

Article

Evaluating Land Use and Land Cover Change in the Gaborone Dam Catchment, Botswana, from 1984–2015 Using GIS and Remote Sensing

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Abstract: Land use land cover (LULC) change is one of the major driving forces of global environmental change in many developing countries. In this study, LULC changes were evaluated in the Gaborone dam catchment in Botswana between 1984 and 2015. The catchment is a major source of water supply to Gaborone city and its surrounding areas. The study employed Remote Sensing and Geographical Information System (GIS) using Landsat imagery of 1984, 1995, 2005 and 2015. Image classification for each of these imageries was done through supervised classification using the Maximum Likelihood Classifier. Six major LULC categories, cropland, bare land, shrub land, built-up area, tree savanna and water bodies, were identified in the catchment. It was observed that shrub land and tree savanna were the major LULC categories between 1984 and 2005 while shrub land and cropland dominated the catchment area in 2015. The rates of change were generally faster in the 1995–2005 and 2005–2015 periods. For these periods, built-up areas increased by 59.8 km² (108.3%) and 113.2 km² (98.5%), respectively, while bare land increased by 50.3 km² (161.1%) and 99.1 km² (121.5%). However, in the overall period between 1984 and 2015, significant losses were observed for shrub land, 763 km² (29.4%) and tree savanna, 674 km² (71.3%). The results suggest the need to closely monitor LULC changes at a catchment scale to facilitate water resource management and to maintain a sustainable environment.

Keywords: land use land cover change; GIS; Remote Sensing; Gaborone dam catchment; Botswana

1. Introduction

Land use land cover (LULC) change is one of the major driving forces of global environmental change and is of major concern because of its impact on various sectors of the economy [1,2]. These changes take place temporally at different times such as a few months or years and spatially such as the extent of area and the intensity of land use [3]. In view of this, the long-term changes are probably the most significant processes for global environmental change [4] and are useful for evaluating the sustainability of natural resources [5]. The natural and anthropogenic factors are identified as drivers of LULC change [6–9]. Historically, these changes are associated with variation in the biophysical environment, whereas recent changes are mainly linked to anthropogenic factors [10]. Therefore, the climate pattern of an area plays an important role in regulating land cover and human land use [11]. Globally, human activities have been seen to be transforming the terrestrial environment at an unprecedented rate, magnitude and spatial scales [12–15]. Such transformations are linked to economic development, population growth and/or technological advancements [3], while human

use of land relate to cultivation of various forms, livestock grazing, settlement, protected lands or timber extraction.

Due to the unprecedented global population growth [16], land as a resource has become scarce [17]. This is associated with rural-urban migration, agricultural expansion, deforestation and climate change, among other factors [18]. For example, a growing population and rural-urban migration has led to consumption and expansion of built-up areas into rural land and in peri-urban zones and is a major concern in many parts of the world [19,20]. Urbanization is the most irreversible and human-dominated form of land use [15]. In developing countries, urban land use has been known to take place on prime agricultural land [21,22]. In Africa, urban land expansion has been observed since the 1980s and is more related to urban population growth than the growth in the Gross Domestic Product (GDP) [15]. In addition, increased agricultural output has brought more land into production to meet the demand for food to feed the growing population [23]. This is more common in developing countries where people migrate for better survival opportunities [24] and whose economies are mainly agriculture based [25–27], leading to LULC changes. Consequently, agricultural land (both croplands and pastures) are approximated to cover 40% of the total land surface and this is so at the expense of natural vegetation and grasslands [19]. A global net loss of 7–11 million km² of forests due to agriculture expansion and timber extraction has been reported in the past 300 years [25,26,28,29], and about 15 million ha of global tropical forest were cleared annually in the period 1990–2000 [30].

In Sub-Saharan Africa (SSA), Brink and Eva [31] observed a 16 and 5% loss in forests and non-forest vegetation, respectively, due to agricultural expansion between 1975 and 2000. Hence, agriculture has been identified as the primary driver of LULC changes globally [1]. LULC changes in SSA have been associated with rapid population growth [32] and the early 1980s drought. Due to unprecedented population growth and agricultural intensification throughout SSA, croplands have expanded into rangelands, and fallowed areas have decreased [33]. Likewise, in semi-arid ecosystems of Southern Africa, long-term changes are attributed to natural variability in rainfall and change in the type and intensity of land use/anthropogenic activities [34]. However, human and livestock population pressure and general development activities are thought to be the main drivers of LULC changes in Southern Africa [35,36]. Furthermore, a lack of well-defined policies, their implementation and weak institutional enforcement also facilitate LULC changes [9]. Thus, the LULC pattern of a region is an outcome of natural and socio-economic factors and their utilization by man in time and space [37].

LULC change effects manifest at different rates and scales and are characterized by varying degrees of reversibility [4], leading to negative consequences in global, regional and local climates, hydrology, global biogeochemical cycles (carbon and nitrogen), biodiversity, as well as changes in ecosystem functions as a whole [19,38–44]. Globally, the explosive growth of industry and agriculture in the past two centuries is identified to have led to increasing concentrations of carbon dioxide in the atmosphere, alterations to the global geochemical cycle of nitrogen, the production and release of persistent organic compounds such as the chlorofluorocarbons, widespread changes in land use land cover and the hunting and harvesting of natural animal populations [14]. In addition, the conversion of natural vegetation to agriculture could be responsible for changes in the atmospheric composition, climate conditions, global warming and the water balance [45–49]. Such changes in particular could relate to, the degree of absorption of solar radiation, surface albedo, surface temperature, transmission of heat to the soil, storage of heat, wind turbulence and alterations in energy [9]. In water resources, LULC changes can affect the partitioning of precipitation between the components of the hydrological cycle which can negatively impact the environment and socio-economic well-being of people [42,44,50–53]. For example, urbanization brings with it increase in impervious surfaces that reduce rainfall infiltration into underlying soils and surface storage capacity [54], altering the rainfall-runoff response of catchments [55,56]. Additionally, urban areas affect local climate through the modification of surface albedo and evapotranspiration and increased aerosols and anthropogenic heat sources, resulting in elevated temperatures [57] and changes in precipitation patterns [58,59].

Therefore, the current and future development of water resources is very sensitive to land use and intensification of human activities [60]. The need for data on LULC change at broad spatial and temporal scales [4] and the quantification of LULC changes is essential for better understanding of the spatial and structural variabilities in LULC and their ecological effects [61]. Additionally, comprehensive knowledge on LULC is useful for reconstructing past LULC changes and for predicting future changes which may in turn help in explaining sustainable management practices aimed at preserving essential landscape functions [62]. However, understanding the process and the pattern of LULC changes over time and space remains one of the challenging exercises, not only in the field of land science, but also in the field of geospatial sciences [63]. Thus, LULC change studies are carried out using Remote Sensing (RS) and Geographic Information System (GIS) technologies. These technologies have been widely accepted and have a long history of supporting map development and monitoring for different purposes [64]. Recent advances in these technologies and methods have enabled researchers to model and predict LULC change effectively using satellite data which can be used to acquire data for inaccessible regions [63]. LULC change models are often both spatially and temporally explicit and are able to help understand relationships and interactions between human and natural phenomena in order to facilitate better decision making and to quantify the type, amount (rate) and location of LULC change [40].

