = 61.33%) and the woodland (Tg = 34.2%) classes increased, whereas the grassland class decreased (Tg = −39.5%). On the other hand, between 2011 and 2015, the bare land and building class still increased (Tg = 29.9%) while that of grassland and woodland decreased with Tg = −37.3% and Tg = −4.9%, respectively. Finally, the dynamics observed from 2015 to 2021 is marked by small changes between classes with Tg values of 2.1%, 1.9% and −8.9%, respectively, for the bare land and building, grassland and woodland classes, respectively. The main spatial transformation processes observed are creation and dissection for the bare land and building class, and the grassland class respectively. In particular, the woodland class underwent the creation process between 1987 and 2011 before undergoing attrition (2011-2015-2021). Reduced vegetated areas give rise to new planning decisions to mitigate the hydrological risks that could result from this situation.

Keywords

Land Use and Land Cover Dynamics, Watershed, Kimemi River, Butembo

1. Introduction

Land use and land cover are the main drivers of environmental changes (Demissie, 2022). Therefore, studying its dynamics is increasingly essential for land management (Djagnikpo, Boukpessi, & Tanzidani, 2016). It sheds light on the different trends in spatial transformation processes (Lambin et al., 2001) which are amplified by demographic pressures and over exploitation of available resources (Bamba, Sadaiou, Barima, & Bogaert, 2010).

Currently, urbanisation is an undeniable phenomenon of enthronisation and landscape transformation in several regions (André, Mahy, Lejeune, & Bogaert, 2014; Justine, 2012). The proportion of the world's population living in urban areas is expected to reach 68% of the world's population in 2050 according to projections made by the UN in 2018 (UN, 2019). Furthermore, Angel et al. (2011) claim that the urban population of developing countries will grow at a rate five times faster than the urban population of more developed countries, particularly in sub-Saharan Africa, followed by South and Central Asia. This demographic growth induces a rapid densification and expansion of the built-up area in urban and periurban zones (Forman, 2008) with the subsequent spatial expansion that remains detrimental to the natural environment with a series of harmful socio-economic and environmental impacts (Burel & Baudry, 1999; Grimm et al., 2008; Sikuzani et al., 2018).

In several African cities, rapid changes in land use reveal a lack of planning (Karolien, Anton, Maarten, Eria, & Paul, 2012). According to Bogaert et al. (2008), the human impact on the environment usually results in the replacement of natural vegetation covered by artificial vegetation or other anthropogenic structures. This situation results in soil sealing with consequent hydrological risks (Moeyersons et al., 2004). Butembo city is a typical case of demographic explosion (Sahani, 2011). This explosion is the result of the rural exodus in general and, in particular, the displacement of populations fleeing insecurity in their areas. Most of the urban expansion resulting from the demographic explosion is taking place in the Kimemi River watershed. This basin is the preferred area for housing development due to its less steep terrain. Unfortunately, these lands are still facing several environmental problems such as gullying, flooding, pollution of water sources, ecosystem degradation, etc. (Sahani, 2011). A quantification of this urbanisation is necessary to mitigate the resulting consequences. Understanding the effects of urban expansion on landscape structure and ecological processes requires knowledge of the land use dynamics (Grimm et al., 2008).

Furthermore, these changes in land use and land cover also have implications for the dynamics of the hydrological process in watersheds (Ferreira et al., 2012). To quantify this change, landscape ecology analysis tools are used too (Dietzel, Hemphill, Clarke, & Gazulis, 2005). These tools allow for an interpretation of observed dynamics in land use and land cover (Justine, 2012). In addition, the development of geographic information systems and remote sensing supports landscape ecology in understanding more precisely the dynamics of land use and land cover (Lunetta, Knight, Ediriwickrema, Lyon, & Worthy, 2006). This study is based on the hypothesis that land use has progressively changed from vegetated areas to built-up areas and bare soil. Therefore, this investigation was carried out to quantify the changes that have occurred in land use and land cover of the Kimemi River watershed from 1987 to 2021 based on, remote sensing, Geographic Information System and landscape pattern analysis.

