

An Assessment of Land Use and Land Cover Change for Lubovane Reservoir Sub-Catchment in Eswatini

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ABSTRACT

The increasing population in rural areas, increased livestock densities and extensive deforestation have been reported as the main drivers of land degradation in Eswatini. Land degradation, along with biodiversity loss and climate change presents serious challenges to the environment, economy and the country's development agenda. This study was conducted to assess the land use land cover (LULC) changes within the Lubovane reservoir catchment. Landsat 4-5 TM images were used for mapping LULC changes for 1995, 2000, 2005, 2009 and a Landsat 8 image was used for mapping 2015 LULC. A supervised LULC classification was conducted using 6 classes (water, settlements, irrigation, cultivation, shrubs and forests, as well as bare land) in ArcGIS version 10.3.1. The classification was validated using a confusion matrix and the results reflected that water, irrigation, cultivation, forests and shrubs were well classified. The LULC assessment results indicated that there was low coverage of water bodies observed from 1996 – 2005, while a 3% increase was observed in 2009. Water coverage decreased to 1.9% in 2015 due to the *El-Niño* induced drought that hit Southern Africa, resulting in low inflow to the dam. A reduction of shrubs and forest cover was experienced in 2000

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due to conversion of forested areas into settlements for resettled households. However, a slight increment of shrubs and forest was observed from 2009 to 2015. A reduction in the concentration of forests cover around the reservoir, an increase of settlements and bare land were also observed.

Keywords: Land use, land cover, catchment, reservoir, vegetation

INTRODUCTION

Land use land cover (LULC) influences global environmental changes. Therefore, it is crucial to undertake LULC assessment in order to understand trends of on-going changes ([17] et al. 2021). Land use is defined as the purpose for which land is utilized, whereas land cover refers to the physical features of the land surface [16]. Changes in LULC may contribute to significant effects on various environmental, ecological and hydrological systems [13]. The changes of LULC are caused by multiple interacting factors which could be anthropogenic or natural processes occurring at different spatiotemporal scales, globally these has been characterized by gains in agricultural land and reduction of forests [8]. The drivers of LULC changes comprise a combination of demographics, politics, socioeconomic systems, institutions, as well as nature, technology and culture. Therefore, due to the diversity of the drivers, LULC change does not comply to a strict model and is non-deterministic [14]. These challenges have direct impacts to the livelihoods of the community and subsequently the population both in urban and rural areas.

The increasing human population densities in rural areas, increased livestock population on poorly managed rangelands and extensive deforestation have been reported as the main drivers for land degradation in the Kingdom of Eswatini [6]. Additionally, agricultural expansion and settlements have led to intensification of land use and adoption of unsustainable practices, which include loss of natural resources, changes in natural habitats and ecosystems, biodiversity loss, decrease in water quality and quantity, as well as reduction in productivity of arable and rangelands in Eswatini [7]. Land degradation, along with biodiversity loss and climate change presents serious challenges to the environment, economy and the country's development agenda [4]. As, such in order to achieve sustainable development, the country has to respond to these challenges.

In response to these challenges, the government of Eswatini implemented the Lower Usuthu Smallholder Irrigation Project - Global Environment Facility (LUSIP-GEF)-Sustainable Land Management (LUSLM) project. Through this project the government intended to reduce land degradation, biodiversity loss and mitigate climate change in the Lower Usuthu River Basin area through the application of sustainable land management practices [6]. The LUSLM project was implemented within the Lubovane reservoir catchment, which also contributed towards improved management of the watershed draining into the reservoir. This study was undertaken to assess the LULC changes within the Lubovane reservoir catchment.

The application of remote sensing (RS) and geographic information systems (GIS) theories has been widely recognized as accurate and highly efficient tools for mapping, characterizing and monitoring changes in LULC [18]; [12]. RS data also provides valuable information regarding the processes, location, rate, trend, nature, pattern and magnitude of LULC changes while GIS

enables mapping and analysing the patterns captured in the remotely sensed data thus enhancing the interpretation and understanding of LULC dynamics [11].

