Tracking conservation effectiveness in the Vhembe Biosphere Reserve in South Africa using Landsat imagery

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Abstract Biosphere reserves (BRs) seek to reconcile a sustainable relationship between human welfare and environmental integrity by adopting a landscape model that distinguishes between three interdependent management zones (core, buffer, transition). Considering the increasing human influence on landscapes in BRs, the tracking land use–land cover (LULC) dynamics is crucial for the development and planning of efficient management strategies for specific management zone. This study aimed at (i) assessing biodiversity protection around the core zones to highlight the threats facing the core zones and (ii) tracking the effect of the proclamation of the Vhembe Biosphere Reserve (VBR) on the LULC dynamics in the management zones through spatio-temporal analysis using Landsat imagery acquired from 1999 to 2018. Six LULC categories (water body, forest/bush, shrubs/grass, agricultural land, bare soil, and built-up/mines) were identified and mapped using the support vector machine (SVM) classification to address both objectives. Assessment of threats around the core zones using artificial buffers (0–5, 10–15, and 15–20 km radius) created around them showed agricultural activities in the most immediate buffers (0–5 km radius). The LULC dynamics showed vegetation increase in all the management zones evidenced by the reduction of bare soil as well shrub/grass lands, and by the corresponding increase in foliage-richer forest/bush lands since the proclamation of the reserve in 2009. The findings might signify a positive outcome of vegetation increase as a consequence of the proclamation of the VBR. However, firmer conservation measures must be adopted and priority must be given to the arrangement of the management zones to strengthen biodiversity protection in the core zone.

Keywords Biosphere reserve · Landsat · Land use–land cover · Vhembe · Support vector machines · Management zones

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Introduction

Land use–land cover has numerous ecological, physical, and socio-economic consequences, and it is globally regarded as a threat to sustainable development and ecosystem functioning (Barkmann et al. 2013; Manzo-Delgado et al. 2014; Yang et al. 2016; Gashaw et al. 2018). One consequence of land cover change is the deterioration of the natural environment due to anthropogenic activities such as tree logging, agricultural expansion, and other livelihood activities. As a way of protecting natural resources, the United Nations Educational, Scientific and Cultural Organization (UNESCO) introduced the Man and the Biosphere (MAB)

programme in 1976, in which biosphere reserves (BRs) are established to harmonize human welfare and nature by combating the effects of environmental change. Accordingly, BRs are designated as terrestrial, coastal, and marine ecosystems or their combination established on the rationale of building a system that fulfills three basic functions including ecosystem and biodiversity conservation, sustainable development, and advancement of research (UNESCO 1996; Batisse 1997; Bridgewater 2002; Coetzer et al. 2014; Mitrofanenko et al. 2018).

The conservation strategy adopted in BRs is based on the spatial stratification of three interdependent zones defined according to levels of human interaction, namely, (i) the core, (ii) buffer, (iii) and transition zones (UNESCO 1996; Batisse 1997). The core zone is usually comprised of protected areas or other conservation landscapes, with controlled human access to sensitive biodiversity. The buffer zone typically protects the core zone and allows activities dedicated to sound ecological practices such as ecotourism and research. The outermost transition zone connecting with the buffer zone is a region where people live, and a diversity of human activities such as infrastructure construction and agriculture are carried out (UNESCO 1996; Ishwaran et al. 2008; Price et al. 2010). Although BRs are widely regarded as "living laboratories" (Van Cuong et al. 2017, p. 13) and reservoirs of important biodiversity, they are vulnerable to human-induced environmental degradation (Taïta 2003; Li et al. 2005; Ortega-Huerta 2007; Kala 2015; Béliveau et al. 2017; Von Thaden et al. 2018). This is likely worsened given that the spatial zonation is delineated based on imaginary boundaries (except for the core zone) which cut across diverse pre-existing land uses in the BR. If uncontrolled, such environmental changes can jeopardize the long-term sustainability of BRs (Olah and Boltiziar 2009; Navarrete et al. 2011; Biswal et al. 2013; Saranya and Reddy 2016; Von Thaden et al. 2018). Globally, various studies have been conducted to investigate land cover characteristics in BRs, for example, in Asia (Li et al. 2005; Chowdhury 2006; Navarrete et al. 2011; Biswal et al. 2013; Satish et al. 2014; Dutta et al. 2016; Parsa et al. 2016; Sahana et al. 2016; Saranya and Reddy 2016; Sharma et al. 2016), North America (Ortega-Huerta 2007; Sánchez-Azofeifa et al. 2009; Navarrete et al. 2011; Manzo-Delgado et al. 2014; Béliveau et al. 2017; Von Thaden et al. 2018; Flores-Casas and Ortega-Huerta 2019), and Africa (Clerici et al. 2007; Coetzer et al. 2010; DeVries et al. 2012; Houessou et al. 2013;

Evans 2017; Konko et al. 2018). The findings stemming from these researches suggest that each BR possesses unique land cover change patterns. It is therefore important to conduct studies on each BR in order to provide useful and timely information for a better understanding of land cover dynamics.