2. Materials and Methods

2.1. Study Area

The Kimemi River watershed is located in Butembo city, eastern Democratic Republic of Congo. This watershed is located between latitude 0˚05' and 0˚12.5' North and longitude 29˚15' and 29˚20' East (Figure 1). The average altitude is

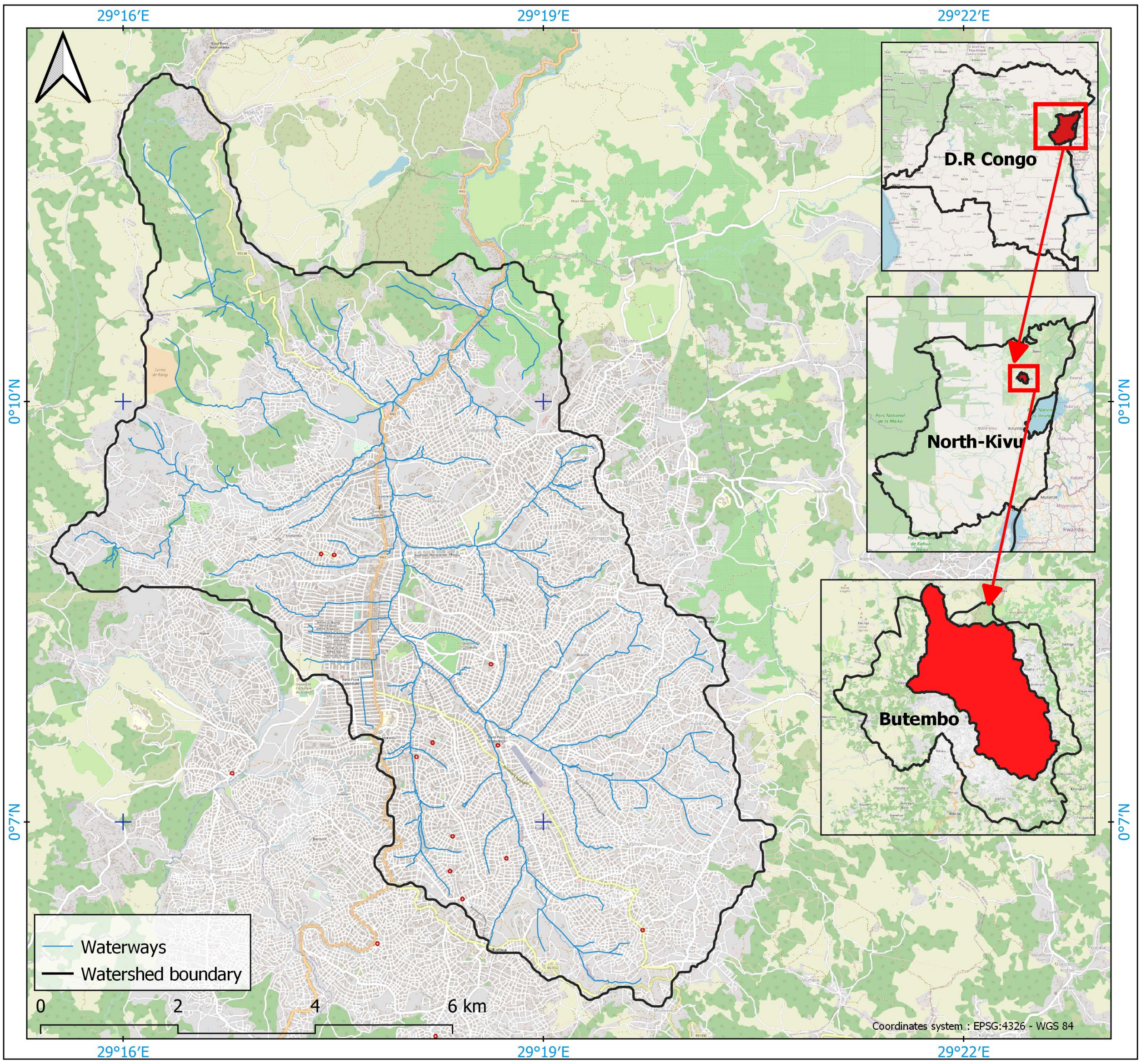

Figure 1. Location of the Kimemi river watershed.

about 1788 m. Kimemi River is one of the main rivers that drain Butembo, along with Mususa and Lwira. It is the most important and crosses the city in a south-north direction. Its main tributaries are Wayimirya, Kanywangoko, Kavaghendi, and Kinyavuyiri. The Kimemi River watershed has an area of 64.54 km^2 and a perimeter of 56.85 km. The Gravelius compactness index of 1.99 reflects its elongated shape. The outlet of this watershed is located where the Lwira River meets the Kimemi River at the northern exit point of Butembo city. **Figure 1** shows the location of the study area.