In Botswana, LULC changes have been observed since the 1980s [32]. For example, central Botswana was identified as one of the “hotspots” of LULC change due to its intensity and extent of change through time [4]. In addition, vegetation changes in the vicinity of settlements [65]; bush encroachment in South East Botswana [66] (the area covering the Gaborone dam catchment); decrease in dense woody vegetation cover; and a significant decline in the area of higher quality rangeland in the Notwane Catchment [67] have been observed. These changes are reported to be due to both human and natural factors with the human dimension being more significant [32]. Likewise, agricultural expansion has been prevalent, thereby promoting deforestation, leading to increased arable production and consequently LULC changes. Similar to many other developing countries, an urbanization wave has been observed in Botswana. This is mainly driven by migration fluxes from rural to urban centers and is directed to the city of Gaborone and its neighboring settlements [68,69]. As a growing city in SSA, the problems of over-urbanization could be more accurate here than elsewhere [70]. Unprecedented population growth and economic and industrial growth in recent years have been massive in and around the city. This necessitated encroachment on surrounding farmlands north and south of the city and sprawling into satellite settlements [71]. These settlements have since developed into dormitory suburbs, taking on the structural, socio-economic and commercial attributes of Gaborone though they still rely on crop farming and livestock agriculture [72]. People commute from these settlements to the city in search of improved socio-economic amenities [32], leading to expansion of the city into the Gaborone dam catchment (south of the city). Small-scale commercial farming, especially poultry, along the Notwane River, has been observed [55,71]. In addition, urbanization has been found to greatly influence runoff coefficients in the upper Notwane Catchment also known as the Gaborone dam catchment [55].

LULC change studies in Botswana have focused on range degradation [34,35,73], rangeland quality in terms of the nature and diversity of vegetation cover [67], bush encroachment [66], LULC change with respect to a rainfall gradient [32] and LULC change with respect to dry land agriculture [74]. However, there is limited information with regards to LULC changes in Botswana’s catchments, making water resource management efforts a daunting task. To effectively manage water resources in a catchment, the historical and present LULC changes as well as their potential impacts need to be assessed. These results are vital in effective land use planning, which is a pre-requisite for effective water resource management. This study aims to fill this gap by assessing trends in LULC changes at a catchment scale to facilitate water resource management and environmental monitoring which takes into account LULC changes. This is achieved by evaluating past and present LULC changes in the Gaborone dam catchment from 1984–2015. This study thus applied GIS and RS techniques to (i)

map LULC in the Gaborone dam catchment, (ii) detect changes, and (iii) characterize the processes of change in terms of the spatio-temporal extent. The study further aims to understand these changes for effective land use planning, environmental management, as well as utilization and protection of natural resources within the context of sustainable development and planning.

2. Materials and Methods

2.1. Study Area

The Gaborone dam catchment is located in Southern Botswana (Figure 1) and the North Eastern part of South Africa, covering an area of about 4000 km². The catchment forms part of the headwaters of the Limpopo River Basin and is drained by the Notwane, Taung, Metsemaswaane and Nnywane rivers. The Gaborone dam forms its outlet. The catchment is a major water source for the city of Gaborone, Lobatse town and surrounding areas. A semi-arid climate is a characteristic of the catchment, with summer rainfall of about 475–525 mm/annum; the maximum temperature ranges between 19.6 °C and 40 °C in summer, and temperatures below 0 °C occur on extremely cold winter nights. Annual evaporation rates are estimated at about 2000 mm.

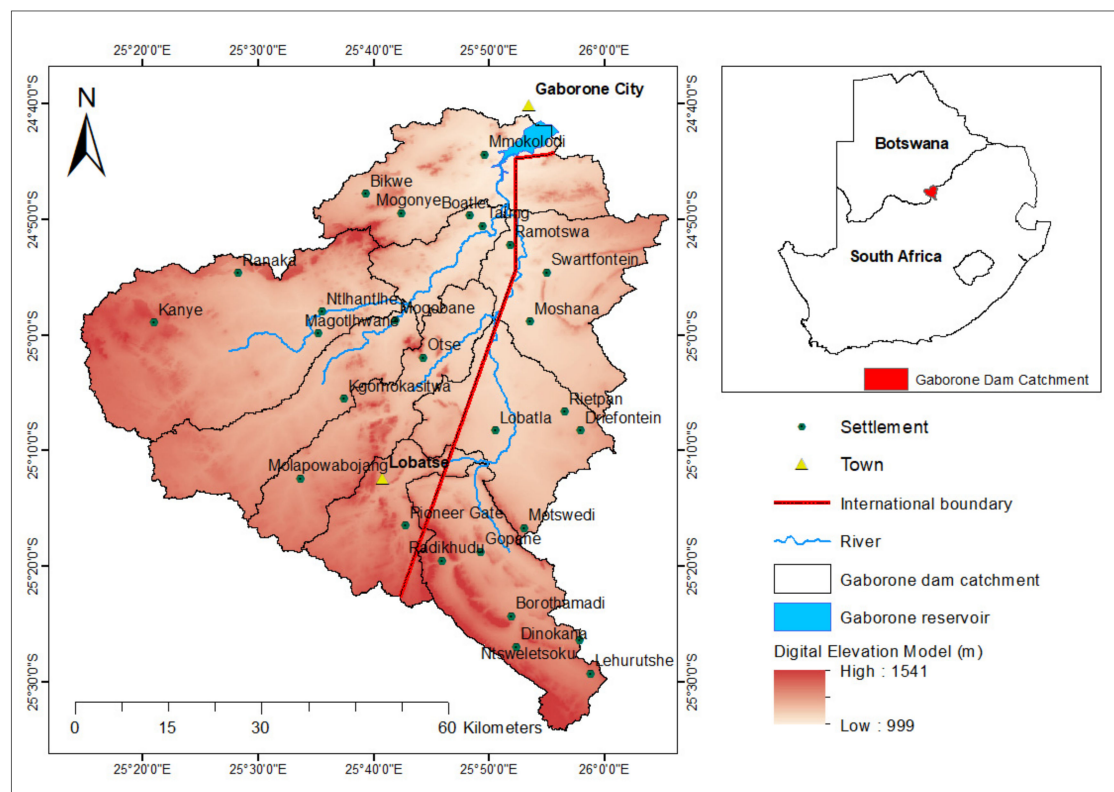


Figure 1. Locational map of the Gaborone Dam catchment.

The population is estimated at about 474,860 (Figure 2) [75]. Domestic water needs dominate water use and the demand is growing rapidly. Small-scale agricultural water use is also observed. Predominant land uses include built-up areas (settlements), areas of agriculture (both cultivating/cropping and grazing), water bodies (rivers and dams) as well as tourism-related areas and key public facilities. Agricultural activities make up the largest land use, followed by built-up areas which are all the major villages and towns, as well as the smaller villages, while the water body category occupies the smallest part of the catchment.

