Land use induced land cover changes and future scenarios in extent of Miombo woodland and Dambo ecosystems in the Copperbelt province of Zambia

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ABSTRACT

The pattern of Miombo woodland conversion to other land uses and the attendant impacts on vital Miombo ecosystems such as dambos is not well understood. Using the Copperbelt province of Zambia as a case study, we assessed the spatio-temporal patterns of Miombo woodland and dambo conversion to other land uses between 1984 and 2016 and predicted the changes to 2050. The effects of land use land cover change (LULCC) on the extent of Miombo woodlands and dambos was determined by intersecting layers of croplands, settlements, plantations, grasslands and barelands on woodland and dambo pixels. Prediction of future LULCC was done using the land change modeller (LCM) in TerrSet. It was observed that in the period between 1984 and 2016, woodlands decreased by 17.9% while dambos increased by 4.9%. The two classes were predicted to lose 26.4% and 2.0%, respectively, by 2050. Conversion to cropland was the highest contributor to woodland loss, accounting for 57.5% of total loss by 2016, and projected to reach 67.6% by 2050. Similarly, establishment of cropland was shown to result into 53.5% (2016) and 58.9% (2050) of loss of dambos. Expansion of croplands caused a decline in woodlands and dambos. Therefore, sustainable agriculture should be adopted.

KEYWORDS: copperbelt, dambo, land use, miombo woodland, modelling

1 INTRODUCTION

Tropical forests cover about 2 billion ha (13%) of the world's land area (FAO, 2015; Gumbo et al., 2018) and account for an estimated 25% of carbon in the terrestrial biosphere (Bonan, 2008). The loss of tropical forests due to land use land cover change (LULCC) is therefore a major concern because it causes global CO_2 fluctuation (Bonan, 2008; Pongratz et al., 2014). Nested within the tropical forests are Miombo woodlands that are dominated by *Isoberlinia*, *Julbernadia* and *Brachystegia* tree species (Backéus et al., 2006; Dewees et al., 2010). This ecosystem covers approximately 2.7 million km^2 in 10 countries of central and southern Africa (Ribeiro et al., 2015). These woodlands hold about 43% of the world's tropical dry forests (Kalaba et al., 2012; Mittermeier et al., 2003) with about 8500 species of higher plants of which 54% are endemic (Chirwa et al., 2008; Mittermeier et al., 2003). The Miombo ecosystem has important ecological functions, because they maintain soil fertility, regulate climate by maintaining carbon stocks, modify the hydrological cycle, control soil erosion and support livelihoods of more than 100 million people within and outside the region (Chidumayo & Gumbo, 2010; Jew et al., 2016; Ryan et al., 2016). Conservative estimates of the benefits (derived from forest and non-forest products) provided by the Miombo woodland range from US$7 to US$11 million per year (Mbanze et al., 2019; Ryan et al., 2016). Despite the benefits provided by the Miombo woodland, approximately 13 million ha of forests are cleared every year (Keenan et al., 2015; Sloan & Sayer, 2015). The ecosystem is threatened by land clearance for settlements, agriculture, logging, firewood collection, charcoal production and tobacco curing (Dam, 2017; Handavu et al., 2019; Mzuza et al., 2019; Shackleton, 2015).

The extent of wetlands globally is projected to be at least 6% of the earth's surface (Finlayson & D'Cruz, 2005). Africa contains in excess of 131 million ha of these wetlands (McCartney et al., 2011). Interspersed within the Miombo ecosystem are wetlands which appear as broad, grassy wet depressions also known as dambos, that cover between 10% and 40% of the landscape (Whitlow, 1990; Zolho, 2005). Dambos are vital habitats for specialised flora and fauna, and they contribute to the livelihoods of the local communities (Mbanze et al., 2019). According to von der Heyden and New (2003), the functionality of Miombo woodlands depends on dambos, because of their ability to capture rainfall and groundwater. Within the hydrological cycle, dambos store water, thereby mitigating extreme events like floods and droughts (Schlaffer et al., 2016). They also play a vital role in biogeochemical cycles, acting both as sources and sinks of carbon and nitrogen emissions (Schlaffer et al., 2016). Nevertheless, wetlands are also vulnerable to climate change and land use conversion activities (Junk et al., 2013; Seki et al., 2018) such as extensive agriculture, over grazing, gulley erosion and fires (Matiza, 1994; Wood et al., 2013). It is widely reported that anthropogenic activities may result in the drying up of dambos, streams and rivers (Mabeza & Mawere, 2012; Nyamadzawo et al., 2014). A number of studies have reported on the influence of dambos on downstream flow regime despite contradictions and lack of consensus on the issue (McCartney et al., 1998; von der Heyden & New, 2003). Research on the effect of anthropogenic activities and extent of dambos are scarce and have been reported in Malawi (Chidanti-Malunga, 2011; Mloza-Banda, 2005), Zambia (Kuntashula et al., 2006; Shimada, 1994), Zimbabwe (Bell, 1987; Bell & Roberts, 1991; Berka et al., 2001; Scoones & Cousins, 1991), Kenya and Tanzania (Franke et al., 2009; Mwita, 2013) and in Mozambique (Mbanze et al., 2019). Globally, few studies have highlighted the role of wetlands and the impacts of LULCC such as in the Himalayas (Alam et al., 2011) and in Beijing, Hanshiqiao wetland (Zhang et al., 2011). Gaps still exist in terms of the extent and current state of dambos in Africa (Rebelo et al., 2010). The choice to study dambos in Miombo woodlands was motivated by their potential role in providing life support for a number of terrestrial and aquatic species (Fynn et al., 2015; Matayaya et al., 2017) and economic benefits through agriculture from the fertile land (Kotze, 2011; Ryan et al., 2016; Whitlow, 1990). Dambos are among the most threatened habitats in the world (Kotze, 2011; Mbanze et al., 2019).