Butembo city has a climate that would be equatorial if it were not contrasted by mountains with average temperatures of around 18˚C and average rainfall around of 1400 mm (Sahani, 2011; Vyakuno, 2006). However, this temperature is increasingly on the rise while the annual rainfall is almost regular. Three main types of rock are encountered in the Kimemi River watershed including 1) the Luhule-Mobisio basic complex, 2) the Luhule-Mobisio sedimentary bedrock, and 3) the orthogeneissic complex. In the Kimemi watershed, the original vegetation has already been removed. The area has been reforested with fast-growing exotic species (*Eucalyptus sp, Eurythrina sp, Grevillea robusta,* etc.). The majority of the population living in the Kimemi watershed in particular and in Butembo in general belong to the Nande ethnic group traditionally called Yira (Mirembe, 2005). Trade and agriculture are the main economic activities in the region (Kitakya, 2007).

2.2. Data Acquisition

The methodological approach of this study is essentially based on an analytical approach of satellite images accompanied by ground truth. The satellite images used were downloaded from the *USGS Earth Explore* website (https://earthexplorer.usgs.gov/) with 30 meters of spatial resolution. They come from the following sensors: Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), and Operational Land Imager (OLI). These images correspond to the years 1987, 2011, 2015 and 2021 and their characteristics presented in **Table 1**. Coordinates of regions of interest were collected using a GPS receiver embedded in a Smartphone using the Android system (with ± 4 m accuracy) and complemented by Google Earth images. ENVI 4.6.1 software was used for image classification and QGIS 3.20 for map layout. Finally, *MS Excel* 2019 and *R* 4.1.2 software under the *Rstudio* 1.2.5001 interface were used to compute the spatial structure indices and data visualisation of variables.

Table 1. Characteristics of the images used.

Sensor	Path/Row	Date	Resolution
LANDSAT_4 TM	173/060	08-August-1987	30 m
LANDSAT_5 ETM	173/060	13-January-2011	30 m
LANDSAT_8 OLI	173/060	08-January-2015	30 m
LANDSAT_8 OLI	173/060	14-April-2021	30 m

2.3. Data Analysis

2.3.1. Image Pre-Processing

Satellite images were pre-processed prior to thematic classification. This included color composition, image enhancement, and extraction of the study area. The colour composition was done to obtain a single multispectral image since Landsat images are designed as individual bands (Djagnikpo et al., 2016). Finally, the extraction of the study area was performed from the obtained multispectral images, following the boundaries of the Kimemi watershed.

2.3.2. Image Classification

To perform image classification, the supervised classification approach was chosen (Ali, 2016; Kabanyegeye et al., 2020; Pham & He, 2012; Salomon et al., 2020). In fact, this approach makes it possible to discriminate between different classes of land use and land cover (Ali, 2016). The Regions of Interest (ROI) were determined on the basis of geographical coordinates collected in the field and a visual interpretation of *Google Earth* images guided by knowledge of the study area. Three relevant classes were selected for the classification namely 1) the bare land and building (houses, roads and bare land), 2) woodland (tree plantations) and 3) grassland (lawns, cropland, etc.). The classification was based on the Maximum Likelihood algorithm. This algorithm is based on the statistics of the training areas, calculating the probability of a pixel belonging to a given class rather than to another. Pixels are assigned to the class for which the probability is highest (Djagnikpo et al., 2016; Girard & Girard, 2010).