Description of the Study Area

The Lubovane reservoir, is located between latitude 26°46'57.60"S and 26°43'46.28"S and longitudes 31°38'42.52"E and 31°42'54.45"E (Figure 1). The reservoir occupies a total surface area of 13.9 km² at the downstream end of the Mhlathuzane River catchment. The Lubovane reservoir catchment sits in the Lower Usuthu sub-basin and the Usuthu Basin within Eswatini covering about 12 700 km² [10]. The LUSIP began in the late 90s, hence the study covered the period prior to construction (1995, 2000) and the period after construction (2005, 2009 and 2015) of the reservoir. These years were chosen so that mapping could cover the time period before the introduction of the project up to 2015, when the project was almost fully implemented and activities in the project area were highly intensified.

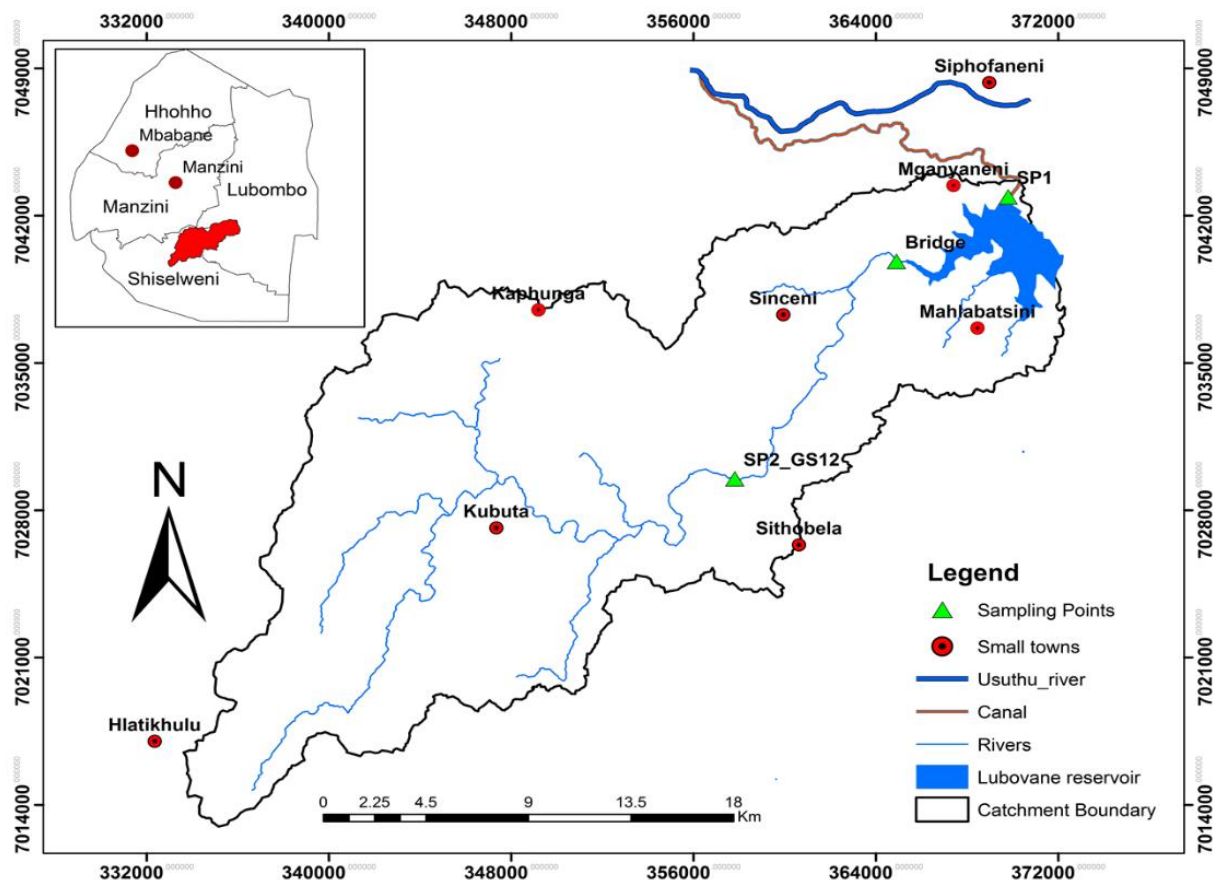


Figure 1. Location of the Lubovane reservoir and its catchment area