In South Africa, there are ten BRs proclaimed by the UNESCO MAB between 1998 and 2018. One of these is the Vhembe Biosphere Reserve which was established in 2009. This reserve is situated in one of the country's prime agricultural regions, housing relatively poor communities. Despite the proliferation of literature on land cover assessments in BRs around the world, studies on South African BRs are rare (Coetzer et al. 2010, 2013; Coetzer-Hanack et al. 2016; Evans 2017). For example, a study conducted in the Kruger to Canyons (K2C) BR used Landsat imagery to characterize land cover changes before (1993–2006) and after (2006–2012) designation in the three management zones of the reserve (Coetzer-Hanack et al. 2016). Of more interest to the present study, Evans (2017) used two South African National Land Cover maps for 1990 and 2013/2014 to show land cover transformations in the Vhembe Biosphere Reserve (VBR), which is the study area for the current investigation. The study in the VBR however used only two time points to compare land cover dynamics. Thus, it undermines the effect of the VBR proclamation and the relevance of the management zones as defined by the founding BR principles. Such limited time points do not allow us to confidently attribute the land use–land cover (LULC) differences between the two times to the BR management. Although the K2C and VBR belong to the same biome (South African National Biodiversity Institute 2019), they are situated under different provincial authorities and/or support, which affects resources available to each. Moreover, K2C enjoys more controlled management interventions and greater research focus that informs the BR management (Coetzer et al. 2014; Smith et al. 2015; Moxley 2016; Linden 2017; Nel et al. 2017). Disparity in management intervention can introduce different land cover dynamics. Furthermore, previous studies that utilized remote sensing to characterize land cover in BRs (Chowdhury 2006; Coetzer-Hanack et al. 2016; Parsa et al. 2016; Evans 2017) did not use high temporal resolution data that could support much needed timely and near-continuous monitoring of biodiversity in BRs. Therefore, developing inexpensive and frequent remote sensing-based tracking of land cover

dynamics suited to a BR is necessary for implementing efficient site-specific management strategies.

The objectives of this study were therefore is (i) to assess biodiversity protection in and around the core zone and (ii) to track the spatio-temporal LULC dynamics in the three management zones of the VBR. To achieve these objectives, we derived LULC types from multitemporal Landsat imagery acquired for the period of 10 years before and 9 years after the proclamation of the VBR in 2009. The findings of this study provided insights on the protection of sensitive biodiversity and the LULC dynamics before and after the proclamation (2009) of the VBR, and therefore, it allows for evaluating the effectiveness of proclaiming this BR.

Methods

Study area

The study was conducted in the VBR (https://www.vhembebiosphere.org/) located in the Limpopo Province (LP) of South Africa (Fig. 1). The VBR covers a total of 30,412 km^2 and is home to a population of more than 1.3 million people. The Vhembe Biosphere Reserve is the sixth proclaimed BR out of the ten BRs (Kogelberg, Cape west coast, Waterberg, Kruger to Canyon, Cape Winelands, Vhembe, Gouritz cluster, Magaliesberg, Garden route, and Marico) in South Africa. Almost 18% of the area is occupied by proclaimed National Parks and provincial Nature Reserves, which form a cluster of eight core zones and part of the buffer zone. The topography varies from flat plains through hills to steep mountain sides with elevations ranging from 600 to above 2000 m (South African National Biodiversity Institute 2019). The area receives rainfall of 200 to 1500 mm per year and an average annual temperature ranging from 10 to above 30 °C (Statistics South Africa 2019). The vegetation is predominantly savannah, grassland, and forest biome embodied by open grasslands with scattered trees and shrubs (Mzezewa et al. 2010; Kenabatho et al. 2012). Common socio-economic activities in the reserve include mining; tourism; and agricultural activities such as the production of subtropical fruit, vegetables, and citrus crops, and subsistence cattle rearing (Mostert and Van Heerden 2015). Given the high levels of unemployment and poverty in the region, people in the rural communities rely on natural resources for their livelihoods (Evans

2017; Scheiter et al. 2018). With increasing rates of unemployment (20.3%) and poor access to water and sanitation, most households depend on fuel wood as the major source of energy for cooking. Moreover, statistics has shown that 67.5% adults in the region live below the upper-bound poverty level of $78 per person per month (Statistics South Africa 2019).