2.3.3. Accuracy and Validation of the Classification

The classification accuracy was assessed through the confusion matrix with the calculation of validation indices such as the overall accuracy and the Kappa index. This confusion matrix makes it possible to compare the predicted land use/land cover, i.e., that resulting from the classification, with the land use observed in the field (Girard & Girard, 2010; Justine, 2012). Kappa values below 50% indicate poor classification, while those between 50% and 75% and those above 75% indicate acceptable and excellent classification, respectively (Bogaert, Vranken, & Andre, 2014; Landis & Koch, 1977).

2.3.4. Detection of Changes in the Spatial Pattern

The spatiotemporal dynamic of the different land use/land cover classes was evaluated through the construction of the transition matrix, the calculation of the overall change rate, and the calculation of the spatial structure indices of the landscape. The transition matrix is a square matrix that allows to highlight in a condensed way the change of state undergone by the elements of a landscape during a given period (Bogaert et al., 2008; Djagnikpo et al., 2016). Three matrix (1987-2011, 2011-2015, 2015-2021) were produced by crossing the maps two by two for the periods considered. In addition, the overall change rate was also calculated to detect changes for each land use class. The spatiotemporal evolution of these classes was evaluated through the relationship between the same class at two different dates. This relationship made it possible to extract the stable, regressive and progressive areas of the focused class. The overall change rate (Tg) were calculated using Equation (1) proposed by the FAO in 1996 (Djagnikpo et al., 2016):

$$\mathrm{Tg} = \frac{S_2 - S_1}{S_1} \times 100 \tag{1}$$

With:

S_1: area of a class at date t1, in km^2;

S_2: area of the same class at date t2, in km^2;

Tg: overall change rate.

A value of Tg close to zero indicates the relative stability of the class, while positive values represent an increase in the area of the class during the period analysed. Negative values indicate the loss or regression of the area occupied by a class between the two dates.

The next step in the analysis was the calculation of spatial pattern indices. These indices are indicators of human impact on landscape configuration (Bogaert et al., 2008). In this study only considered the number of patches (n), the total area of patches (at), and the dominance index (D) computed after Bamba et al. (2008) as follows:

$$a_{tj} = \sum_{i=1}^{n_j} a_{ij} \tag{2}$$

$$D_J(a) = \frac{a_{\max j}}{a_{tj}} \times 100 \tag{3}$$

(2) Total patches area and (3) dominance index

With:

n_j: Total number of patches;

a_{ij}: area of patch (i) of class (j), in ha;

a_{tj}: total area of the class (j), in ha;

$a_{\max j}$: area of the largest patch of the class (j), in ha;

$D_j(a)$: dominance index in %.

The spatial transformation processes during the study period were identified using the decision tree proposed by Bogaert, Ceulemans and Eysenrode (2004). This tree is based on the evolution of the number of patches, the total area and the total perimeter of patches of the land use class. The choice between fragmentation and dissection were based on a predefined reference value t = 0.5.

3. Results and Discussion

3.1. Results

3.1.1. Classification and Mapping

Table 2 presents the different values of the precision index found in this study. The analysis of the accuracy of the supervised classification of the images reveals overall accuracy values of 99.2%, 99.9%, 100%, 98.5% and Kappa index of 0.9871, 0.9981, 1, 0.9761, respectively, for the images of 1987, 2011, 2015, 2021.

Table 2. Overall accuracy and Kappa index for the different classification dates.

date	Overall accuracy (%)	Kappa index
1987	99.2	0.9871
2011	99.9	0.9981
2015	100	1
2021	98.5	0.9761

These values indicate a statistically reliable discrimination of the different land cover classes.

3.1.2. Change in Land Use and Land Cover

The evolution of land use between 1987 and 2021 is globally characterised by an increase in the area occupied by the bare land and building class on the expense of the grassland class. The woodland class, on the other hand, has evolved with less pronounced variations (Figure 2).

Between 1987 and 2011, the class of bare land and building (Tg = 61.33%, from 18.5 km^2 to 29.8 km^2) and the woodland class (Tg = 34.2%, from 9.3 km^2 to 12.5 km^2) increased, while the grassland class decreased (Tg = −39.5%, 36.7 km^2 to 22.2 km^2). The increase in the class of bare land and building is due to the conversion of 19.2% of grassland and 3.2% of woodland. The woodland class increased due to the conversion of 11.4% of grassland and 1.9% of bare soil (Table 3).