Understanding the elements and processes generating LU/LC in terms of interactive environmental and social subsystems requires land systems theory (Rounsevell et al., 2012). However, such theories remain elusive (Zhou et al., 2019). According to Steffen et al. (2018), land system approaches have previously emphasised the application of the integrated social-ecological systems (SESs), for understanding LULCC. However, human-environmental research fields, such as resilience (Biggs et al., 2015), sustainable landscapes (Wu, 2013) and land systems (Verburg et al., 2013), have emerged from those previously focussed on either the environmental or social subsystems. According to Roy Chowdhury and Turner (2019), approaches focussed on the environmental subsystem tend to treat anthropogenic activities such as land use, as disturbances to ecosystem functioning, with minimal interactions within the social subsystem. Resilience approaches on the other hand emanate from ecosystems research (Meerow et al., 2016) and calls for SES integration and adaptation in terms of general systems attributes, rather than, LU/LC outcomes. To a large extent, theories and explanations addressing land dynamics do not fully integrate both the social and environmental dimensions of the SES but tend to focus on one subsystem. Among these research approaches, however, land system science seeks to improve the observation, monitoring, understanding, modelling, and sustainability of land systems and their change (Robinson et al., 2018; Verburg et al., 2015).

The main aim of the study was to investigate the effect of LULCC on the extent of Miombo woodlands and dambos and predict the changes to 2050. We have used the Copperbelt province of Zambia as a case study. LULCC in the province has significant impact on the environment and livelihoods of people particularly in mining dominated areas of the Miombo eco-region. No LULCC and modelling study information was available in the province, suggesting that information on the current and future extent, rate of resource utilisation, gains, losses and impacts are unknown. The relative contribution of human induced land uses (cropland, settlements, barelands, grasslands and plantations) to the loss of woodlands and dambos have not been assessed. Investigations into wide temporal and spatial scale for changes in dambos are also not available prompting this study to assess 32 years (1984–2016) of LULCC. LULCC determined using remote sensing and modelling techniques would play a vital role in assessing, planning and monitoring changes in the woodlands and dambos.

2 METHODS

Study area

This study was conducted on the Copperbelt province of Zambia. The Copperbelt is one of Zambia's ten provinces covering 31,328 km² (3.1328 million ha), 4.2% of the total area of the country. The name Copperbelt is derived from the copper mining activities associated with the area. The province lies between latitude S12° to S13° 50′ and longitude E27° to E29° (ACCC, 2010) and is bounded by Central (in the south), North-Western provinces (to the west) and the Democratic Republic of the Congo (to the north and east). The province lies on the eastern central African plateau that is characterised by a gently undulating plateau of between 1200 and 1455 m above sea level. The Kafue River flows in the southward direction through the province forming dambos along the River and its numerous tributaries. The

Copperbelt province was chosen because of its high population density (63.0 persons per square kilometre) that has increased pressure on natural resources as an alternative source of livelihood thereby impacting on the environment of the area (CSO, 2014). According to CSO (2014), the population of the province was 1,972,317 (15.2% of Zambia's total population) with about 81% and 19% living in urban and rural areas, respectively. Land use in the province are influenced by livelihood activities that are based on agriculture, forestry and mining. The unemployment rate of the province is over 22% (CSO, 2014).

Image acquisition and pre-processing

The study area falls within Landsat path/row: 172/69, 172/70, 173/69 and 173/68. Landsat images covering the period 1984–2016 were obtained from the United States Geological Survey (USGS) website (ESRI, 2016). These images were assessed at the following intervals: Landsat 5-TM images for 1984, 1989 and 1999; Landsat 7-ETM for 2004, and 2009 and Landsat 8 images for 2016. Landsat images were used in land cover classification, change detection, prediction of LULCC into the future (2050) and planning some field data collection on land use activities. The images were geometrically corrected and projected to the Universal Transverse Mercator zone 35s coordinate system and the World Geodetic System (WGS) 84 datum. This was essential in change detection because it ensured alignment of images of different years so that corresponding elements of the same ground area appear in the same place thereby increasing accuracy (NOAA, 2005). Radiometric correction and normalisation of the images was done in order to ensure that the changes in pixel values from various images reflect actual changes on the surface (Du et al., 2002). ArcGIS 10.3 (ESRI, 2015) and ENVI 4.7 (Solutions, 2018) software were employed in the analysis process using both raster and vector data.

Field data collection on land use activities

One hundred and fifty random sample sites amounting to a total sample area of 45,151 ha (out of 3,138,589 ha total study area) were generated for ground truthing the LU/LC giving a sampling intensity of 1.44%. Ground truth data were collected between October and December 2016. Data on land use types, fauna and flora, land use activities such as agriculture, settlements, charcoal production, firewood collection and fires were recorded during ground truthing. The data collected from observations were supplemented by desk research on published literature.

Data analysis-land cover classification

Supervised image classification using the maximum likelihood classification method was applied (ESRI, 2012). Training site data were selected in easily identifiable areas of classes such as water; indigenous and plantation forest; and non-forest areas such as bare soil and built-up areas, using a GPS receiver and Google Earth. Representative sites were visited and their locations recorded with a GPS unit as ground truth points in order to match the land use class with the digital number (DN) in each band (Millard & Richardson, 2015). Classes adapted from IPCC (2003) and Münch et al. (2017) were applied and are described as follows: dambo (depressions with grasses and seasonal water); woodland/Forestland (land of >.5 ha with trees ≥5 m and a canopy ≥10%); settlement (urban, industrial land covers with buildings and roads); bareland (barren land, bare soil and rock outcrops); grassland (grasses, shrubs, pasture or herbaceous rangeland); cropland (agricultural land with standing or harvested crops including livestock); water (water bodies such as ponds, lakes, rivers, streams and canals); and plantation (felled or standing trees of pine, eucalyptus and other exotic tree species).

Classification accuracy assessment

For accuracy assessment, 150 sample points were evenly distributed to each category of the LU/LC by the class area ratio using the stratified random sampling method. Each sample point location representing a class was located using the GPS receiver. The validation of features collected on the ground was crossed with each of the classified maps to create an error matrix (confusion matrix) according to Olofsson et al. (2013). The overall accuracy was computed through kappa statistic by dividing the correctly classified points by the total number of points multiplied by 100% using ENVI 4.7 software. An overall accuracy of 85% was acceptable in the study (Kamusoko & Aniya, 2007).