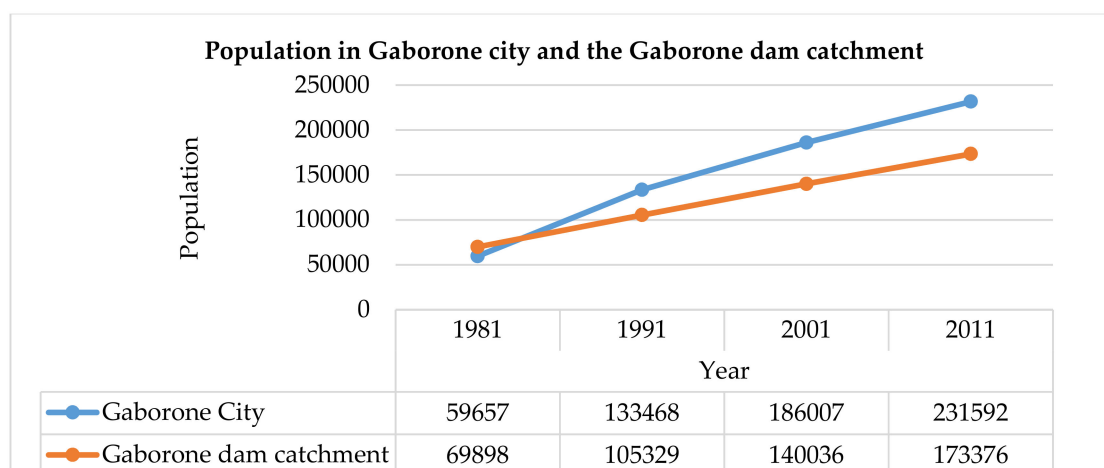


Figure 2. Population in Gaborone City and the Gaborone dam catchment [75].

2.2. Data Collection

For LULC classification of the Gaborone dam catchment, Landsat images acquired from the United States Geological Service (USGS) Earth Explorer (<http://earthexplorer.usgs.gov>) were used. These were dry season Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) for the years 1984, 1995, 2005 and 2015 (Table 1).

Table 1. Landsat image characteristics for the study.

Year	Sensor	Spatial Resolution	No. of Bands	Date of Acquisition	Sources
1984, 1995 & 2005	TM	30m	7	6 July 1984 5 July 1995 4 June 2005	USGS
2015	OLI	30m	11	12 July 2015	USGS

Reference/ground truth data for verifying the classification results and validating the LULC categories of the study areas were collected from 12th to 16th February 2018. For the selection of the representative sample points, binomial probability theory was applied. Thus, sample size N to be used to assess the accuracy of a land use classification map for the binomial probability theory is given below (Equation (1)):

$$N = \frac{Z^2(p)(q)}{E^2} \quad (1)$$

where: N : sample size, p : expected % accuracy of the LULC, q : 100- p , E : allowable error, Z : 2 (from the standard normal deviate of 1.96 for the 95% two-sided confidence level). For the LULC types of 1984, 1995, 2005 and 2015, the expected accuracy was determined to be above 95% at an allowable error of 5% (i.e., it is 95% accurate). A total of 376 ground truth points were selected and collected using a Garmin handheld GPS receiver with ≤ 3 m accuracy. Besides the field data, Google Earth was also used to collect some of the reference data for the years 1985, 1995, 2005 and 2015 (South African side). From the ground truth points, 188 were used for image classification and the remaining 188 for accuracy assessment.

2.3. Data Processing and Analysis

Landsat images are known to have distortions; hence, pre-processing techniques such as radiometric, atmospheric and geometric corrections are done to establish a more direct linkage between the data and biophysical phenomena. Radiometric, atmospheric and geometric corrections of the four images were done using the Environment for Visualization Images (ENVI) 5.3. All image

data were geometrically corrected to the Universal Transverse Mercator (UTM) WGS84, Zone 35 South local projection type. In addition, image enhancement, mosaicking and sub-setting were also done. A wavelet resolution merge was employed to enhance the spatial resolution of each image from 30 m × 30 m into 15 m × 15 m using the Landsat 8 pan-chromatic image. Furthermore, preliminary image interpretations were conducted using false color composites of red, green and blue. These processes were done on the Earth Resources Data Analysis System (ERDAS) Imagine 2015. Figure 3 below illustrates the process work flow used for this study.

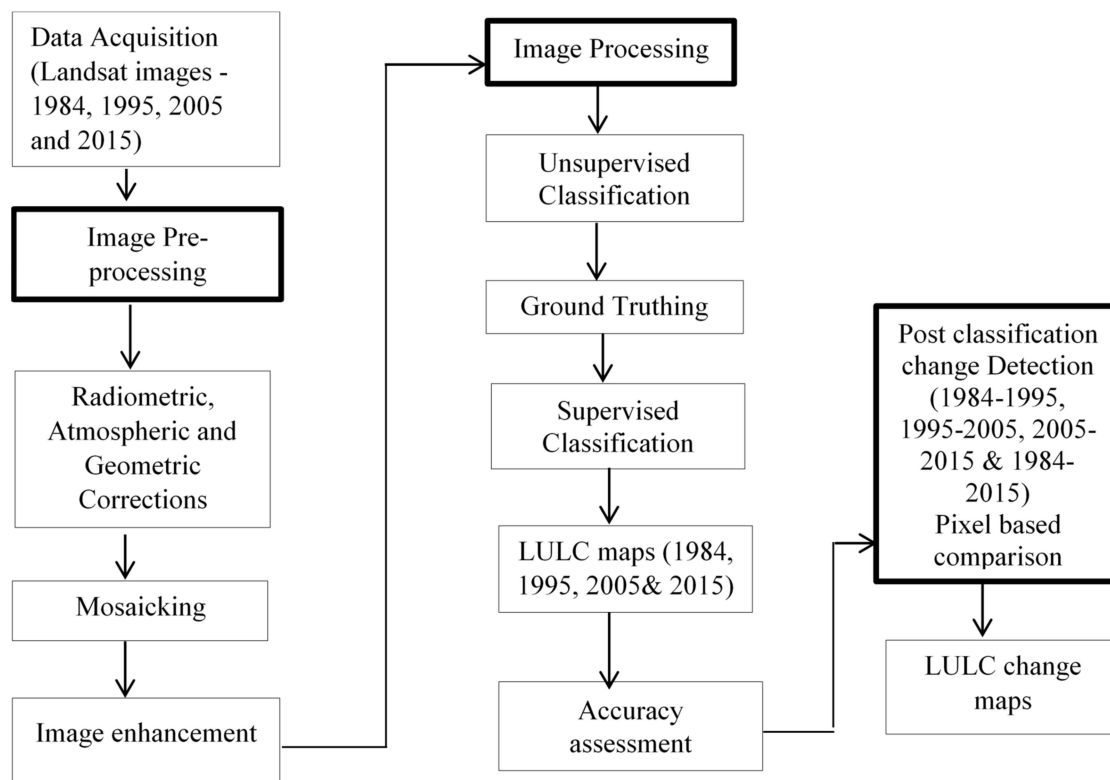


Figure 3. Flow chart of methodology for LULC change (Authors' construction).