From 2011 to 2015, the class of bare land and building class increased at a rate 7.5% per year (29.8 km^2 to 38.7 km^2), while that of grassland and woodland decreased from 22.2 km^2 to 13.9 km^2 (Tg = −37.3%) and from 12.5 km^2 to 11.9 km^2 (Tg = −4.9%), respectively. During this period, the increase observed for the bare land and building class is justified by the conversion of 9.4% of grassland and 5.7% of woodland (Table 3).

The dynamics observed during the period spanning from 2015 to 2021 is rather marked by small changes between classes. The overall change rates corresponding to each of the classes reveal a slight increase in the class of bare land and building (Tg = 2.1%), as well as in that of grassland (Tg = 1.9%). On the other hand, the woodland class decreased (−8.9%). In this period, 2.1% of the woodland class was converted to bare land and building and 4.3% to grassland. A portion (3.6%) changed from grassland to woodland, while 6.7% changed to bare land and building. Furthermore, 2.1% of the woodland area was converted to bare soil and built-up area (Table 3). Table 3 presents the transition matrix, and Figure 2 and Figure 3 illustrate the different changes in land use and land cover during the study period.

3.1.3. Spatial Dynamics of Landscape Structure

From 1987 to 2011, the most dominant process in the class of bare land and building is creation, explained by a simultaneous increase in the number of

Table 3. Transition matrices (1987-2011; 2011-2015; 2015-2021). 1% corresponds to 0.65 km^2.

	Area (in %)	year 2011			
		Bare land and building	Grassland	Woodland	Total
year 1987	Bare land and building	23.8	3.4	1.9	29.1
	Grassland	19.2	26.1	11.4	56.7
	Woodland	3.2	5.0	6.1	14.2
	Total	46.2	34.5	19.3	100.0
	Area (in %)	year 2015			
		Bare land and building	Grassland	Woodland	Total
year 2011	Bare land and building	44.9	0.8	0.5	46.2
	Grassland	9.4	16.6	8.4	34.5
	Woodland	5.7	4.2	9.5	19.3
	Total	60.0	21.6	18.4	100.0
	Area (in %)	year 2021			
		Bare land and building	Grassland	Woodland	Total
year 2015	Bare land and building	52.5	6.4	1.1	60.0
	Grassland	6.7	11.2	3.6	21.6
	Woodland	2.1	4.3	12.0	18.4
	Total	61.3	22.0	16.7	100.0