Change detection

Land use land cover change detection used the "Postclassification" function in ENVI 4.7. The classified images were compared using cross-tabulation in determining the changes between the initial year (1984) and the final year (2016/2050) in a transition matrix. The magnitude and percentage of changes were calculated using the formula:

$$K = F - I \tag{1}$$

$$A = \frac{(F - I)}{I} \times 100 \tag{2}$$

where K = magnitude of changes between the initial year and the final year in hectares; A = percentage of changes; F = the final year, and I = the initial year (Mahmud & Achide, 2012). Additional change detection statistics as outlined in (Aldwaik & Pontius, 2012) and (Pontius, 2019) were adapted into the methods using the following formulae:

$$\mathrm{L_X} = \mathrm{CT}F_x - \mathrm{P_x} \tag{3}$$

$$\mathrm{G_X} = \mathrm{CT}I_x - \mathrm{P_x} \tag{4}$$

$$\mathrm{NQC_X} = \mathrm{G_x} - \mathrm{L_x} \tag{5}$$

$$\mathrm{S_X} = (\mathrm{G_X} + \mathrm{L_x}) - \mathrm{NQC_x} \tag{6}$$

$$\mathrm{TC_X} = \mathrm{S_x} + \mathrm{NQC_x} \tag{7}$$

where L_x = the loss in area (class change) for class x; CTF_x = the class total for the final year of class x; P_x = the area of unchanged pixels for class x between the initial and final year; G_x = the gain in area for class x; CTI_x = the class total of the initial year for class x; NQC_x (image difference) = the Net Quantity Change for class x; S_x = the swap in LU/LC classes; TC_x = the total change in area between the final year and initial year for class x.

Prediction of land use land cover change into the future (2050)

Prediction of LULCC analysis was done through the land change modeller (LCM) for ecological sustainability available in TerrSet. The multi-layer perceptron (MLP) and Markov chain analysis (MCA) method were applied for prediction to the year 2050. The MLP was chosen because it is one of the most commonly used artificial neural networks (ANN) that gives accurate predictions (Ahmed & Ahmed, 2012; Eastman, 2012; Mishra et al., 2014). The

Markov chain projection was performed by creating a matrix to estimate the area of each LU/LC class for future dates and the quantity of change for each transition. The probability of each transition was computed in order to assess the change potential (Eastman, 2009; Mas et al., 2014). Finally, transition potential modelling, prediction and validation were done. The transition potential maps for each sub-model were produced based on dynamic and static variables, LU/LC transitions, with the help of the multi-layer perceptron neural network (MLPNN). The transition probability matrix was calculated for the time period of 1984–2016 for the prediction of LU/LC map of 2050. To carry out validation, the predicted LU/LC map of 2016 was compared with the observed LU/LC map of 2016 using kappa index statistics (Aburas et al., 2016; Kamusoko et al., 2009; Wang et al., 2012).

Land use induced land cover changes in woodlands and dambos

To determine the contribution of each degrading LU/LC class on the extent of Miombo woodlands and dambos, values for each class were extracted from transition matrix derived from LULCC analysis. In this study, croplands, bareland, settlements, plantations and grasslands were considered as degrading LU/LC to woodlands and dambos because they are human induced and have been shown to impact on naturally occurring land cover (Gondwe et al., 2020; Malunga, 2009). To create Boolean maps for the area of woodlands and dambos converted by each degrading LU/LC, mask layers were created through the “Band Threshold to ROI” and the “Subset Data via ROIs” in ENVI. The “AND” function in the Raster calculator of ArcGis was applied in order to intersect the woodland and dambo class layers to each degrading LU/LC layers.

To test the contribution of each degrading LU/LC type to woodland and dambo loss, multiple regression analysis was applied using Microsoft Excel 2016 set at 95% confidence level through the “Data Analysis” function. The area of woodlands and dambos of 1984 and 2016 were the dependant variables, while the areas of the degrading LU/LC (croplands, settlements, grasslands, barelands and plantations) were the independent variables. The determination coefficient (R^2) was used in evaluating the multiple regression model. All variables retaining p values > .05 were considered to have insignificant influence on the area of woodlands and dambos, while those retaining p values < .05 were taken to have significant effect.

3 RESULTS

Land use land cover change between 1984 and 2016

Classified images for all the years under review yielded robust and reliable results with 87.04% as the lowest user and producer accuracy. Model performance results indicated an overall accuracy of 90.57% and kappa statistic of 0.89. Table 1 provides the transition matrix for the initial year (1984) and final year (2016). The bold diagonal values indicate areas that did not change (Persistence). Woodland was the largest class in 1984 (64.9% of the landscape), followed by dambos (12.5%). Grasslands covered 11.08%, and croplands were within 6.43% of the landscape. Settlements, barelands, water and plantations each fell below 2.5% in landscape coverage. Land cover changes show that woodlands gained 8.14% and lost 26.05% to give NQC of −17.91%. Croplands gained 15.93% but lost 4%; dambos gained 13.16% and lost 8.3% giving NQC of 4.9%; grasslands gained 9.59% against a loss of 8.97% giving NQC of −1.50%.

TABLE 1. Overall transitions matrix for land use land cover change (per cent in brackets) in the Copperbelt province, Zambia between 1984 and 2016