For image classification, supervised classification was applied using the Maximum Likelihood Classifier (MLC) algorithm in ERDAS Imagine 2015 to determine the Gaborone dam catchment LULC categories. The MLC relies on the probability that different pixels belong to different classes [59] and is given by Equation (2);

$$L_k = P\left(\frac{k}{X}\right) = P(k) \times P\left(\frac{X}{k}\right) / \sum P(i) \times P\left(\frac{X}{i}\right) \quad (2)$$

where $P(k)$: prior probability of class k ; $P(X/k)$: conditional probability to observe X from class k , or a probability density function. Table 2 shows the LULC categories for the study as adopted.

Post classification was then carried out. This is a comparative analysis of independently produced classifications of different dates via a simple mathematical combination pixel by pixel, and it includes an accuracy assessment and change detection. In this study, a classification accuracy assessment was performed based on the 188 ground truth points representing the different LULC classes in the study area, and the statistical analysis was done using an error matrix accuracy assessment to determine the effectiveness of pixels grouped into the correct feature class in the area under investigation and to estimate the accuracy of image classification by comparing the classified map with reference data. The overall accuracy, user and producer accuracy were then determined from the error matrix. The overall accuracy indicates the accuracy of the whole classification, user accuracy indicates the probability that a pixel classified on the map actually represents that class on the ground or reference data, while producer

accuracy indicates how well trained set pixels of the given cover type are classified. In this study, the user, producer and overall accuracies were mathematically analyzed as follows (Equations (3)–(5));

$$\text{User accuracy} = \frac{C_{aU}}{C_{a+U}} \times 100 \quad (3)$$

$$\text{Producer accuracy} = \frac{C_{aR}}{C_{a+R}} \times 100 \quad (4)$$

$$\text{Overall accuracy} = \sum_{a=1}^u \frac{C_{aa}}{Q} \times 100 \quad (5)$$

where C_{aU} is the total number of correct classifications of a particular map class; C_{a+U} is the total number of pixels classified in a particular map class; C_{aR} is the number of reference points classified accurately, while C_{a+R} is the total number of reference points for that particular map class. Furthermore, Kappa analysis was carried out. The Kappa coefficient (K_{hat}) is the measure of reproducibility and assesses the probability of chance agreement between the reference dataset and the classified land cover map [61]. The Kappa coefficient was estimated as follows (Equation (6));

$$K_{hat} = \frac{M \sum_{i=j=1}^r n_{ij} - \sum_{i=j=1}^r n_i n_j}{M^2 - \sum_{i=j=1}^r n_i n_j} \quad (6)$$

where r is the number of rows in error matrix; n_{ij} is the number of observations in row i , column j ; n_i is the total number of observations in row i ; n_j is the total number of observations in column j ; M is the total number of observations in matrix. In Kappa analysis, a Kappa of 0.8 or above is considered a good classification; 0.4 or below is considered poor [76].

Table 2. LULC types/classification in the study area [27].

Land Use and Land Cover Type	Description
Built-up	Residential, commercial, industrial, transportation, communication and urban areas
Cropland	Cropland, forage, orchards, nurseries, horticultural land, fallow land, intensively, moderately and sparsely cultivated lands
Shrub land	Woody plant, less than 5 m in height, no defined crown, a mixture of trees with grasses
Water Body	Streams, canals, lakes, dams or reservoirs, ponds
Bare land	Exposed soils, sand, bare rocks, with less than 10% vegetation cover, floodplain, quarries, sparse vegetation
Tree Savanna	Woody plant more than 5 m in height with a somehow definite crown

For change detection, the study applied the Post Classification Comparison (PCC) method to detect the LULC changes that have occurred in the Gaborone dam catchment. Change detection aims to recognize LULC on digital images that changes features of interest between two or more dates [77]. The PCC employs the pixel-based comparison to produce change information on a pixel basis and thus interpret the changes more efficiently taking the advantage of “from-to” information [78–80]. A change matrix was produced with the help of ArcMap 10.5 software. Gains and losses in each LULC category between 1984 and 2015 were also compiled (i.e., 1984–1995, 1995–2005, 2005–2015 and 1984–2015). The different rates and magnitude of change for two periods were calculated as in equation (7) [81]:

$$D = \frac{A2 - A1}{A1} \times 100 \div (T2 - T1) \quad (7)$$

where D is the average annual rate of change (%), A_1 : average of land cover type at time 1 (T_1), A_2 : amount of land cover type at time 2 (T_2).

3. Results

3.1. LULC Categories for the Years 1984, 1995, 2005 and 2015

LULC categories for the Gaborone dam catchment from 1984–2015 were analyzed from Landsat images using supervised and maximum likelihood algorithm classification techniques. Six major LULC categories were identified: cropland (CPL), bare land (BL), shrub land (SB), built-up (BU), tree savanna (TS) and water bodies (WB) (Table 2 & Figure 4).

Accuracy Assessment for the four LULC classifications was done and the user accuracy (UA), producer accuracy (PA), overall accuracy (OA) and the Kappa coefficients (KC) for 1984, 1995, 2005 and 2015 are shown in Table 3. The OA of the land cover classification ranged between 80% and 86%. According to Mango [82], an overall accuracy between 60 and 90% is acceptable; this thus implies that the accuracy of the LULC categories is within the acceptable limit. Likewise, a KC of 0.7 is of allowable discriminant accuracy [83].

Table 3. Accuracy assessment of LULC classification for 1984, 1995, 2005 and 2015.

LULC Category	1984				1995				2005				2015			
	UA (%)	PA %	OA %	KC %	UA %	PA %	OA %	KC %	UA %	PA %	OA %	KC %	UA %	PA %	OA %	KC %
Cropland	73	58			97	84			85	95			86	89		
Bareland	86	86			65	65			87	83			85	69		
Shrubland	70	90	81	0.75	97	76	81	0.76	82	88	85	0.81	83	91	86	0.82
Built-up	93	67			73	87			88	78			97	90		
Tree Savanna	95	83			82	84			83	80			83	79		
Water body	80	67			57	73			100	71			86	80		

As shown on Table 4 and Figure 3, shrub land and tree savanna were found to be the most dominant LULC categories in 1984, 1995 and 2005, while shrub land and cropland dominated the catchment area in 2015. Shrub land showed minimal changes, covering areas of about 2597 km² (59.7%) in 1984 and 2591.8 km² (59.6%) in 2015. Built-up and cropland categories were observed to increase during the entire study period from 26.4 km² (0.6%) and 635.5 km² (15.0%) in 1984 to 228.2 km² (5.2%) and 1011.4 km² (23.2%) in 2015, respectively. In addition, the bare land category covered an area of 122.4 km² (2.8%) and 180.6 km² (4.2%) in 1984 and 2015, respectively, showing an increase in coverage. On the other hand, water body and tree savanna categories in the Gaborone dam catchment were found to cover respective areas of 5.7 km² (0.1%) and 945.3 km² (21.7%) in 1984 and increased to 19.6 km² (0.5%) and 975.1 km² (22.4%) in 1995, which then decreased to 6.9 km² (0.2%) and 331.8 km² (7.6%) in 2015.