Dataset

The boundary of the VBR including the core, buffer, and the transition zones was sourced from the Department of Environment, Forestry and Fisheries (DEFF) of South Africa (https://www.environment.gov.za). The proportion of the core zone is estimated at 15.2%, the buffer zone is 14.8%, and the transition zone occupies approximately 70% of the reserve. Geometrically and topographically rectified multitemporal Landsat images were used to analyze the land cover of the reserve. The images were acquired free of charge from the US Global Survey (USGS) online portal (https://earthexplorer.usgs.gov). Landsat was chosen due to its spatial resolution (30 m) that is deemed suitable for landscape-level assessment used in the study. Furthermore, the imagery has a long archival collection dating back to 1972 and therefore allows for tracking long-term historical land cover dynamics (Xie et al. 2008; Vittek et al. 2014). The images were radiometrically and atmospherically corrected by the data supplier, and thus the images represented surface reflectance values, thereby avoiding the need to apply such correction procedures. We sought to evaluate the LULC dynamics 10 years before and 9 years after the proclamation of the reserve in 2009. An attempt was made to assess the dynamics at an annual or shorter time interval; however, this was not possible due to unavailability of Landsat images at such regular intervals. Therefore, the study was constrained by the images that were available for the study area. It should also be noted that four satellite scenes were needed to cover the study area; it was essential to ensure that these scenes were taken within a month (of the same season) from each other to avoid the potential effect of time differences in defining the land cover type of the specific year. This criterion has therefore contributed to the lack
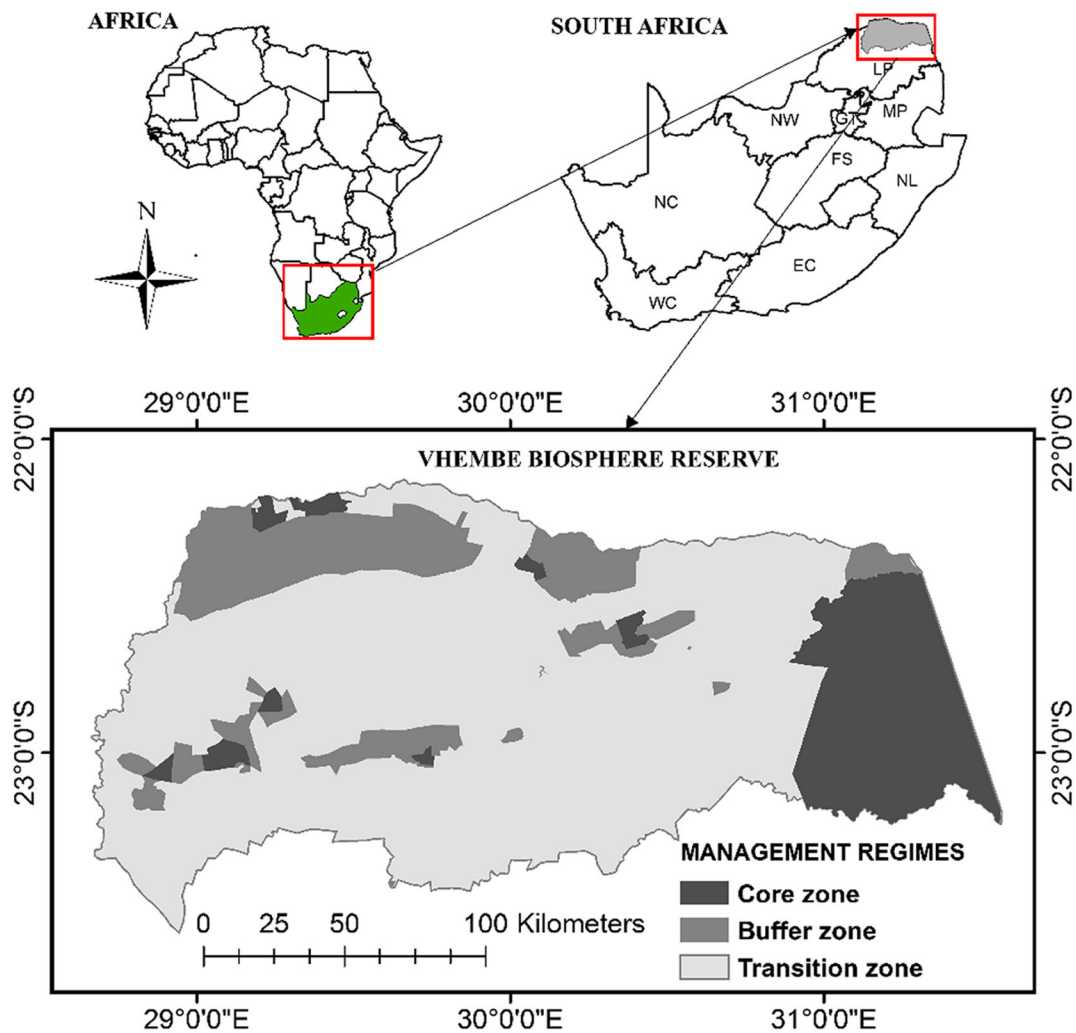
Fig. 1 The location of the Vhembe Biosphere Reserve, South Africa, showing the outlines of the core, buffer, and the transition zones (management zones)

of temporal regularity in the dataset available for the study. Landsat 4–5 Thematic Mapper (TM) images were acquired for the years 2005, 2007, 2008, 2009, 2010, and 2011. Another Landsat 8 Operational Land Imager (OLI) images for 2014, 2015, 2016, 2017, and 2018 were collected. Only images acquired in the wet months of the year (November–May) were utilized. These months were chosen to capture the peak vegetative conditions to allow for identifying and discriminating vegetation types as well as other land cover types (Coetzer et al. 2010; Mzezewa et al. 2010; Kenabatho et al. 2012; Mpandeli 2014). Optical bands (visible and infrared regions of the electromagnetic spectrum) of the images were stacked

together to create a multispectral image per year. A final visual assessment was then made to ascertain the quality of each image. Although preprocessed images showing surface reflectance were used, there were patches of clouds in some of these images. Areas covered by the clouds were masked to avoid classification error. The methodology applied in this study is summarized in Fig. 2.