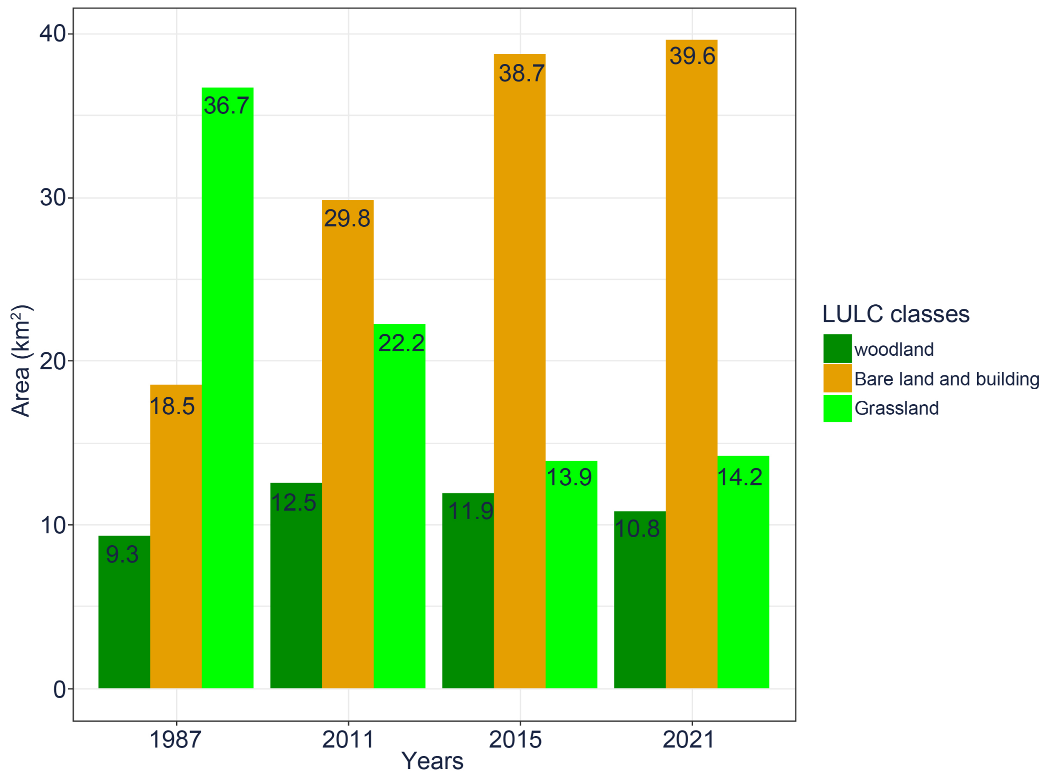

Figure 2. Observed change in land use classes in terms of surface in km^2.