3.2. LULC Change Detection in the Gaborone Dam Catchment

Notable changes in the spatial distribution of the major LULC categories were observed during the course of the study period (Table 4). LULC categories changed into other categories, reducing their spatial extent. Substantial increases in built-up and cropland in the Gaborone dam catchment were observed during the study period (1984–2015). The built-up category showed the highest increases in areal coverage in the 2005–2015 change period, about 113.2 km² (98.5%). Likewise, growth in cropland category was also observed, at about 263.9 km² (35.3%) in the 2005–2015 change period. However, a slight increase in cropland was observed in the 1995–2005 change period (2.0 km²/0.3%). Additionally, bare land category revealed an increasing trend, especially in the 1995–2005 and 2005–2015 change

periods, about 50.3 km² (161.1%) and 99.1 km² (121.5%), respectively. Despite a general increase in the bare land category, a reduction in its expanse was observed in the 1984–1995 change period.

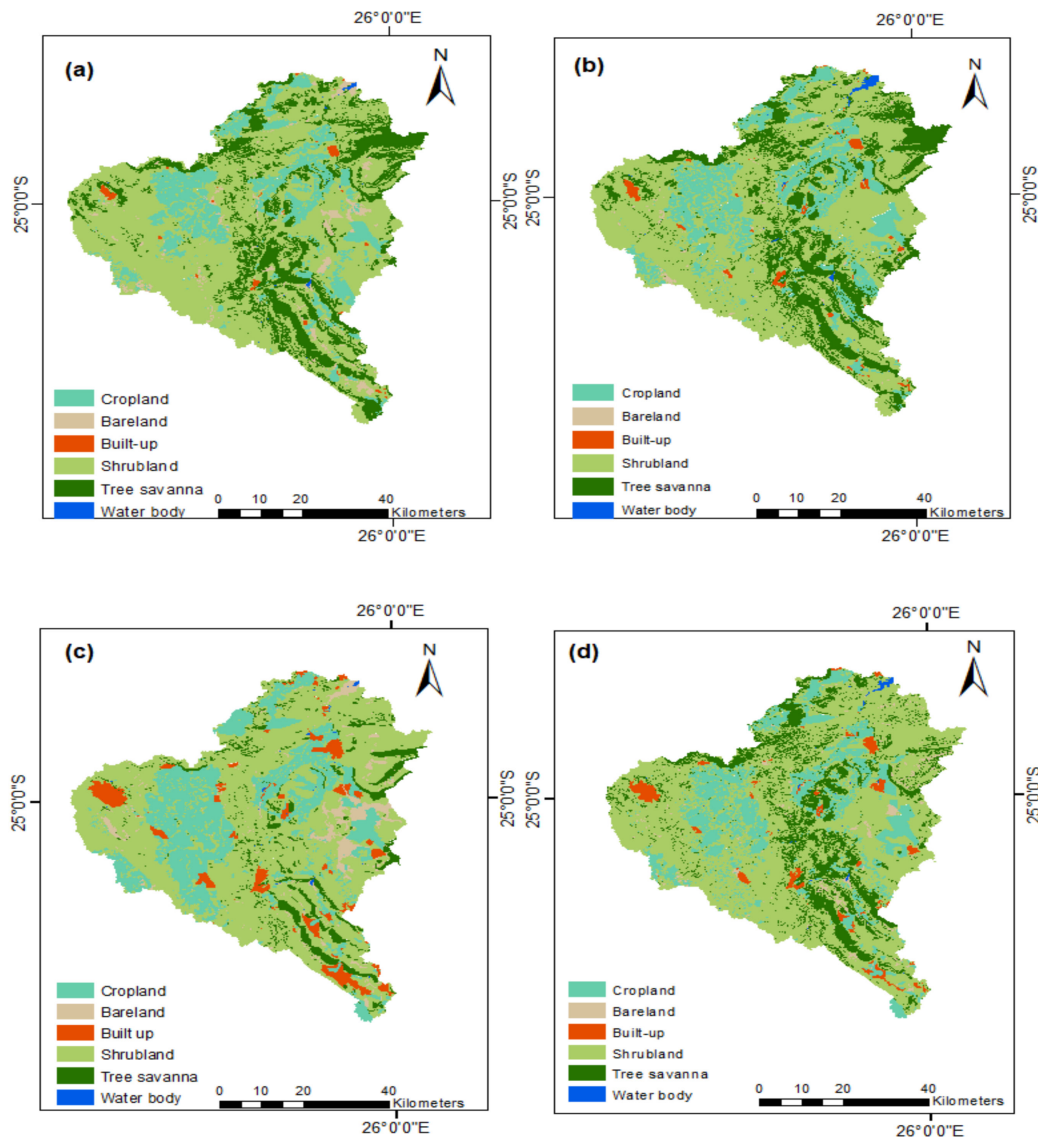


Figure 4. LULC categories for (a) 1984 (b) 1995 (c) 2005 and (d) 2015.

Conversely, other LULC categories revealed a decreasing trend. The shrub land category declined by 73.3 km² (2.8%) and 39.8 km² (1.5%) in the respective 1984–1995 and 2005–2015 change periods. Similarly, the tree savanna category shrank, with highest reductions of about 430.9 km² (56.5%) noted for 2005–2015 change period. On the contrary, tree savanna showed a slight increase during the 1984 to 1995 change period. Furthermore, a significant decrease was also observed for water body category in the catchment, with the highest decrease of about 7.3 km² (37.4%) in the 1995–2005 change period. Nonetheless, an increase of 13.9 km² (244%) was noted during the 1984–1995 period.

Annual change rates for each LULC category were also estimated. Spatially, the 2005 to 2015 change period showed the highest annual changes in LULC categories compared to other change periods. Tree savanna decreased annually at a rate of 43.1 km² (0.1%), while cropland and built-up categories increased at a rate of 26.4 km² (0.4%) and 11.3 km² (1.0%) between 2005 and 2015. The massive growth in built-up areas has been attested to by López [84], who reported that settlements in developing countries are, at present, growing five times faster than those in developed countries. The bare land category was estimated to decrease at an annual rate of 8.3 km² (6.8%), making it the highly

reduced category in the 1984–1995 change period. Of note also are the significant changes in the water body category in the 1984–1995 change periods. The category was estimated to be increasing at an annual rate of 1.3 km² (22.2%) during this period. However, this may not be true as the country and Southern Africa were still experiencing a drought period in the late 1980s and early 1990s.

Table 4. LULC change in the Gaborone dam catchment from 1984 to 2015.