Image classification

We reviewed the 2013/2014 South African National Land Cover Map (Geoterraimage 2015) to acquaint with and define the land cover types found in the VBR. The

Fig. 2 Summary of the methodology used for land use–land cover assessment of the Vhembe Biosphere Reserve
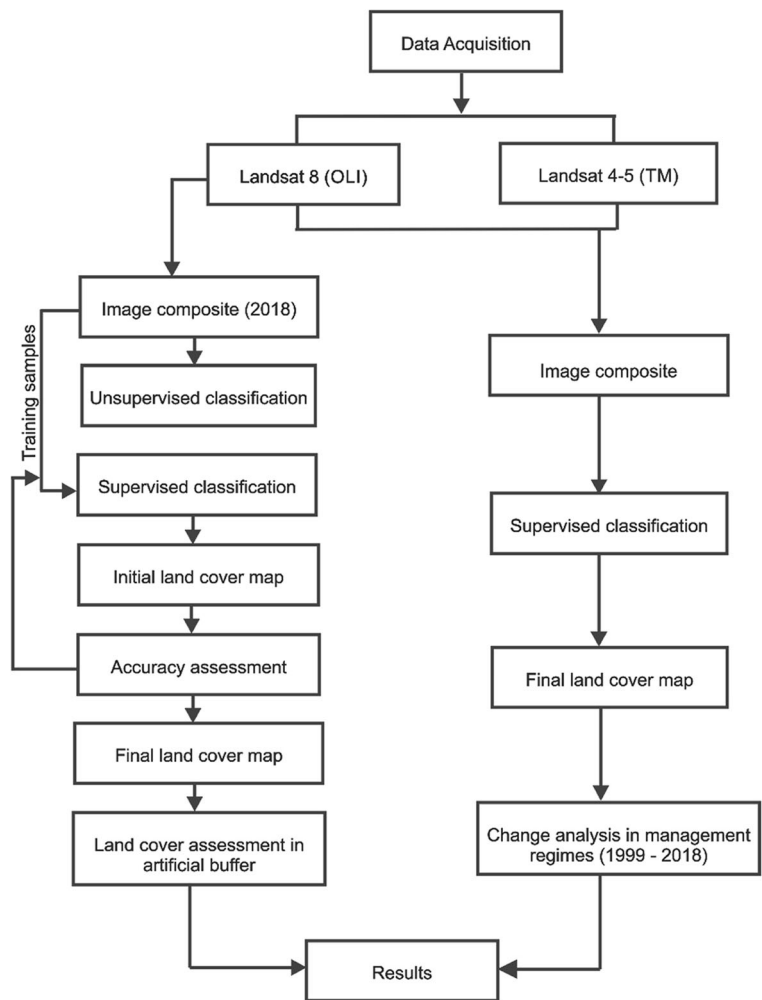
National Land Cover map containing 72 land cover classes in South Africa was produced on a 1:250000 scale, using unsupervised classification of multi-seasonal Landsat 8 imagery. An initial classification using Iso-cluster unsupervised classification was run on the multispectral image of the year 2018 to create 20 land cover classes in the entire reserve. We opted to classify the four scenes of 2018 separately to avoid pixel value recalibration as a result of mosaicking the unclassified data. Assisted by visual assessments of the classified images, the original multispectral Landsat imagery, and the South African National Land Cover Map of 2013/2014, the twenty land cover classes were aggregated into six categories for easy discrimination. Such broad classifications have commonly been used for landscape-level assessment using Landsat imagery (Kim 2016; Yirsaw et al. 2017; Shawul and

Chakma 2019). Similarly, broad classifications were applied in assessments for conservation purposes (Parsa et al. 2016; Kamwi et al. 2017; Gambo et al. 2018). The final land cover types included water body, forest/bush, shrub/grass, agricultural land, bare soil, and built-up/mines (Table 1). These land cover types served as inputs to generate training samples for a supervised classification that produced the final land cover maps for each year. Seven training samples were generated from each land cover per scene by manually digitizing polygons containing 84 pixels (Table S1) The seven training samples captured the variability within each class as much as possible; therefore, these samples were not selected randomly; instead, they were identified with the assistance of the original unclassified image. It was important to ensure that each polygon contained relatively homogenous pixels on the original image to avoid

Land cover category	Description
Water body	Areas of open surface water which includes natural and man-made water bodies.
Forest/bush	Natural/semi-natural indigenous forest, plantation, and woodlots; thickets/dense bush; woodland/open bush.
Shrub/grass	Natural/semi-natural low shrub-dominated areas, grasslands with sparse shrubland and wood-land areas.
Agricultural land	Cultivated lands used primarily to produce rainfed or irrigated temporary crops. Typically represented by small field units often in dense local clusters. Cultivated lands used as permanent orchards of shrubs and non-woody plants such as coffee, grapes, and tea.
Bare soil	Bare or non-vegetated grounds with little or very sparse vegetative cover, fallow cropland, and recently burned areas.
Built-up/mines	All built-up areas including residential, commercial, and industrial areas; roads; transportation; communications; facilities; and other surface infrastructure including mines, extraction pits, waste dumps, and tailings.

mixed classes within a polygon; this was confirmed by referring to the original image. These polygons comprised of either pure pixels or a mixture of subcategories in the same class. Note that these selected variations may not tally with the subcategories as provided in the description of land cover classes, because some subcategories appear in patches covering less than a pixel size (30 m). Furthermore, to maintain an equal weight of training samples across all classes and scenes, 84 pixels were selected based on the maximum pure pixels collected for the rarest class.