	2016-Area in ha									
	Dambo	**Woodland**	**Settlement**	**Bareland**	**Grassland**	**Cropland**	**Water**	**Plantation**	**Area in 1984**	**Loss**
Dambo	**131,837.94 (4.20)**	111,730.77 (3.56)	4329.09 (0.14)	733.32 (0.02)	55,748.16 (1.78)	72,030.51 (2.29)	12,710.25 (0.40)	1765.35 (0.06)	392,280.75 (12.50)	260,442.81 (8.30)
Woodland	247,892.85 (7.90)	**1,217,998.62 (38.81)**	13,686.57 (0.44)	2600.10 (0.08)	197,821.89 (6.30)	310,781.43 (9.90)	17,368.02 (0.55)	15,939.36 (0.51)	2,035,694.25 (64.86)	817,664.40 (26.05)
Settlement	4422.06 (0.14)	4075.11 (0.13)	**15,026.67 (0.48)**	1114.38 (0.04)	3938.13 (0.13)	8115.93 (0.26)	648.09 (0.02)	243.18 (0.01)	37,624.95 (1.20)	22,598.28 (0.72)
Bareland	1131.03 (0.04)	730.8 (0.02)	1890.63 (0.06)	**4803.93 (0.15)**	1093.77 (0.03)	2462.49 (0.08)	506.79 (0.02)	19.17 (0.00)	12,649.86 (0.40)	7845.93 (0.25)
Grassland	89,848.53 (2.86)	72,393.84 (2.31)	10,999.53 (0.35)	2731.14 (0.09)	**66,476.07 (2.12)**	94,126.86 (3.00)	7738.65 (0.25)	2679.03 (0.09)	347,898.15 (11.08)	281,422.08 (8.97)
Cropland	32,727.69 (1.04)	39,912.39 (1.27)	14,326.74 (0.46)	1523.16 (0.05)	32,598.54 (1.04)	**76,879.80 (2.45)**	2273.67 (0.07)	995.76 (0.03)	201,837.51 (6.43)	124,957.71 (3.98)
Water	30,249.81 (0.96)	12,189.33 (0.39)	324.27 (0.01)	791.19 (0.03)	6026.67 (0.19)	6887.16 (0.22)	**6816.78 (0.22)**	483.39 (0.02)	64,147.50 (2.04)	57,329.19 (1.83)
Plantation	3619.98 (0.12)	6258.24 (0.20)	292.5 (0.01)	35.64 (0.00)	2577.24 (0.08)	3418.11 (0.11)	382.86 (0.01)	**29,734.29 (0.95)**	46,471.77 (1.48)	16,737.48 (0.53)
Area in 2016	544,867.47 (17.36)	1,473,405.75 (46.94)	60,991.47 (1.94)	14,349.96 (0.46)	367,444.80 (11.71)	577,004.94 (18.38)	48,644.82 (1.55)	51,879.96 (1.65)	3,138,589.17 (100)	
Total gain	413,029.53 (13.16)	255,407.13 (8.14)	45,964.80 (1.46)	9546.03 (0.30)	300,968.73 (9.59)	500,125.14 (15.93)	41,828.04 (1.33)	22,145.67 (0.71)		
Total change	(21.46)	(34.19)	(2.18)	(0.55)	(20.67)	(19.92)	(3.16)	(1.24)		
Swap	(16.6)	(52.10)	(1.44)	(0.50)	(22.17)	(7.96)	(3.65)	(1.07)		
Net quantity change	(4.86)	(−17.91)	(0.74)	(0.05)	(−1.50)	(11.95)	(−0.49)	(0.17)		

Note: Transition matrix with initial year (1984) in rows and final year (2016) in columns; −NQC indicate loss, and +NQC indicate gain. Bold diagonal values indicate areas that did not change (Persistence).

TABLE 2. Transitions matrix for land use land cover change (per cent in brackets) of the Copperbelt province between 1984 and 2050

	2050-Area in ha									
	Dambo	**Woodland**	**Cropland**	**Water**	**Settlement**	**Bareland**	**Plantation**	**Grassland**	**Area in 1984**	**Loss**
Dambo	**83,301.12 (2.65)**	93,264.48 (2.97)	119,148.48 (3.80)	13,502.16 (0.43)	7381.08 (0.24)	733.32 (0.02)	1766.52 (0.06)	73,183.68 (2.33)	392,280.84 (12.50)	308,979.72 (9.84)
Woodland	144,225.18 (4.60)	**1,003,300.11 (31.97)**	585,630.09 (18.66)	22,070.25 (0.70)	26,873.28 (0.86)	2600.28 (0.08)	15,957.27 (0.51)	235,037.79 (7.49)	2,035,694.16 (64.86)	1,032,394.05 (32.89)
Cropland	17,597.16 (0.56)	32,405.04 (1.03)	**92,955.78 (2.96)**	2965.14 (0.09)	15,452.73 (0.49)	1523.16 (0.05)	995.76 (0.03)	37,942.74 (1.21)	201,837.51 (6.43)	108,881.73 (3.47)
Water	20,965.50 (0.67)	10,744.83 (0.34)	14,380.92 (0.46)	**6552.81 (0.21)**	811.53 (0.03)	791.19 (0.03)	483.39 (0.02)	9417.33 (0.30)	64,147.50 (2.04)	57,594.69 (1.84)
Settlement	2433.69 (0.08)	3276.90 (0.10)	10,012.41 (0.32)	733.5 (0.02)	**15,149.34 (0.48)**	1114.29 (0.04)	243.27 (0.01)	4661.55 (0.15)	37,624.95 (1.20)	22,475.61 (0.72)
Bareland	736.47 (0.02)	564.03 (0.02)	2911.86 (0.09)	457.65 (0.01)	1918.80 (0.06)	**4803.93 (0.15)**	19.17 (0.00)	1237.95 (0.04)	12,649.86 (0.40)	7845.93 (0.25)
Plantation	2047.59 (0.07)	4933.26 (0.16)	5689.53 (0.18)	485.55 (0.02)	364.86 (0.01)	35.73 (0.00)	**29,773.71 (0.95)**	3141.54 (0.10)	46,471.77 (1.48)	16,698.06 (0.53)
Grassland	55,666.62 (1.77)	58,534.29 (1.86)	127,566.36 (4.06)	8674.20 (0.28)	13,396.23 (0.43)	2731.14 (0.09)	2679.12 (0.09)	**78,650.19 (2.51)**	347,898.15 (11.08)	269,247.96 (8.58)
Area in 2050	326,973.33 (10.42)	1,207,023.21 (38.46)	958,295.43 (30.53)	55,441.26 (1.77)	81,347.85 (2.59)	14,333.04 (0.46)	51,918.21 (1.65)	443,272.77 (14.12)	3,138,589.17 (100)	
Total gain	243,672.21 (7.76)	203,723.10 (6.49)	865,339.65 (27.57)	48,888.45 (1.56)	66,198.51 (2.11)	9529.11 (0.30)	22,144.50 (0.71)	364,622.58 (11.62)		
Total change	(17.61)	(39.39)	(31.04)	(3.39)	(2.83)	(0.55)	(1.24)	(20.20)		
Swap	(19.69)	(65.79)	(6.94)	(3.67)	(1.43)	(0.50)	(1.06)	(17.16)		
Net quantity change	(−2.08)	(−26.40)	(24.10)	(−0.28)	(1.39)	(0.05)	(0.17)	(3.04)		

Note: 1984 is in rows, predicted 2050 in the columns with area in hectares and %; −NQC indicate loss, and +NQC indicate gain. Bold diagonal values indicate areas that did not change (Persistence).