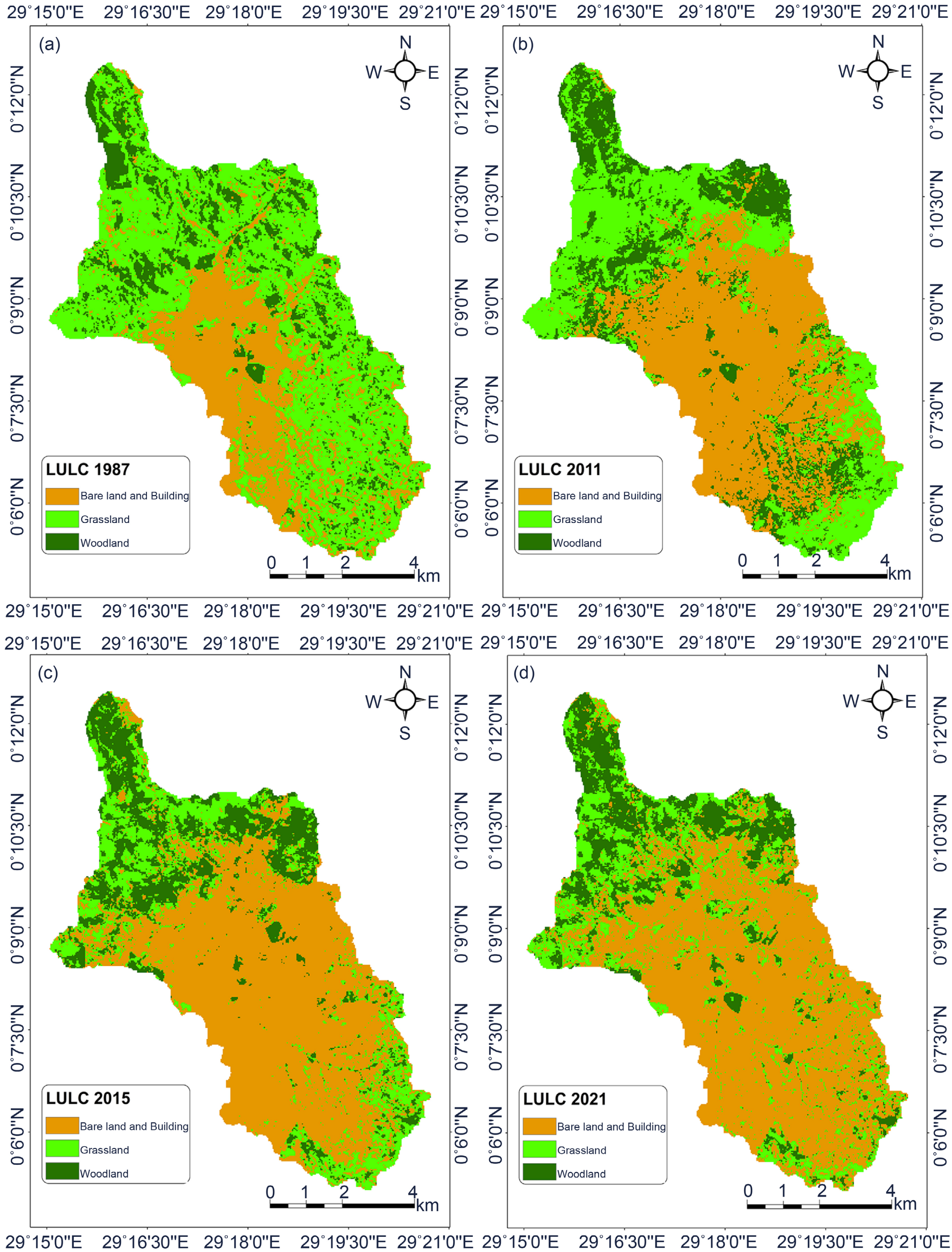

Figure 3. Land use and land cover: (a) 1987, (b) 2011, (c) 2015, (d) 2021.

patches (Figure 4(a)) and their total area (Figure 4(b)). On the other hand, for the grassland class, the spatial transformation process was dissection following an increase in the number of patches followed by a decrease in their surface but with t value (0.61) higher than 0.5. On the other hand, for the woodland class, the creation of new patches was also observed. From 2011 to 2015, the dominant process in the class of bare land and building remains the creation resulting from the simultaneous increase in the number of patches and their surface during this period. Similarly, for the grassland class, the dominant process remains dissection. However, the woodland class underwent the attrition process (Table 4) following the simultaneous decrease in the number of patches (Figure 4(a)) and their area (Figure 4(b)). Finally, between 2015 and 2021 patches of the bare land and building class continued to be created while the grassland class underwent dissection (t = 0.99) and the woodland class continued to undergo attrition (Table 4).

Figure 4. Evolution of spatial indices by land use and land cover class. (a): number of patches (b): total area of patches (ha), (c): dominance index (%).

Table 4. Spatial transformation process identified through the decision tree proposed by Bogaert, Ceulemans and Eysenrode, (2004) for each of the land use classes from 1987 to 2021 in the Kimemi watershed.

LULC classes	1987-2011	2011-2015	2015-2021
Bare land and building	Creation	Creation	Creation
Grassland	Dissection	Dissection	Dissection
Woodland	Creation	attrition	attrition

In general, the dominance values in the bare land and building class are high compared to other classes. The dominance increased from 75.89% in 1987 to 90.32% in 2011 reflecting the increase of the largest patch of the class in the landscape. This value stabilised until 2021 at around 91.33%. For the woodland class, the value of dominance also increased during the study period with values of 11.43%; 19.03%; 23.18%; 29.30% in 1987, 2011, 2015 and 2021 respectively. However, the dominance values of grassland class decreased drastically from 93.21% in 1987 to 10.55% in 2021.

3.2. Discussion

This study was carried out on a watershed scale in an urban context. Sow (2020) states that the watershed is an integrating territory of different physical-human processes (e.g., hydrological processes) evolving in time and space, under the effect of the influences of societies. To assess changes in land use and land cover, freely available Landsat satellite images have made it possible to achieve this objective. Although not very suitable for studies of urbanised environments, these images have been used by several researchers (Chen, Tabssum, & Nguyen, 2019; Dan-jumbo, Metzger, & Clark, 2018; Diallo & Bao, 2010; Karolien et al., 2012; Salomon et al., 2020; Song, 2019). In this kind of landscape, the surface of a single pixel can cover different land uses (Kabanyegeye et al., 2020).

No approach of satellite image classification is sufficient if it is not confronted with the ground truth, which also contributes to reducing the degree of confusion between thematically related pixels (Foody, 2002, 2010; Mama & Oloukoi, 2003). In this study, this evaluation was carried out using the confusion matrix and the calculation of the Kappa index and the overall accuracy. Foody (2002) stated that the confusion matrix and precision indices remain valid and useful in the case of the existence of a reliable land database. The values of the precision indices obtained in this study (**Table 2**) reveal an excellent classification.