The samples were then used as an input to train land cover types using a non-parametric machine learning classifier, namely, the support vector machine (SVM). Support vector machines are used for a variety of applications in the remote sensing field due to the ability to produce high accuracy in complex classifications compared with other commonly used classifiers such as maximum likelihood (Ahmad et al. 2018), the random forest (Rodriguez-Galiano and Chica-Rivas 2014; Noi and Kappas 2018), and regression tree (Qian et al. 2015). A fundamental concept that benefits

SVMs is the excellent performance in classifying heterogeneous land cover types with bias or un-learned data not included in the training sets (Xu et al. 2014; Yee et al. 2015; Gu and Sheng 2017).

The SVM operates by drawing a linear decision hyperplane between nearest samples belonging to different classes, whereas the kernel trick is used to separate classes that have a non-linear arrangement as is the case of most natural features (Boser et al. 1992; Corinna and Vapnik 1995). A unique characteristic of this classifier is that individual features are not consulted to determine their class assignment; instead, it draws boundaries that maximize the separation between classes (Boser et al. 1992). Features that fall within a specific boundary are assigned a class, with incorrectly assigned features contributing to the overall misclassification. We applied the SVM classification available in the ArcGIS software (ESRI® ArcGIS, Version 10.6, Redlands, CA) on each scene. Finally, the resultant multispectral landcover maps were mosaicked to produce a seamless map per year; this approach was preferred for the classification of a mosaicked image, which carries modified pixel information as a result of mosaicking.

Classification accuracy assessment

Accuracy assessment was performed on the 2018 dataset. To assess the accuracy of the classification, we first generated 1015 stratified random points within the study area (Table 2). Stratified random sampling scheme collects points proportionate to the extent of each class in the area of interest (Skidmore 1999). Following the establishment of the random points, a 15-m radius buffer was created around each point to obtain an area comparable to a pixel size of the Landsat imagery. The buffer was used to interpret the prevailing land cover type on the reference data and therefore minimizes misrepresentation that would result from point-based interpretation in a heterogeneous landscape (Freire et al. 2014; Cai et al. 2018). In this study, Google Earth imagery was used as a source of reference for accuracy assessment (GE, http://earth.google.com). The Google Earth platform offers high spatial resolution imagery (0.3- to 1.5-m resolution) that is effective for assessing classification accuracy of land cover maps produced using coarse spatial

resolution data (Giri et al. 2011; Jacobson et al. 2015; Tilahun and Teferie 2015). Agreement between the classified image and reference data was evaluated using overall accuracy, user's accuracy, producer's accuracy (Story and Congalton 1986), and the kappa coefficient (Cohen 1960). Overall accuracy measures the agreement/disagreement of a map with the reference map by estimating the proportion of correctly classified samples of all classes to the total number of samples. The user's accuracy is estimated as the ratio of accurately classified samples of a class to the total number of samples assigned to that class. On the other hand, the producer's accuracy is measured as the ratio of correctly identified reference samples in a class to the total number of samples in the reference data of that class. The kappa coefficient measures whether or not the overall classification accuracies are reliable or a chance occurrence, and thus informs the level of consistency in the classification accuracy.

Assessment of land cover in artificial buffers surrounding the core zone

We assessed land cover in two phases; the initial phase involved the assessment of recent (the year 2018) land cover in the area surrounding the core zone. Essentially, the zonation of BRs is intended for checkmating the degree of human interference in the three management zones, with the strictest conservation emphases placed on the core zone (UNESCO 1996; Van Cuong et al. 2017). Accordingly, the management guidelines of BRs prescribe a periodic assessment of land cover in order to preserve sensitive biodiversity in the core areas (UNESCO 1996). Although the buffer zone is aimed at providing protection to the core zone, it may not necessarily enclose the core zones within the VBR, that is, the core zone can be directly connected to the transition zone in certain instances. Therefore, it is important to assess the shielding effect of the buffer and transition zones on biodiversity in the core zone. In the interest of assessing land cover patterns around the core zone, we created three concentric artificial buffers covering 0–5 km, 5–10 km, and 10–15 km, all radiating out from the core zone and cutting across the buffer and transition zone (Fig. 3), whereas in the final phase, we assessed LULC change patterns in the core, buffer, and transition zones from 1999 to 2018.

Results

Accuracy of LULC classes

Classification accuracies of the six land cover types generated from Landsat imagery acquired in the year 2018 are presented in Table 2. The overall classification accuracy for the final land cover map was estimated at 88% and the Kappa value of 0.87, indicating a substantial reliability of classification compared with the ground situation as described in Table S2. The best classification accuracy was attained for water body, according to the high producer's and user's accuracies. High accuracies were also estimated in the classification of shrub/grass. However, the misclassifications in built-up/mines were largely due to the classification of built-up/mines as bare soil and shrub/grass, resulting to low producer's accuracy (55%) and user's accuracy (57%).