Land use land cover change and statistics for predicted 2050

Table 2 shows the transition matrix for the change between 1984 and 2050. The area expected to remain unchanged in this period is 1,314,486.99 ha. Woodlands would lose 32.89% and gain 6.49%; croplands would lose 3.47%, gain 30.53%; water would loss 1.84%, gain 1.56%; dambos would lose 9.84%, gain 7.76% giving NQC of −2.0%; settlements loss would be 0.72%, gain 2.11%; bareland would lose 0.25%, gain 0.30%; plantations loss would be 0.53%, gain 0.71% and grasslands would lose 8.58% and gain 11.08%. Woodlands and croplands would undergo the highest NQC with −26.40% and 24.1, respectively. Trends in LULCC are shown in Figure 1.

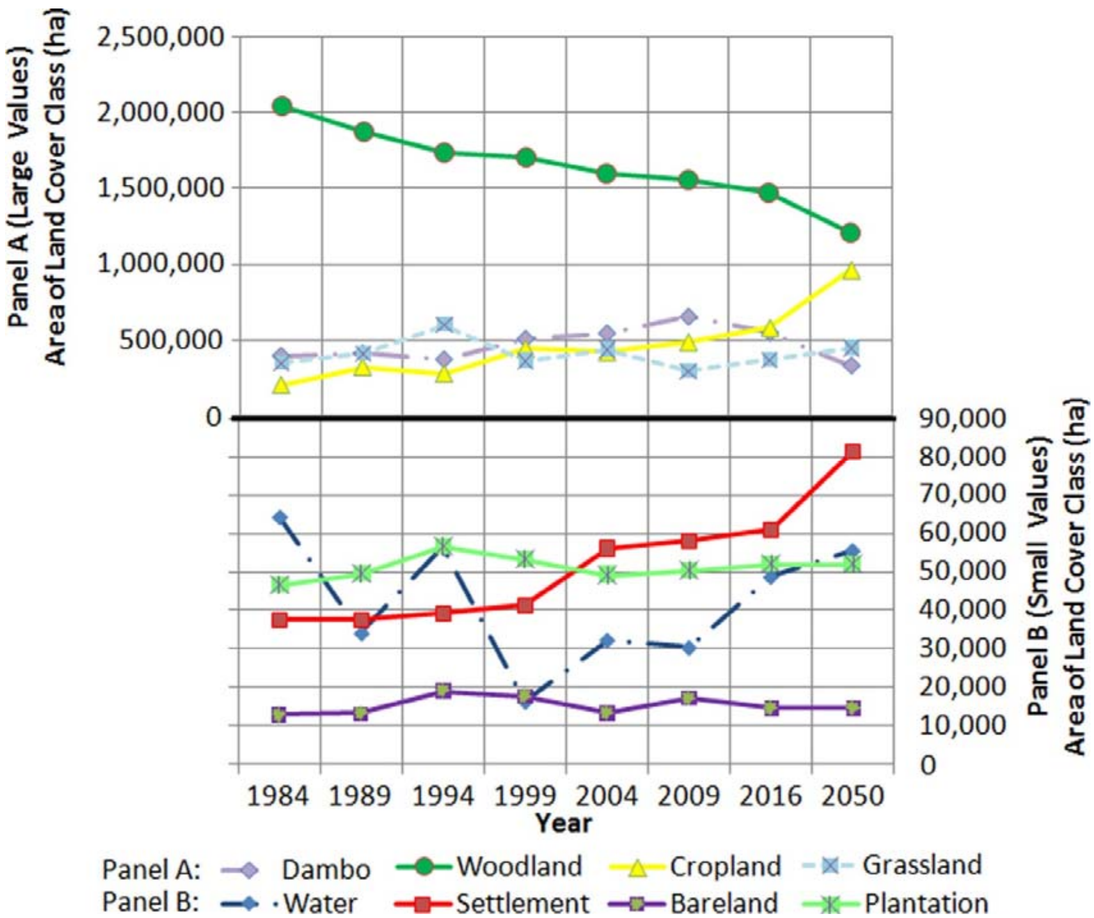

FIGURE 1. Panel chart A and B showing trends in land use land cover from 1984 to 2050; Panel A (high value classes >200,000–2,500,000 ha) and Panel B (low value classes >0–90,000 ha)

Change in the extent of Miombo woodlands and dambos

Table 3 shows that in the period between 1984 and 2016, woodlands lost 17.9% while dambos gained 4.9% of the total area and are projected to lose 26.4% and 2.0% by 2050, respectively. Expansion of croplands was responsible for major loss in woodlands with over 310,768.50 ha (57.5% of total area lost) between 1984 and 2016 and projected to lose 585,623.20 ha (67.6% of total area) by 2050. The contribution of cropland and grasslands to forest loss was significant with $p = .023$ and $p = .038$ (at 95% confidence level), respectively. Woodlands are predicted to cover 38.46% of the Copperbelt province in 2050 (Figure 2).

TABLE 3. Extent of woodlands and dambos converted to degrading land use type for the period 1984–2016 and 1984–2050 in the Copperbelt province

Degrading LULC	**Area of woodlands converted by degrading land use**				**Area of dambos converted by degrading land use**			
	1984–2016		**1984–2050**		**1984–2016**		**1984–2050**	
	Forest converted (Ha)	**%**	**Forest converted (Ha)**	**%**	**Dambos converted (Ha)**	**%**	**Dambos converted (Ha)**	**%**
Cropland	310,768.50[a]	57.5	585,623.20	67.6	72,030.51	53.5	119,148.50	58.9
Grassland	197,813.30[b]	36.6	235,031. 90	27.1	55,748.16	41.4	73,183.68	36.2
Settlement	13,686.12	2.5	26,873.10	3.1	4329.09	3.2	7381.08	3.7
Plantation	15,939.18	2.9	15,957.09	1.8	1765.35	1.3	1766.52	0.9
Bareland	2600.10	0.5	2600.28	0.3	733.14	0.5	733.32	0.4
Total area converted to degrading Land use	540,807.20	**27%**	866,085.57	**43%**	134,606.25	**34%**	202,213.1	**52%**
Rate of conversion to degrading land use/Annum (Ha/Year)	−16,900.23		−13,122.51		−4,206.45		−3,063.83	

Note: Areas with superscript letters (ab) show statistically significant contribution to conversion of woodlands to degrading land use ($p < .05$).