The catchment area of the Lubovane reservoir is 524 km² with a Mean Annual Runoff (MAR) of 70 x 10⁶ m³ as well as a slightly high coefficient of variation (98%) [2]. The average temperature range for Lubovane Reservoir catchment is 19° C to 30°C, with maximum temperatures reaching 40°C, usually around December and January (Figure 2). The annual rainfall in the basin ranges from 600 to 1000 mm, with the lower parts of the basin receiving the least rains [9].

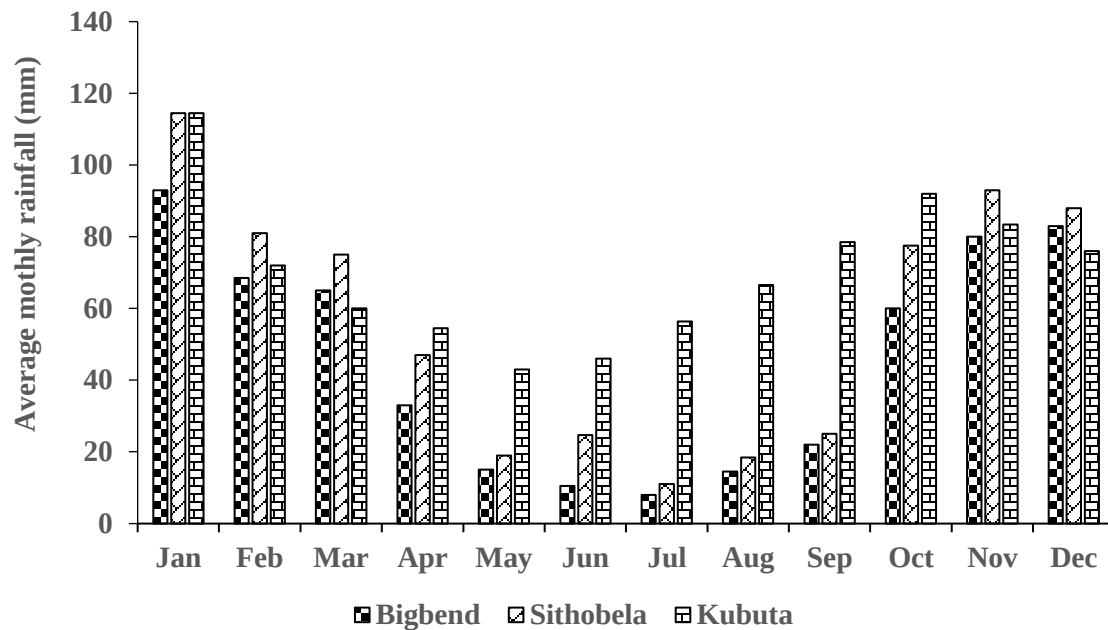


Figure 2. Average monthly rainfall for Lubovane reservoir Catchment (1981 - 2015)

The dominant land uses in the Lubovane dam catchment were agriculture and rural settlements. There were various farms both for subsistence and commercial purposes within the catchment. The areas around Kubuta were characterized by large fruit tree plantations with the main products being banana and oranges. There were noticeable spots of sand mining both for coarse grained sand from the streams and also fine-grained plaster sand on the mainland. The mining posed a risk of soil erosion in the micro-catchment and subsequently sedimentation, as the sand could be left bare and uncovered.