The urbanisation of Butembo city and specifically in the Kimemi river watershed is characterised by the replacement of grassland areas by the construction of new quarters. To refine the understanding of this phenomenon, much more adequate time scales must be considered (Bogaert et al., 2004). Nevertheless, this result is in line with results found in several cities in Africa where green spaces and/or urban fields are transformed into built-up areas: Kisangani (Justine, 2012), Lubumbashi (Sikuzani et al., 2017), Bujumbura (Kabanyegeye et al., 2020), and Bamako (Diallo & Bao, 2010). Furthermore, in other cities around the world, researchers have observed a similar trend of reduction in vegetated areas: Shanghai (Liu et al., 2021), Cap-Haïtien (Salomon et al., 2020), Upper Dhaka (Byomkesh, Nakagoshi, & Dewan, 2012). According to Sahani (2011), the growth of Butembo was located preferentially along the main roads before being generalised to almost the entire city. These road axes for the development of the city are mainly located in the Kimemi watershed. This situation explains the increase in the surface of bare land and building observed in this study. The spatial transformation process of the landscape observed for the bare soil and built class from 1987 to 2021 was creation. In addition, the dominant spatial transformation processes for the woodland and grassland are mostly dissection and attrition. Both processes (dissection and attrition) are classified as land degradation processes (Bogaert et al., 2004; Forman, 1995). Furthermore, the decrease in the dominance index value for the grassland class confirms the degradation of this class, while for the woodland class the opposite is true. In fact, there is an increase in the dominance value for the woodland class followed by an extension of the surface between 1986 and 2011, although less noticeable. This increase would be due, on the one hand, to the reforestation that the region has undergone (Sahani, 2011) and, on the other hand, to a weak confusion observed between this class and those of grassland during the classification. Turan, Ali Ihsan Kadıogulları and Günlü (2010) also observed an increasing forest area situation in their study of the response to urbanization in the Kastamonu region of Turkey. It should be noted that in their case, the increase in forests was justified by the abandonment of peri-urban land. Furthermore, Phinzi and Ngetar (2019) also found an increase in the area occupied by forests in the Umzintlava basin in South Africa between 1989 and 2017.

Furthermore, the trend of replacement of forests (woody vegetation) and/or grass by bare land, field, or buildings is common in several other watersheds in Africa and elsewhere, both urban and nonurban: Huluka in Ethiopia (Gebreslassie, 2014), Umbulo in Ethiopia (Moges & Holden, 2009), Luzinzi in DRC (Chuma et al., 2021), Grand Port Harcourt in Niger (Dan-jumbo et al., 2018), Chongwe in Zambia (Tena, Mwaanga, & Nguvulu, 2019), Nashe in Ethiopia (Leta, Demissie, & Tränckner, 2021), Anzali in Iran (Aghsaei et al., 2020). This situation leads in some cases to an amplification of surface runoff water in the watershed. Salomon et al. (2020) also reports that the increase in sealed areas in the city of Cap-Haitien could lead to hydrological risks such as gullying, flooding, landslides. Additionally, Kabanyegeye et al. (2020) reported similar situations in the city of Bujumbura in Burundi. In the Kimemi watershed these phenomena (gullying, flooding, landslides) are also visible (Sahani, 2011). Indeed, vegetation would have a protective effect against this phenomenon, although it remains effective up to a certain threshold (Rey, Ballais, Marre, & Rovéra, 2004).

4. Conclusion

This study is an analysis of the land use and land cover dynamics in the Kimemi watershed. A combination of remote sensing, GIS, landscape ecology tools and ground-truth approaches were used to quantify and identify the LULC changes. The results of this study underline that the LULC in the Kimemi river watershed has evolved globally by increasing the class of bare land and building on the expense of the grassland class. The woodland class has not changed much. Between 1987 and 2011, the bare land and building class and the woodland class increased on the expense of the grassland class. In the following decades (2011-2015-2021), the area of bare land and building continued to increase, while that of grassland and woodland decreased. The dominant spatial transformation processes observed are mainly creation for the bare land and building class and dissection and attrition for the grassland and woodland class, respectively. This dynamic, characterised by the sealing and denudation of soils, would have an effect on the hydrological processes in the catchment leading to more and more flooding, erosion and landslides. Despite the lack of some data, further research should focus on the driving factors of these changes and quantifying this risk to inform planning decisions that reduced the landscape degradation and promote the restoration of the ecosystem.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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