LULC Type	1984		1995		LULC Dynamics between 1984–1995			
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Annual Change Rate in km ²	%
CPL	635.5	15.0	745.5	17.1	92.0	14.1	8.4	1.3
BL	122.4	2.8	31.2	0.7	−91.2	−74.5	−8.3	−6.8
SB	2597.3	59.7	2524.0	58.0	−73.3	−2.8	−6.7	−0.3
BU	26.4	0.6	55.2	1.3	28.8	109.1	2.6	9.9
TS	945.3	21.7	975.1	22.4	29.8	3.2	2.7	0.3
WB	5.7	0.1	19.6	0.5	13.9	244.0	1.3	22.2
Total	4350.5	100.0	4350.5	100.0	-	-	-	-
LULC Type	1995		2005		LULC Dynamics between 1995–2005			
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Annual Change Rate in km ²	%
CPL	745.5	17.1	747.5	17.2	2.0	0.3	0.2	0.0
BL	31.2	0.7	81.5	1.9	50.3	161.1	5.0	16.1
SB	2524.0	58.0	2631.6	60.5	107.6	4.3	10.8	0.4
BU	55.2	1.3	115.0	2.6	59.8	108.3	6.0	10.8
TS	975.1	22.4	762.8	17.5	−212.3	−21.8	−21.2	−2.2
WB	19.6	0.5	12.3	0.3	−7.3	−37.4	−0.7	−3.7
Total	4350.5	100.0	4350.5	100.0	-	-	-	-
LULC Type	2005		2015		LULC Dynamics between 2005–2015			
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Annual Change Rate in km ²	%
CPL	747.5	17.2	1011.4	23.3	263.9	35.3	26.4	0.4
BL	81.5	1.9	180.6	4.2	99.1	121.5	9.9	1.2
SB	2631.6	60.5	2591.8	59.6	−39.8	−1.5	−4.0	0.0
BU	114.9	2.6	228.2	5.2	113.2	98.5	11.3	1.0
TS	762.8	17.5	331.8	7.6	−430.9	−56.5	−43.1	−0.6
WB	12.3	0.3	6.9	0.2	−5.4	−44.1	−0.5	−0.4
Total	4350.5	100.0	4350.5	100.0	-	-	-	-
LULC Type	1984		2015		LULC Dynamics between 1984–2015			
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Annual Change Rate in km ²	%
CPL	635.5	15.0	1011.4	23.3	375.9	54.8	11.5	0.1
BL	122.4	2.8	180.6	4.2	58.2	47.5	1.9	0.0
SB	2597.3	59.7	2591.8	59.6	−5.5	−0.2	−0.2	0.0
BU	26.4	0.6	228.2	5.2	201.8	764.5	6.5	0.8
TS	945.3	21.7	331.8	7.6	−613.4	−64.9	−19.8	−0.1
WB	5.7	0.1	6.9	0.2	1.2	20.3	0.0	0.0
Total	4350.5	100.0	4350.5	100.0	-	-	-	-

3.3. LULC Losses and Gains from 1984 to 2015

LULC categories were converted into other categories during the 1984–2015 study period and thus, LULC category losses and gains were also examined (Figure 5 & Table 5). The results indicate that cropland and built-up categories were generally increasing during the study period. Cropland and built-up categories increased by up to 483.5 km² and 202.4 km², respectively. Likewise, the bare land category increased compared to other LULC categories. The category gained about 151.9 km² between 1984 and 2015. However, a loss of about 114.7 km² in the bare land category was observed in the 1984–1995 change period. Cropland and built-up categories were generally gaining from the

shrub land category. Conversely, categories such as shrub land, tree savanna and water bodies were significantly losing their areal extent to other LULC categories. Shrub land lost a total of 763.3 km², while tree savanna lost 674 km² between 1984 and 2015. Shrub land lost was mainly to crop land and tree savanna categories. However, a gain in shrub land was observed in the 1995–2005 change period and this was at the expense of tree savanna category. Furthermore, water bodies lost their areal extent to both bare land and shrub land, with the highest losses to bare land in the 2005–2015 change period. Overall, the highest losses (shrub land and tree savanna) and gains (crop land, built-up and bare land) were observed in the 2005–2015 period. However, the water body category expansively lost its areal coverage in the 1995–2005 change period.

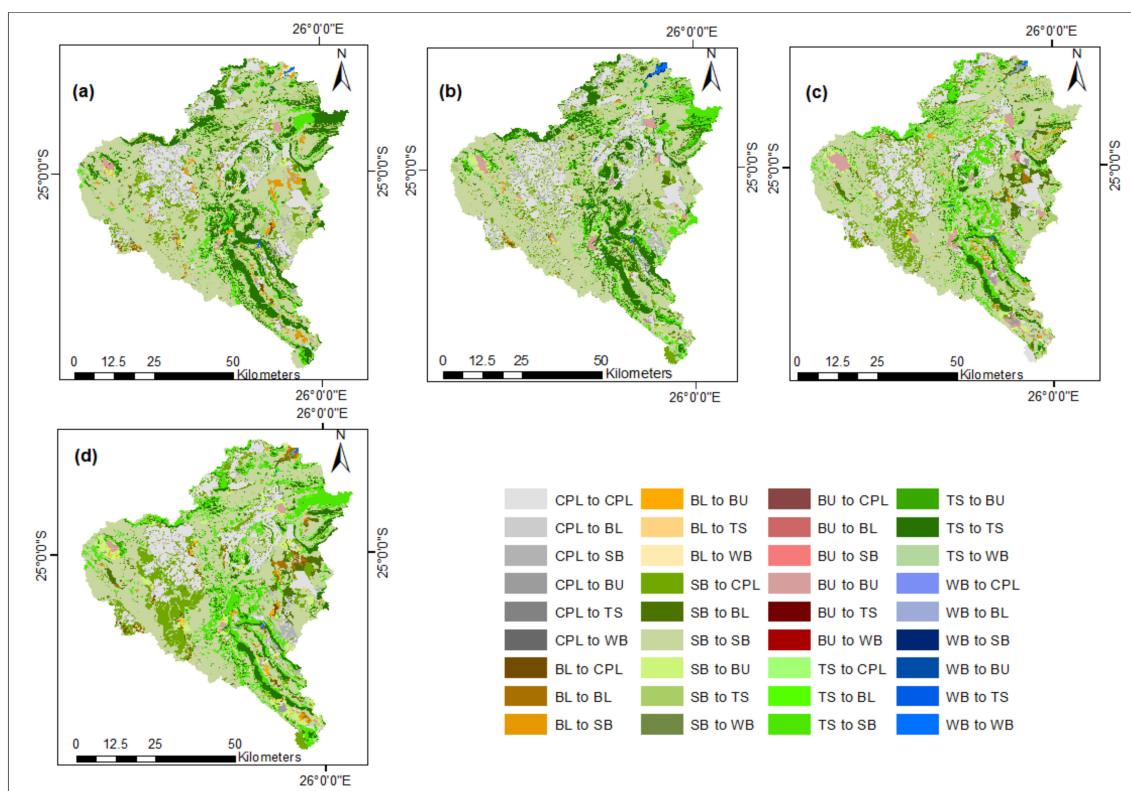


Figure 5. LULC loss and gains from (a) 1984 to 1995; (b) 1995 to 2005 (c) 2005 to 2015 and (d) 1984 to 2015. (Note: CPL—Crop land; BL—Bare land; SB—Shrub land; BU—Built-up; TS—Tree savanna; WB—Water bodies.)

Table 5. Transition matrix of LULCs in the Gaborone dam catchment from 1984–1995, 1995–2005, 2005–2015 and 1984–2015 (in km²).