Note: The contribution of all degrading LU/LC to dambo loss are statically insignificant ($p < .05$).

	Regression statistics, woodland conversion: adjusted R^2 = 99.9; Significance F = 0.0160			**Regression statistics, dambo conversion: adjusted R^2 = 57.71; Significance F = 0.4389**		
	Standard error	***t* Stat**	***p*-value**	**Standard error**	***t* Stat**	***p*-value**
Intercept	130,100.40	12.2472	.0519	1,814,315.68	0.5281	.6907
Cropland	0.0553	−27.6226	.0230	0.7721	0.3939	.7611
Grassland	0.0634	−16.6198	.0383	0.8843	−0.3593	.7804
Plantation	2.4712	9.7207	.0653	34.4618	−0.3724	.7731
Settlement	1.0081	1.3272	.4111	14.0572	0.1351	.9145
Bareland	0.9744	−13.9435	.0456	13.5890	0.6591	.6290

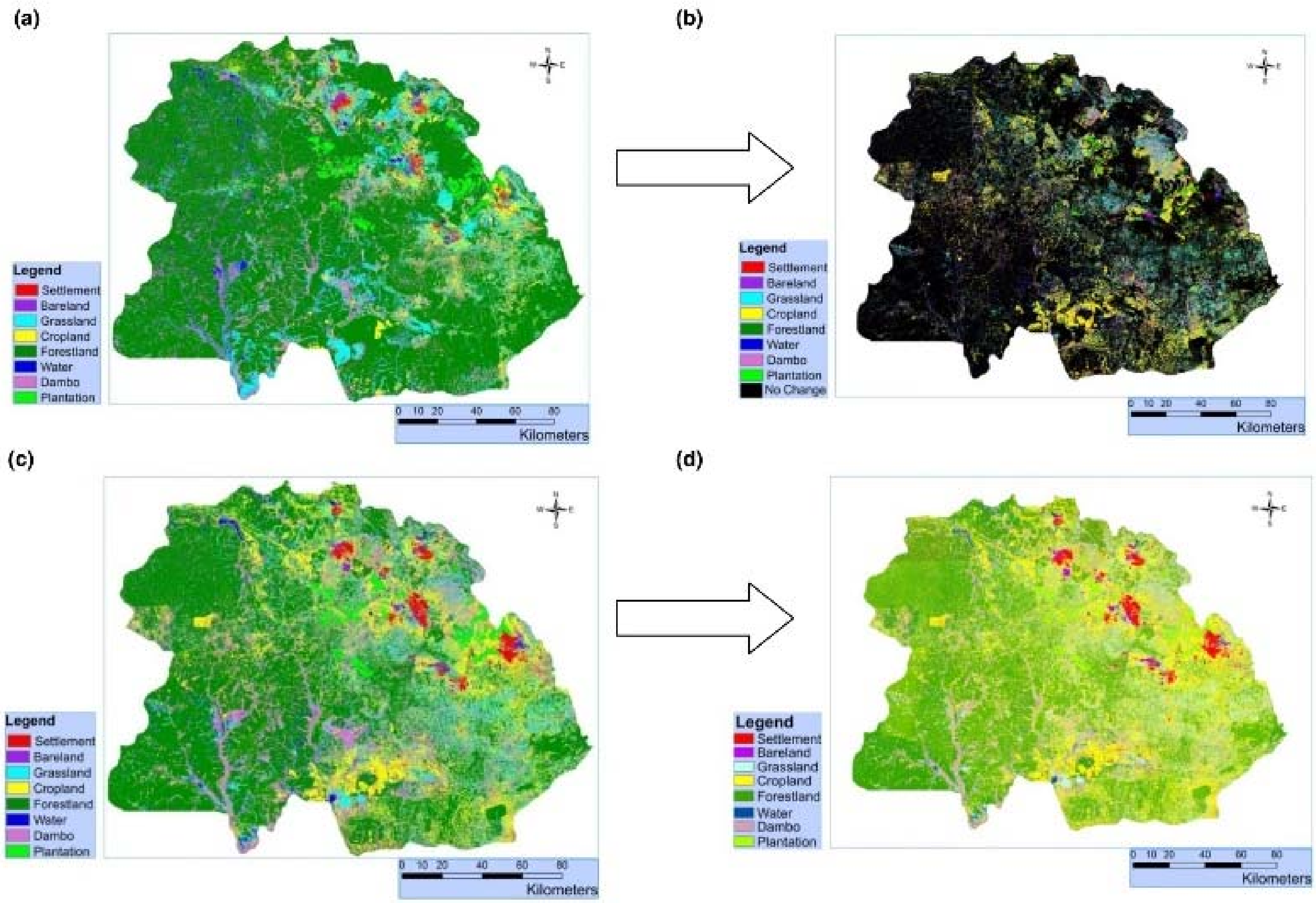

FIGURE 2. Land cover and change map of the Copperbelt province. (a) presents the initial land cover map of 1984. (b) shows the change map between 1984 and 2016. (c) shows the land cover map of 2016. (d) shows the predicted land cover map of 2050