MATERIALS AND METHODS

Data Requirements and Acquisition

Data required for this study included rainfall data (1995 - 2015), slope and elevation maps, land cover/land use changes from the year 1995 to 2015 as well as data on the type of soils in the study area. This period was chosen in order to cover the period before the construction of the reservoir, resettlement period which saw a lot of deforestation around the water body, during the construction and after the reservoir was commissioned. Data for rainfall from the period 1995 to 2015 was acquired from the Eswatini Meteorological Services for three stations (Big Bend, Sithobela and Khubutha) falling in and closest to the study area. Coordinates for the stations were collected using a GPS and then the stations were overlain on the map for the study area to show their spatial distribution. The Thiessen polygon method in GIS was used to determine the areas of influence of each station and the rainfall for each location was the resultant rainfall from the influence of the interpolated stations.

ASTER Digital Elevation Model (DEM) covering the study area was retrieved from the Global ASTER GDEM website (<http://gdem.ersdac.jspacesystems.or.jp/>). This was used to create a sub-catchment map of the Lubovane reservoir to delineate the area that drains into the reservoir. The elevation and slope factors were also determined from the DEM. Cloud free

Landsat TM images were downloaded from the United States Geological Survey website (<http://www.glovis.usgs.gov>) for the years 1995, 2000, 2009 and 2015. The land cover maps were necessary for mapping land use changes in the reservoir catchment from 1995 to 2015. The DEM hydro-processing for catchment delineation was performed using the Integrated Land and Water Information System (ILWIS) in order to obtain the boundary of the Lubovane catchment area which enclosed all points draining into the reservoir.

Land Use and Land Cover Classification

Landsat 4-5 TM images were used for mapping land cover changes for 1995, 2000, 2005 and 2009. A Landsat 8 image was used for mapping land cover for 2015. This period was preferred for the study because it covers the both the situation prior and post construction of the Lubovane reservoir. The LULC classification was done using ArcGIS version 10.3.1. Since the researcher was familiar with the study area, the supervised land cover classification method of classification was opted for this study. Additionally, this land cover classification method provides a high level of accuracy than other existing image classification methods [3].

Before beginning the classification, the dynamic range adjustment (DRA) function under image analysis was used to enhance visualization of the image. Classification was done using a signature of points extracted from the image and assigned classes according to the researcher's knowledge of the area. Six land cover classes were selected namely; water, settlements, forest and shrubs, irrigated area, cultivated area and bare land.

A confusion matrix was used for assessing the accuracy of the land cover classification. The confusion matrix was also conducted using ArcGIS version 10.3.1. The use of confusion matrix in accuracy assessment is based on the assumption that each pixel can be allocated to a single class in both the ground and map data sets, and that these two data sets have the same spatial resolution and are perfectly registered [15]. Figure 3 shows a layout of a typical confusion matrix and the equations for computing the producer's and the user's accuracy.