Periods	LULC Type	Cropland	Bare Land	Built-Up	Shrub Land	Tree Savanna	Water Body	Losses (km ²)	% Losses
1984–1995	Cropland	502.4	2.3	2.0	133.1	13.7	0.1	151.2	23.1
	Bare land	16.1	7.8	3.5	85.1	2.1	7.9	114.7	93.6
	Built-up	0.7	0.1	21.5	3.9	0.1	0.0	4.8	18.3
	Shrub land	219.3	20.5	27.2	2042.3	283.0	4.9	554.9	21.4
	Tree savanna	7.0	0.5	1.0	259.3	675.9	1.4	269.2	28.5
	Water body	0.0	0.0	0.0	0.2	0.1	5.3	0.3	5.4
	Gains (km ²)	243.1	23.4	33.7	481.6	299	14.3	1095.1	
% Gains	32.6	75.0	61.1	19.1	30.7	73.0			

Table 5. Cont.

Periods	LULC Type	Cropland	Bare Land	Built-Up	Shrub Land	Tree Savanna	Water Body	Losses (km ²)	% Losses
1995–2005	Cropland	547.2	5.1	7.5	176.4	9.3	0.0	198.3	26.6
	Bare land	3.6	8.5	1.2	17.4	0.4	0.0	22.6	72.7
	Built-up	1.8	0.1	48.6	4.5	0.2	0.0	6.6	12.0
	Shrub land	188.2	62.8	54.9	2036.6	180.9	0.5	487.3	19.3
	Tree savanna	6.5	3.6	2.7	390.6	571.4	0.2	403.6	41.4
	Water body	0.1	1.4	0.0	5.9	0.5	11.6	7.9	40.5
	Gains	200.2	73	66.3	594.8	191.3	0.7	1126.3	
	% Gains	26.8	89.6	57.7	22.6	25.1	5.7		
2005–2015	Cropland	623.1	17.1	27.5	77.8	1.7	0.3	124.4	16.6
	Bare land	7.6	24.2	3.7	41.5	4.1	0.4	57.3	70.3
	Built-up	2.2	1.1	110.2	1.2	0.2	0.0	4.7	4.1
	Shrub land	359.0	126.2	81.0	1967.1	97.1	0.9	664.2	25.2
	Tree savanna	19.3	5.3	5.7	503.6	228.6	0.2	534.1	70.0
	Water body	0.1	6.6	0.0	0.4	0.1	5.1	7.2	58.5
	Gains	388.2	156.3	117.9	624.5	103.2	1.8	1391.9	
	% Gains	38.4	86.6	51.7	24.1	31.1	26.1		
1984–2015	Cropland	527.7	11.8	18.6	92.7	2.5	0.3	125.9	19.3
	Bare land	26.2	42.2	17.0	35.6	0.7	0.7	80.2	65.5
	Built-up	0.3	0.1	25.8	0.1	0.0	0.0	0.5	1.9
	Shrub land	443.5	111.8	148.8	1833.9	57.4	1.7	763.2	29.4
	Tree savanna	13.5	13.2	18.0	628.9	271.2	0.4	674	71.3
	Water body	0.0	15	0.0	0.3	0.0	3.7	15.3	33.9
	Gains	483.5	151.9	202.4	757.6	60.6	3.1	1659.1	
	% Gains	47.8	84.1	88.7	29.2	18.3	44.9		

4. Discussion

The study considered the spatial and temporal LULC changes in the Gaborone dam catchment through the integration of GIS and freely available RS data from 1984 to 2015. Overall, a faster LULC change was revealed during the 1995–2005 and 2005–2015 change periods compared to 1984–1995, with major increases noted for bare land and built-up areas while other LULC categories such as tree savanna and water bodies decreased significantly during these periods. Akinyemi and Mashame [74] also observed a similar scenario in the Palapye area (280 km north of Gaborone dam catchment). They noted faster change rates in the 2000–2014 change periods and attributed the fast change to the social and economic transformation of Palapye since the beginning of the 21st century. This can also partly explain the pattern of change in the Gaborone dam catchment.

Croplands increased in the catchment during the study period. The catchment is mainly rural, similar to the majority of the population in Botswana; therefore, the population in the catchment derives its livelihood from rain-fed subsistence farming combined with livestock keeping [85]. Thus, agricultural production remains the core of the rural economy, hence the reported increase in croplands and LULC changes. Therefore, as Bessah [86] noted, the agricultural land expansion trend is global irrespective of the economic status and location of the country. The expansion in croplands or intense use of land for cultivation as observed in the Gaborone dam catchment may result in higher runoff rates, unless water conservation measures are introduced on cultivated land [87]. In addition, this may have significant effects on biodiversity, water and radiation budgets, carbon cycling and livelihoods [88]. The expansion in croplands has been mainly at the expense of shrub land category. This has also been observed in the Ameleke watershed in Ethiopia [89] and other developing countries where loss

of forests to crop production is critical with expanding cropland area [31,33,90–92]. Nkambwe and Totolo [93] also observed a similar scenario in the areas surrounding Gaborone city where arable lands have been expanded into the woodlands and open grasslands of all territories, which have been used for communal grazing. Cropland gains in the catchment can also be explained by the introduction of the agrarian programs which attractively gives different opportunities for subsistence farmers to increase their incomes [94]. For example, the highest gains in cropland in 2005–2015 can be attributed to the introduction of the Integrated Support Program for Arable Agricultural Development (ISPAAD) in 2008. This program together with its fore runners was introduced in an effort to meet food self-sufficiency, alleviate poverty, diversify the economy and reduce dependence on the diamond led-economy [95,96]. As more land is reserved for cropland expansion, less remains for wildlife and other environmental purposes leading to environmental changes [92] which may in turn impact biodiversity, water resources and overall ecosystem functions. Cropland expansion may also lead to pollution of water sources downstream [92] and exposure of land to erosion, leading to the loss of topsoil which is required for agricultural production [97] and hence, drought and flood prevalence. The observed stagnation in croplands between 1995 and 2005 could be explained by the abandonment of fields by individuals, the failure of the Arable Land Development Program (ALDEP) and the Arable Rain-Fed Agricultural Program (ARAP) and rural-urban connections [98]. Abandonment of agricultural land has been noted to have increasing globally [29,99] and within Sub-Saharan Africa [100], despite the clear need for increased agricultural engagement and productivity. In South Africa, crop abandonment has been attributed to a lack of draught power, rainfall variability and droughts and a more modernized youth hesitant to living a marginal agrarian lifestyle [101]. This could also explain the Gaborone dam catchment despite government efforts.

The bare land category was shown to be increasing significantly and was more significant around the Gaborone dam area and thus gained from water bodies. The gain has shown not to be permanent as during heavy rainy seasons, the bare lands change back to water bodies as also observed by Akinyemi and Mashame [74]. The Gaborone dam water levels dropped in the years 2004/2005 and in 2014/2015/2016. This led to the Water Utilities Corporation (WUC) declaring the dam failed, when it recorded a low of 1.7%. The reduction in dam water levels increased the bare land areal coverage, as the areas around the Gaborone dam and other small dams in the catchment dried up, resulting in bare soils. A high proportion of land area under bare land was also observed in 1984. Bare land intensification was also noted between 1984 and 2015 in Raya, Northern Ethiopia [102]. This pattern can be attributed to the prolonged dry periods resulting from the major impact of rainfall variability as reported by Akinyemi and Mashame [74], Batisani and Yarnal [103], and Byakatonda [104], who observed a decrease in rainfall in Botswana since the early 1980s. In addition, fuel wood gathering, and goat grazing in combination with land clearing for crop cultivation have been noted to lead to an increase in bare lands [105]. The increase in bare land area may lead to erosion and leaching of nutrients in the catchment and agricultural chemicals to groundwater, streams and rivers [42]. Additionally, due to the interaction of both climate and human activities [74], which include drought, floods and livestock overstocking, the loss of the shrub land category led to an increase in bare land areal coverage during the study period. The study is in agreement with Akinyemi and Mashame [74], who concluded that climate change impact is the driver of land transition in semi-arid environments and that the highest amounts of bare lands recorded coincide with prolonged drought periods, which indicates climate impact.