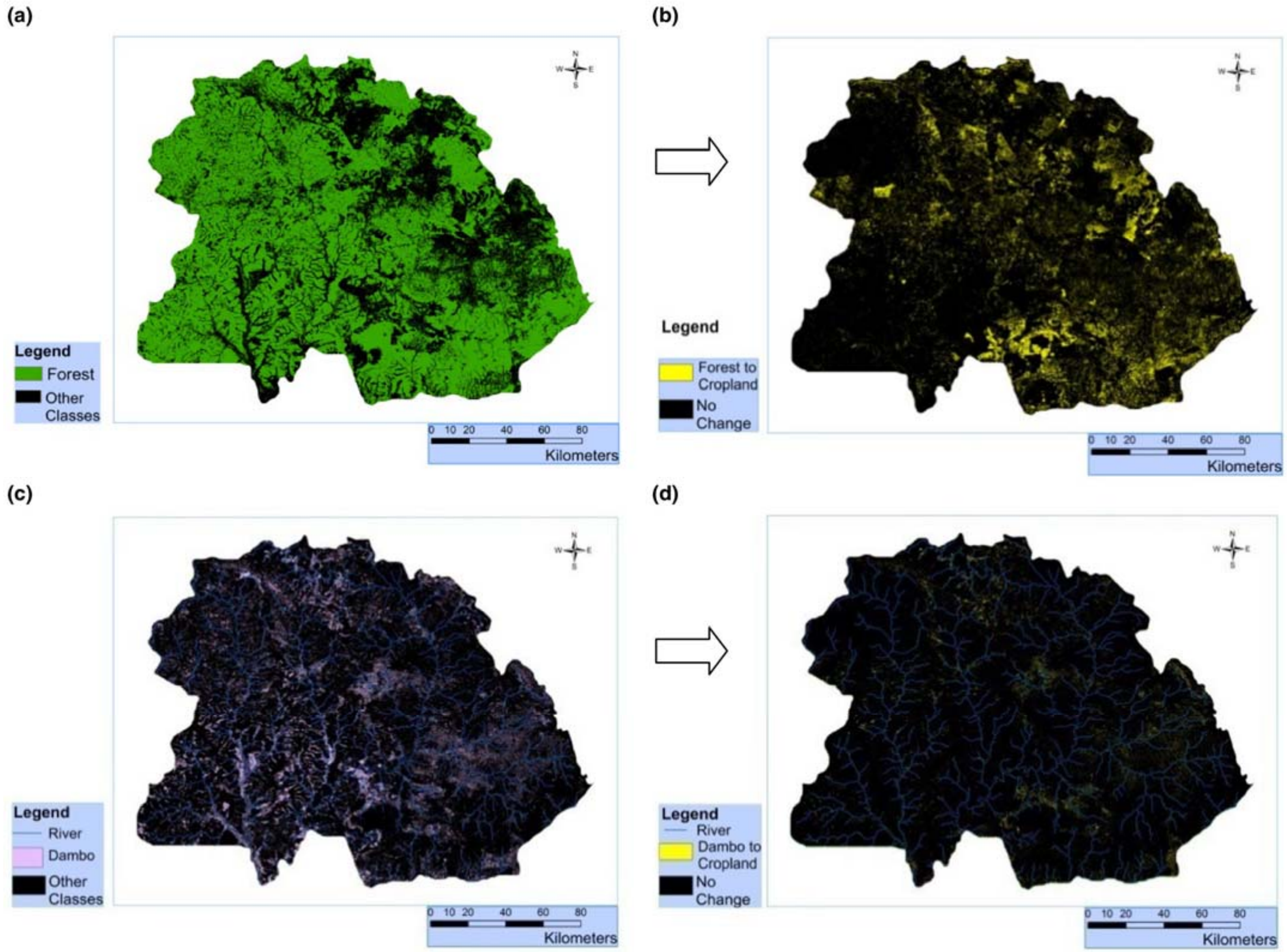

FIGURE 3. State of woodlands and dambos in the Copperbelt province. (a) Presents the initial state of woodlands in 1984. (b) Shows the woodlands converted to cropland by 2016. (c) Shows the initial state of dambos in 1984. (d) Shows the dambos converted to croplands in 2016

Expansion of croplands accounted for the highest loss in dambos with 72,030.51 ha (53.5% of total area lost) and is projected to lose 119,148.50 ha by 2050 (Figure 3). Dambos will decline from 12.5% in 1984 to 10.42% in 2050.

4 DISCUSSION

Land use land cover change between 1984 and 2016 and prediction to 2050

Woodland was the most dominant land cover class in 1984 covering 64.9% of the landscape despite declining to 46.9% in 2016 (Table 1) and projected to 38.5% in 2050 (Table 2). The high initial area of forests in 1984 was logical because 90% of the Coppebelt province landscape was originally Miombo woodland (GRZ, 1998). The results have shown that the establishment of croplands accounted for between 57% and 68% of woodland loss (Table 3). However, Chirwa et al. (2017) found that agriculture was responsible for 80% of forest loss in Africa while Mwitwa et al. (2018) reported a higher figure of 90% in Zambia. The reason for the difference could be attributed to the assessment methods. In this study, the assessment was based on the number of actual dambo and woodland pixels converted to cropland while other studies have used social economic data and this may have led to over estimating the results.

These findings are supported by the observation that people preferred to clear primary forests to take advantage of fertile soils using the slash and burn system (Gondwe et al., 2020). According to Mulungushi (2007), the drive towards agriculture in the province was further triggered by high poverty levels arising from macroeconomic policies such as economic liberalisation, privatisation and the Structural Adjustment Program (SAP) initiated in the 90s. Some of the established croplands in earlier years were abandoned (due to shifting cultivation) leading to an increase in grasslands, settlements, barelands and in some areas regenerating forests as indicated by Swap and NQC values (Tables 1 and 2). The impact of agriculture on other land uses increased over time especially with the introduction of the Fertiliser Support Program (FSP) in 2002 (now called Farmer Input Support Programme; FISP) (Funsani et al., 2016; MAL, 2013). The increase in the number of beneficiaries to the FISP over the years suggests that more land was needed for anthropogenic activities, hence the recorded increase in the area of croplands from 4% in 1984 to 18.4% in 2016 (Table 1) and is predicted to further increase to 30.5% by 2050 (Table 2). These results agree with the national trend in agricultural land area for Zambia reported by World Bank (2020) showing an increase from 26% in 1961 to 32% in 2016. Clay (2013), Hosonuma et al. (2012), Ogg (2016), Ricker-Gilbert et al. (2013) and World Bank (2012) also observed that rapid loss of forest resources occurred in Nigeria, Ethiopia, Kenya, Zambia, Malawi, Tanzania and Ghana where the cost of fertiliser, water or credit for farmers have been heavily subsidised.