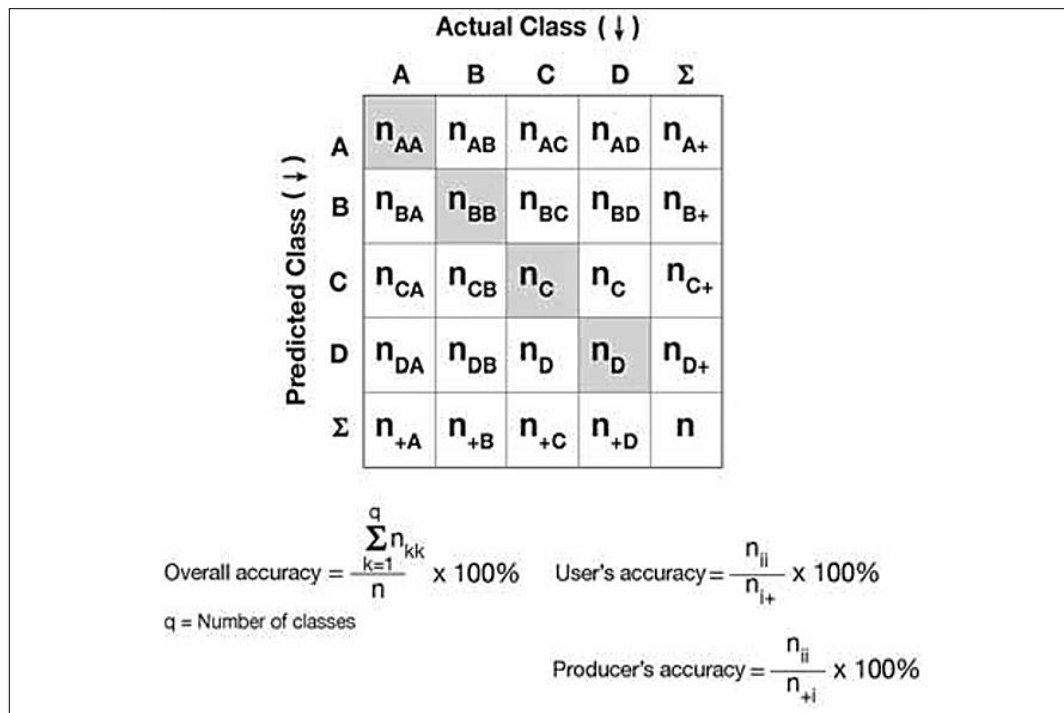


Figure 3 Layout of a typical confusion or error matrix, showing computation of user's and producer's accuracies [15]

RESULTS AND DISCUSSION

Validation of the Land Cover Classification

Land cover classification, even though supervised, may possess some errors in the classification where pixels are assigned a class that they do not represent in the real image [1]. The accuracy of land cover assessment is considered to be poor below 50%; fair above 50% and good above 70% [5] ; [15] and [19]. The Land cover classification performed in this study was good according to the above-mentioned classification. Table 1 and Table 2 presents the results of the confusion matrix used to determine the accuracy of land cover classification for the study.

Table 1. Confusion matrix for Land cover classification

	W	SL	IRR	CU	F&S	BL	SUM	Producers' accuracy
Water (W)	52	0	1	0	0	0	53	98.1
Settlements (SL)	8	24	1	8	19	17	77	31.2
Irrigation (IRR)	0	0	59	0	0	0	59	100.0
Cultivation (CU)	0	2	0	14	0	0	16	87.5
Forest and Shrubs (F&S)	0	0	0	5	24	0	29	82.8
Bare land (BL)	0	3	0	3	0	6	12	50.0
SUM	60	29	61	30	43	23	246	
User's accuracy	86.7	82.8	96.7	46.7	55.8	26.1		72.4

The results reflected that the water, irrigation, cultivation, forests and shrubs were well classified, whilst bare land and settlements were poorly classified. Water, irrigation and cultivation were probably easy to identify and classify, especially in the 2015 image. This was because the reservoir and the large areas under sugarcane production downstream of the Lubovane reservoir fell in the same tile. The Mhlatuzane catchment was predominantly composed of rural settlements, which had sparse homesteads, as opposed to clustered high density settlement patterns. It is worth noting that some of the homesteads were made out of thatched, stick and mud houses that had the same reflectance as bare land. That made it difficult to distinguish between most settlements and bare land, hence the poor classification between the two classes.

Table 2. Class and Overall Accuracy

	Class Accuracy (%)	Overall Accuracy (%)
Water	92.4	
Settlements	57.0	
Irrigation	98.4	
Cultivation	67.1	
Forest and Shrubs	69.3	
Bare land	38.0	
Average	70.4	72.8

Land Use/Land Cover Changes

The results in Figure 4 and Figure 5 indicated that there were some noticeable changes in the land cover and land use patterns over the mapped period (1995, 2000, 2005, 2009 and 2015). The changes observed included forest coverage, changes in bare land and changes in farming activities. These changes have a direct impact on soil erosion and subsequently sedimentation. On the other hand, the land area covered by water bodies was low during the period 1995 – 2005. Significant amount of land area covered by water started showing in the 2009 assessment. It is worth noting that this was the period when the dam started receiving water. The areal coverage of water increased from 0.05% coverage in 2005 to 3% coverage in 2009.