Water bodies on the other hand were generally losing areal coverage during the study period, with the exception of the 1984–1995 change period, where an increase in water bodies was observed. During this period, a number of small farm dams were shown to be active as observed by DWA [106] and Meigh [107]. The Gaborone dam wall was also raised by 7 m between 1983 and 1985 expanding its capacity, which explains the increase in areal coverage of water bodies. In addition, critical to the expansion is the high rains received in the country post drought period (1993–1995) [108]. Even though the number of small farm dams increased in the catchment [109], land under water body category

reduced significantly between 1995–2005 and 2005–2015. In addition, land under water occupied the smallest land area in 1984 at 5.7 km² (0.1%). The low areal coverage of water bodies can be explained by the low rains or prolonged droughts experienced in Botswana and Southern Africa in the early 1980s, 1991–1992, 2004–2006 and 2013–2016 [110–113]. The decline in the water body category in 2005 and 2015 could be an indication of decreased runoff within the catchment area, which in turn reduces the Gaborone dam yield, leading to water supply restrictions in the supply areas.

Built-up areas were significantly increasing, indicating population growth (as shown in Figure 2). The expansion is a result of rural-urban migration to Gaborone city, which in turn overflows into the neighboring settlements [68,69] and may lead to unprecedented challenges and environmental problems. Sebege and Gwebu [72] concur with this as they found out that built-up areas were increasing in the city, taking land in the surrounding areas and impacting the rural-urban link as observed by Keiner and Cavric [68]. The built-up category led to a loss of shrub land during the study period. This disagrees with the notion that built-up areas in both developed and developing countries often infringe upon cropland areas as shown by Ju [114], d'Amour [115], Islam [116] and Seto [22]. This thus shows how distant settlements and croplands are in the Gaborone dam catchment. On the contrary, croplands expanding into shrub lands could be taking land reserved for forage, therefore reducing land for livestock grazing which may in turn lead to overgrazing and degradation. The conversion of natural vegetation to residential land uses increases impervious areas and hence, decreased infiltration to underlying soils and storage capacity [54], increased storm runoff, which may lead to high levels of pollution (surface and groundwater) [117] and floods, and may also cause the surface temperature to rise leading to urban heat islands [102]. This is the case of Ramotswa village within the catchment, where nitrate levels were found to be high in boreholes with samples of faecal coliform contamination, suggesting mainly a human source (i.e., from seeping pit latrines) [112]. Therefore, with increase in the population of an area, more land will be required for settlements, leaving the water sources susceptible to pollution. Furthermore, Parida [55] found that urbanization greatly influences runoff coefficients in the catchment as they were significantly correlated with the percent increase in urbanization. Thus, appropriate water management practices are needed to avert the threats of future floods. Urbanization will thus potentially alter the rainfall-runoff response of a previously rural or low urban density catchment [56], consequently, leading to unprecedented challenges and environmental problems in the rural-urban link [68].

Natural vegetation, i.e., shrub land and tree savanna, showed an overall decrease in the catchment during the study period. Likewise, woodland loss to shrub lands has been observed in Zimbabwe, [118]. Shrub land losses were mainly to croplands. This may thus reduce land area reserved for forage as well as quality of forage and may lead to degradation elsewhere. Tree savanna loss around the catchment hills was also observed and this may be due to the proximity of farming lands to timber for fencing. The loss in natural vegetation can also be attributed to rainfall variability, as vegetation production in semi-arid regions is closely related to the long-term average precipitation as noted by Rutherford [119] and inter-annual average rainfall [120]. Therefore, improvement in the tree savanna category in 1995 is related to the increase in mean annual precipitation in the 1993–1995 normal rainfall conditions in Botswana as observed by Dube and Pickup [34] and Vanderpost [121]. This shows that the natural covers are able to regenerate even after drought. On the contrary, even with continued human pressure; climate variability, drought and competition for water may lead to the death of some plants. Shrub land gain from bare land in the change period 1984–1995 can be attributed to bush encroachment in the catchment at the expense of grasslands. This was also observed by Dougill [73] in Southern Kalahari and South Africa where savanna landscapes have shown extensive bush encroachment and changes in herbage [122]. In addition, the loss of vegetation cover may lead to changes in the soil water holding capacity [123], thus affecting groundwater recharge.

There are potential sources of uncertainties in the image classification which may have impacted the derived LULC classes and hence the estimated change. These are related to the spectral ambiguity for some classes with large spectral resemblance and the limited number of training data available,

particularly of uncertain quality for earlier periods. Although transitions from one LULC category may be explained, some of these effects might also be related to misclassification. This situation is not uncommon, especially when mapping LULC for the past periods for which it is impossible to obtain ground information [124].

5. Conclusions

The study has examined the spatio-temporal patterns and rate of LULC changes in the Gaborone dam catchment from 1984 through 2015 using the GIS and RS techniques. In the process, the entire study period has been divided into smaller decadal time periods such as 1984–1995, 1995–2005 and 2005–2015. It identified six (6) major LULC categories which include cropland (CPL), bare land (BL), shrub land (SB), built-up (BU), tree savanna (TS) and water body (WB). Among these, shrub land was found to be the most dominant LULC category with the water body being the least dominant category during all time periods. However, significant gains were observed under three categories: built-up (with 202.4 km²), bare land (with 151.9 km²) and cropland (with 483.8 km²). On the other hand, significant losses were observed for water body (with 15.3 km²), tree savanna (with 674 km²), and shrub land (with 763.2 km²) categories. The expansion in cropland and built-up areas has been shown to affect natural vegetation (shrubs and tree savanna), which may in turn exacerbate climate change, affect livelihoods, worsen the catchment condition and increase land degradation impact in the catchment. In addition, the increase in built-up areas arising from population growth in the catchment may remain a challenge in the future. Even an increase in the use of the cropland area could increase incidences of soil erosion by water or wind due to poor tillage or exposure of soil. The loss in the water body category clearly explains the low water levels in the Gaborone dam and droughts in the catchment. This may lead to water supply shortages in the City of Gaborone and surrounding areas as well as contribute to drought severity, causing a significant impact for both humans and livestock. These changes may have significant environmental impacts that need to be closely monitored for the sustainability of the environment.

Overall, the findings of this study could be incorporated into land management strategies to facilitate better decision making and formulation of evidence-based and environmentally friendly policies for an urbanizing catchment and other similar environments to improve sustainability of natural resources.

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