As land became scarcer, people began to use existing crop fields for longer periods of time leading to the construction of permanent structures for accommodation. This suggests that the structures would eventually increase with growing population leading to the recorded increase in the area of settlements, grasslands and barelands (Figure 1). According to CSO (2014), the population of the Copperbelt province rose from 2,143,413 in 2011 to 2,362,207 in 2015 and projected to 3,823,642 people in 2035. An increase in population, coupled with poor economic conditions, high poverty levels, high electricity tariffs, contributed to the rising pressure on forest resources further inducing LULCC.

Dambos on the other hand had shown similar trends with woodlands attributing the highest loss to croplands followed by grassland and settlement expansion (Figure 2, Table 3). The interaction between woodland cover and dambos was worth noting. It was found that a decline in forest cover led to an increase in the area of dambos in 1999, 2004, 2009 and 2016 (Figure 1). Part of the reason for the increase is that dambos are found interspaced within Miombo woodlands (Malmer & Nyberg, 2008; Mbanze et al., 2019; Whitlow, 1990; Zolho, 2005). This suggests that clearing of forestland/riparian forests meant that more dambos and water bodies became visible to the LU/LC classifier (Figure 3). The fluctuations in the loss and gain in the area of dambos also suggest that there was constant clearing and use of land for agriculture followed by periods of abandonment that led to recovery as observed in Swap and NQC values in Tables 1 and 2. These results show that dambos are especially targeted by people because they present moist and fertile soil conditions that can support crops and animals during drought periods thereby serving as safety net for livelihoods (Kotze, 2011; Lupankwa et al., 2000; Ryan et al., 2016; Whitlow, 1990). The trend is hypothesised to have reduced the area of dambos from 12.5% in 1984, 17.36% in 2016, to 10.42% in 2050 (Tables 1 and 2). Results of this study are consistent with regional and global trends as reported in Malawi by Gondwe et al. (2020), Alam et al. (2011) in the Himalayas; Zhang et al. (2011) in Beijing; Franke et al. (2009) and Mwita (2013) in Tanzania. The results have shown that -NQC were recorded for woodlands and dambos while +NQC were recorded in plantations, settlements, grasslands, croplands and bareland further confirming that the latter five are degrading land uses.

Implications

Miombo woodlands and its dambos play an important ecological and socio-economic role at provincial, national and global scale. However, the ecosystem is declining at an alarming rate indicating that policies, laws and institutions responsible for their management are not effective (GRZ, 2018). The decline in woodlands will have devastating consequences on Miombo woodlands and dambos, climate and the people. This is because LULCC affects the hydrology of a watershed by altering the rainfall, evaporation and runoff balance (Nyirongo, 2009). According to Mumeka (1986) and Nyirongo (2009), stream flow and erosion increases while infiltration reduces with an increase in deforestation. Therefore, disturbances induced by LULCC will have wider impact on the Kafue river basin subsequently affecting countries like Mozambique, Angola, Namibia, Botswana, Zimbabwe and Malawi and other regions that depend on the catchment area. Similar findings were reported by Malmer and Nyberg (2008) and Mwita (2013). Hydrological characteristics are altered when land use is changed to croplands because trees are able to transpire more water than agricultural crops meaning that more rain that would have been intercepted by canopies is lost through evapotranspiration (Nyirongo, 2009).

According to Acreman and Holden (2013), dambos have been shown to influence the hydrological cycle by decreasing or increasing a particular component of the cycle such as transpiration, runoff and infiltration. Dambos are natural sponges absorbing water during the wet season and slowly releasing the water to streams during the dry season thereby controlling floods and maintaining dry season river flows (Balek & Perry, 1973). Therefore, the disturbances recorded in dambos will affect the ability to effectively provide these ecosystem services. Nevertheless, the rapid recovery of woodlands and dambos in abandoned areas observed in the study provides the motivation to conserve deforested areas for restoration purposes. This view is also shared by Geldenhuys (2010), Gonçalves et al. (2017) and Syampungani et al. (2017) who reported that the resilience and stable characteristics of the Miombo ecosystem present opportunities to initiate recovery programmes. The use of dambos for agriculture also indicates a potential that should be optimised to offer both economic and ecological benefits for the nation. The findings underscore that improvement in land system science theory requires accurate monitoring, understanding and modelling for sustainable land management.

Study limitations

Findings of this study could have been affected by lack of consistent cloud free multitemporal Landsat data from the same season for some years and scenes under review. This would have affected identification of features during classification and subsequently cover change analysis. Furthermore, misclassification arising from similarity in classes such as dambos and grasslands also caused difficulties in visual interpretation and the classification process. Nevertheless, the LU/LC classification accuracy results were above 87%. According to Kamusoko and Aniya (2007), LU/LC accuracies of above 85% are considered reliable. In modelling to 2050, the availability and choice of socio-economic and biophysical data used as factors and constraints was challenging. This may have created some uncertainty in predicting LULCC to 2050 and could have further affected the precision of the model. Similar challenges were pointed out by Aburas et al. (2016) and Amthor et al. (2001) who reported that these limitations also affected testing and validation of models. Despite the limitation, modelling accuracy results in this study indicated strong association between the predicted map and the observed map because according to Zheng et al. (2015), kappa values >0.8 show strong association or agreement.

5 CONCLUSION

The study concluded that extensive LULCC had occurred in the Copperbelt province between 1984 and 2016 and the trend was predicted to continue to 2050. The study showed that over time, Miombo woodlands and dambos have been decreasing in extent as indicated by the −NQC, thereby loss of their benefits. Settlements, barelands, plantation, grasslands and croplands showed +NQC indicating an increase in proportion with devastating effects. Cropping accounts for more than half of the total area lost and the current trajectory suggests it will get worse if nothing is done. We can conclude from the study that adoption of economic policies such as FISP and SAP led to loss of natural resources such as forests and dambos as these were used as safety-nets or coping strategy for the livelihoods of communities. Overall, the loss of the woodlands and dambos would have a devastating impact on the quality of the ecosystem that supports endangered fauna and flora in the region. It is therefore recommended that interventions to curb the loss should be put in place through strategies like land zoning of woodlands and dambos in order to balance between economic and ecological benefits. Safe agricultural practices and the enforcement/sensitisation of land and water use laws and policies are vital. Institutions should be strengthened in order to enhance coordination and optimisation of resources for effective management.

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CONFLICT OF INTEREST

No conflict of interest to declare by the authors.

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