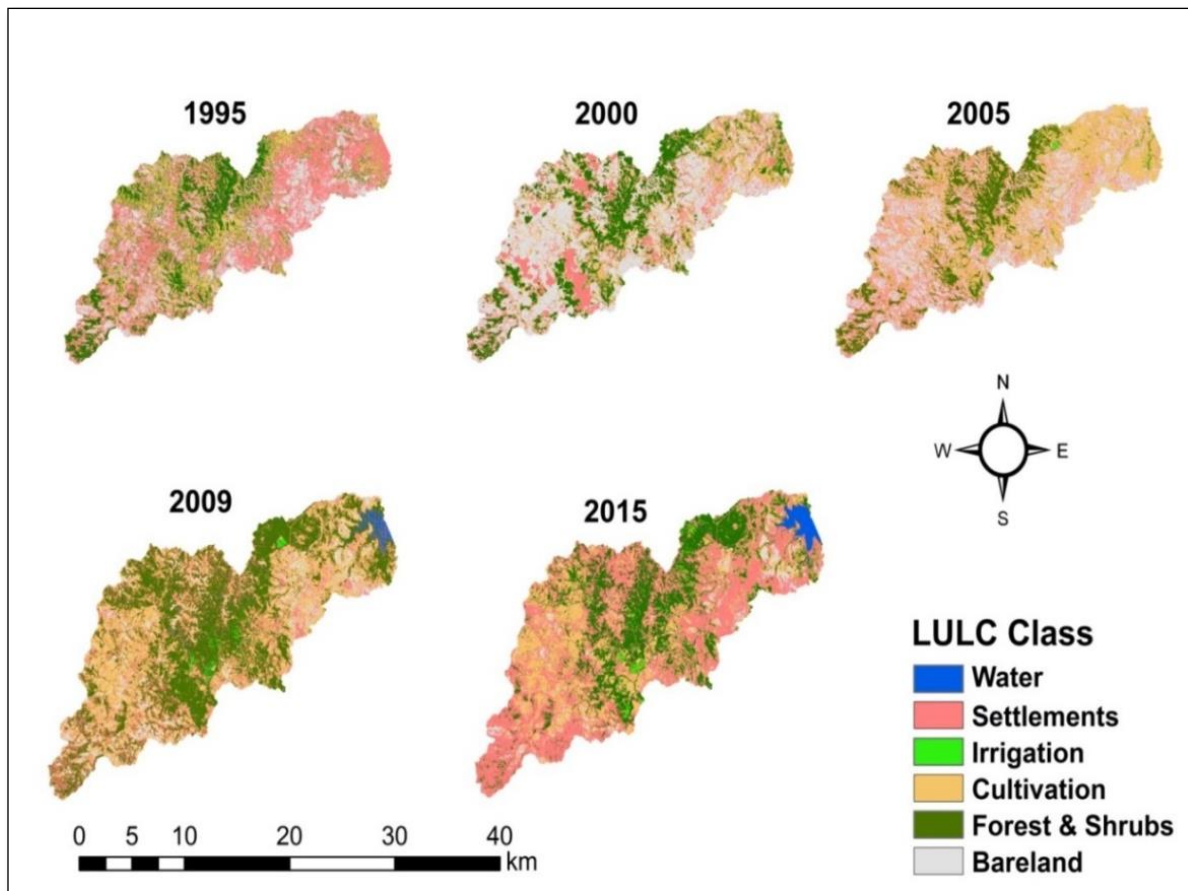


Figure 4. Land use land cover changes in the Lubovane catchment

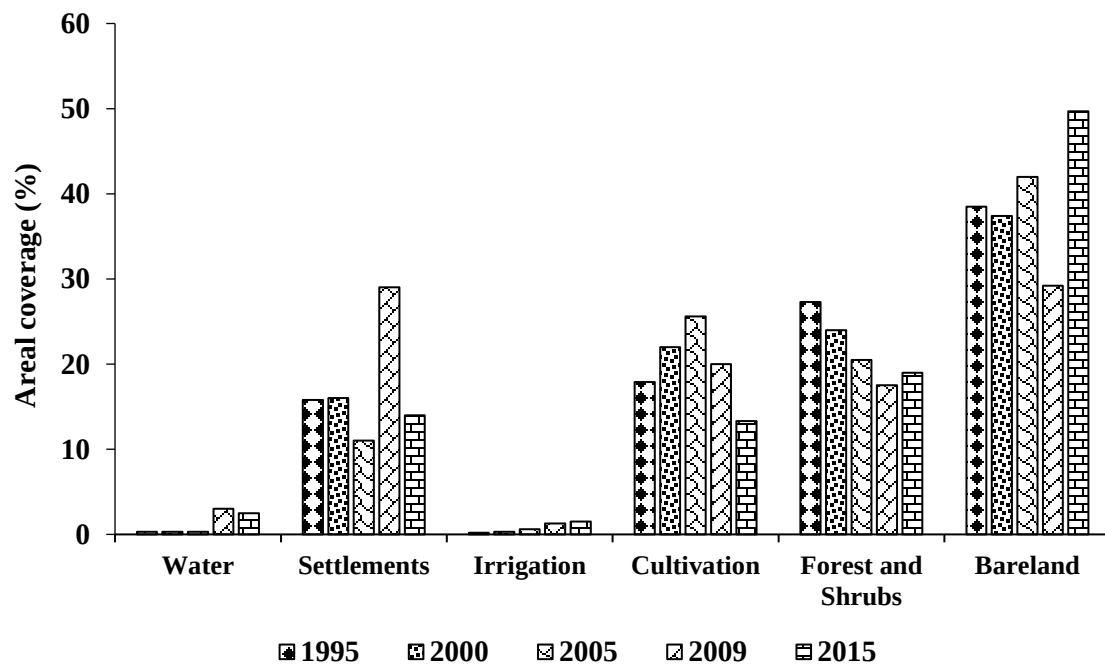


Figure 5. Land use and land cover changes in Lubovane reservoir catchment

In 2015 the areal coverage of water decreased to 1.9% of the total catchment area. This was driven by the expansion of irrigated land area and the *El-Niño* induced drought that hit Southern Africa, resulting in low inflow to the dam. The low runoff from the river contributed to the low inflows to the Lubovane reservoir, hence the low water coverage in 2015 compared to 2009.

Forest and shrubs covered 27% of the total catchment area in 1995. This land use decreased by 3% and 4% in 2000 and 2009, respectively. There was a 2% increase in forested areas from 2009 to 2015. The increase of forest and shrubs between 2009 and 2015 was attributed to the implementation of the LUSLM project, which focused on improved land management practices within the catchment area from 2009 to 2015 [7] (IFAD 2016). Such interventions safeguard the huge investment made by the Government of Eswatini in implementing the LUSIP, which relies on the Lubovane reservoir for irrigation.

The 2009 and 2015 images shown in Figure 4 also indicated that although an increase of forest was observed, there was a decrease in the concentration of forests in the areas around the reservoir. It is worth noting that the forest was unfortunately replaced by settlements and bare land. Bare land covered 38% of the total catchment area in 1995 and it moderately increased towards 2005. These changes could be attributed to the observed livestock overgrazing and deforestation on the sites in question. Since the catchment mostly contained rural settlements, firewood was the common source of fuel that was used, hence the deforestation increases observed.

CONCLUSION

The LULC assessment of the Lubovane reservoir catchment indicated that significant changes were observed from the study area over the years (1995 to 2015). An average of 10% decrease in forest and shrubs, as well as 11% increase in bare land was observed for the 1995 to 2015 period. There was also an increase in forested area observed between 2009 and 2015. However, forest areas surrounding the reservoir were unfortunately replaced by settlements and bare land.

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