Land use–land cover distributions in the three management zones

The LULC distribution for the year 2018 across the core, buffer, and transition zones are shown in Fig. 4. A general visual assessment of the land cover revealed that shrub/grass is the predominant land cover class across all the management zones, occupying about 75% of the reserve. The transition zone protects around 65.8% of the total shrub/grass land cover. The second dominant land cover is the forest/bush category, which occupies about 14.7% of the reserve. Moreover, less than 14% of the total forest/bush is protected in the core and buffer zones. Particularly, forest/bush is concentrated in the transition zone along the south-east and ranges towards the north-eastern part of the reserve. Water body is the least dominant land cover in the three management zones, with the larger water bodies mostly situated in the transition zone. Agricultural land is mostly found in the transition zone around forest/bush edges. Noticeable patches of bare soil and built-up/mines are scattered around the region, especially in the transition zone.

Land use–land cover distribution in the artificial buffers radiating from the core zone

The 2018 LULC map was used to delineate artificial buffers around the core zones to show the threat levels facing these zones of the VBR. Shrub/grass is the dominant land cover type in each of the artificial buffers

Table 2 Classification accuracy assessment matrix of land cover types of the Vhembe Biosphere Reserve for the year 2018. Italicized values represent accurate classifications, while the rest show misclassifications from one class to another

Reference data

		Water body	Forest/ bush	Shrub/ grass	Agricultural land	Bare soil	Built-up/ mines	Total	User's accuracy
Classified data	Water body	*21*	0	0	0	0	0	21	100
	Forest/bush	3	*68*	23	1	0	0	95	72
	Shrub/grass	0	8	*703*	17	12	4	744	94
	Agricultural land	0	6	4	*36*	0	0	46	78
	Bare soil	0	1	7	0	*33*	19	60	55
	Built-up/mines	0	0	11	1	9	*28*	49	57
	Total	24	83	748	55	54	51	1015	
	Producer's accuracy	88	82	94	65	61	55		

Overall accuracy = 88%; Kappa coefficient (K-hat) = 87%

covering 2000 in the immediate buffer (0–5 km) to approximately 3000 km^2 in the farthest buffer zone (10–15 km) (Fig. 5). Forest/bush land was the second commonly found land cover and has almost comparable coverage across the three artificial buffers. Although agriculture has a relatively low extent in the three artificial buffers, it is vital to note its worrying proximity to the core zone. In addition, the immediate artificial buffer (0–5 km) has the most agricultural lands than the other buffers (Fig. 5). Figure 6a shows outlines of the management zones and the artificial buffers in the VBR, while Fig. 6b and c illustrate a closer look at agricultural practices in the artificial buffers.

Most of the agricultural activities appear to be large scale (intensive crop farming), as can be seen from the consistency of farm shape that is usually designed to assist for efficient management such as irrigation systems. It is important to note that these agricultural activities were observed near the core zones surrounded by the buffer management zone (Fig. 6b) as well as near the core zones that are adjacent to the transition management zone (Fig. 6c). Furthermore, significant amount of bare soil land cover types in Fig. 6b and c appears to be agricultural lands that have been harvested or are at an early stage of farming but were misclassified as bare soil.
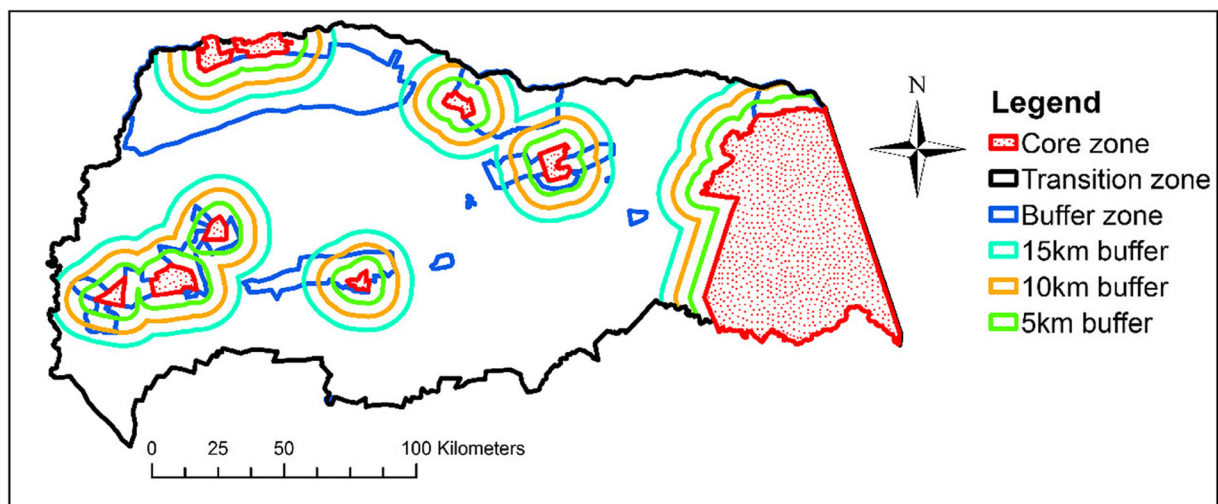

Fig. 3 Three artificial buffers created at 0–5 km, 5–10 km, and 10–15 km radiating from the core zone
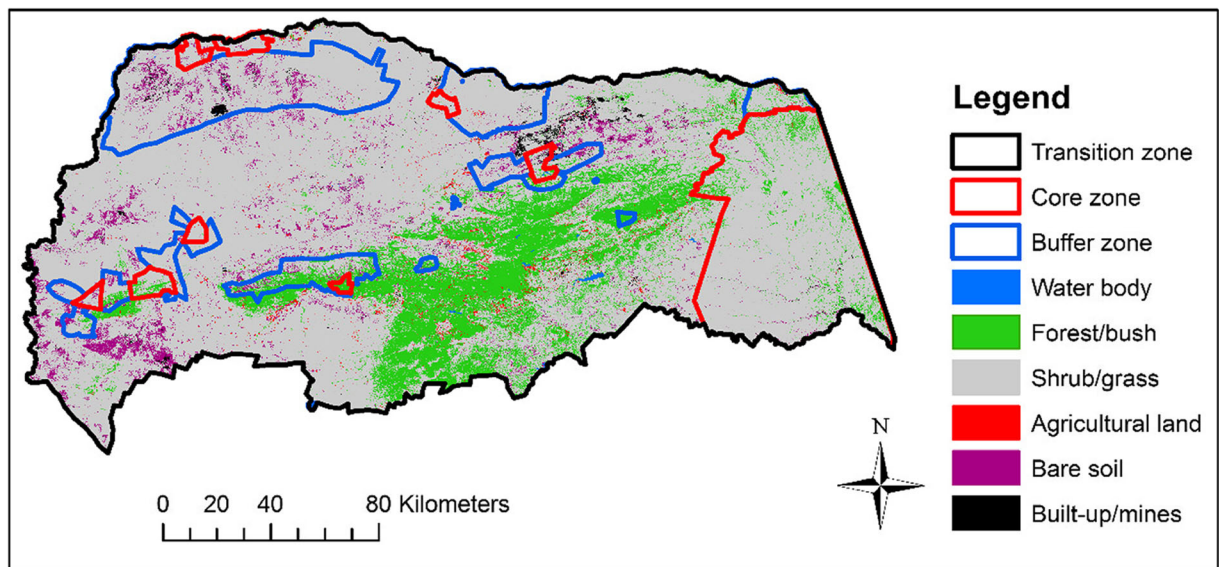
Fig. 4 The spatial distribution of six major LULC classes in the management zones of the Vhembe Biosphere Reserve for Landsat data acquired in 2018

Land use–land cover change dynamics

Land use–land cover trends in the management zones

The spatial patterns of the LULC dynamics in the VBR from 1999 to 2018 are shown in Fig. 7. In general, shrub/grass is the most common land cover in the reserve throughout the study period. Forest/bush showed a sustained increase along the south-eastern part of the reserve, mostly replacing shrub/grass. Land use–land cover trends were created for each land cover class in the management zones and showing a demarcation,

which indicates the proclamation year for the VBR in 2009 and is presented in Fig. 8. Further summaries of the linear regression model generated from the trends are shown in Table 3. Results indicate that across all the management zones, water body exhibited similar trends. Generally, there was an increase in water body before and after 2009, although the increase was statistically significant only in the core zone ($R^2 = 0.2896$, $p \leq 0.1$). Forest/bush land cover maintained lower values for most periods before 2009, whereas higher values were attained after 2009 with a more noticeable increase between 2011 and 2018 across all zones. The overall

Fig. 5 LULC distribution in three artificial buffer zones (0–5 km, 5–10 km, and 10–15 km) radiating from the core zone
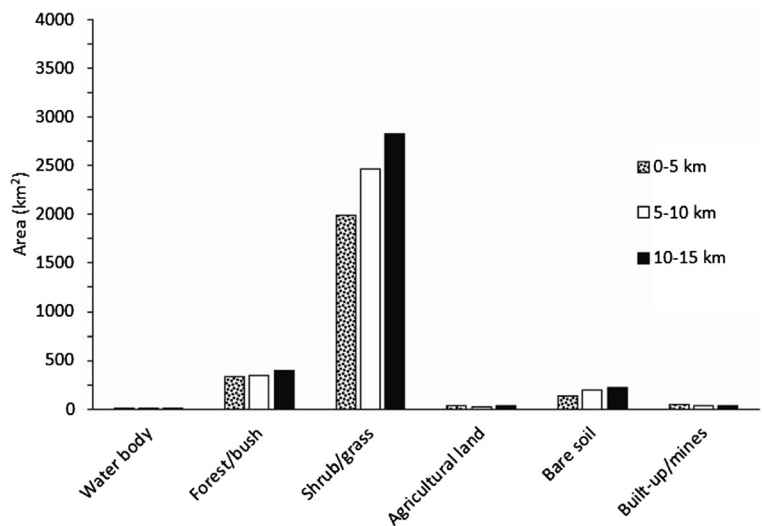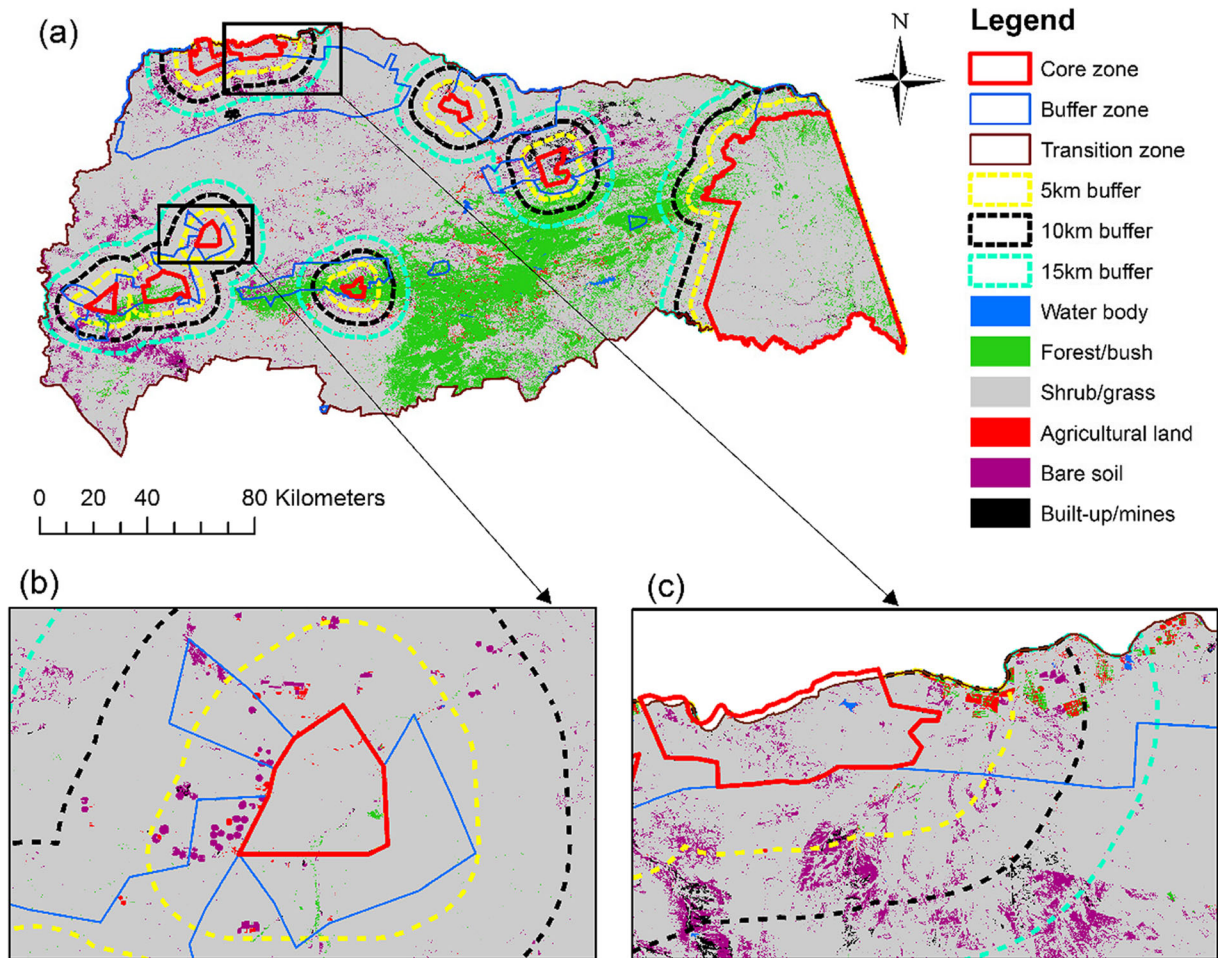
Fig. 6 a LULC map showing the outlines of the management zones and the artificial buffers. b The occurrence of agricultural activities within the buffer zone. c The occurrence of agricultural activities within the artificial buffers in the areas not covered by the buffer zone

trend of forest/bush showed significant growth in all zones, with the highest increasing trend observed in the transition zone ($R^2 = 0.7383$, $p \leq 0.0003$). Shrub/grass declined almost steadily before and after 2009 across the three zones, with the highest decline in the transition zone followed by the core zone, while the change in the buffer zone was not significant. Land cover trends revealed that agricultural lands increased throughout the reserve, including after the proclamation of the VBR. The increase in agricultural land in the core zone was not consistent over the years; however, it is noticeable after 2009. Extent of bare soil showed a slight overall increase in all the three zones during the period before 2009 but decreased modestly in the core and buffer zones and significantly in the transition zone. Built-up/mines remained almost unchanged between

1999 and 2018 in the core zone, while a small overall increase is observed in the other two zones; however, these trends were not significant.

Land cover change matrices in the management zone

The patterns of LULC conversion before and after the proclamation of the VBR were quantified for the three zones using change matrices from 1999 to 2009 and 2009 to 2018 (Table 4). In the core zone, water bodies, agricultural lands, bare soil, and built-up/mines showed overall increases between 1999 and 2009, with the highest (net change = 100.4 km^2) being for bare soil. Most of the increase in bare soil was due to conversion from shrub/grass land. Built-up/mines also increased mainly as a

Fig. 7 Land use–land cover map showing the six land cover classes in the core, buffer, and transition zones of the Vhembe Biosphere Reserve over a 20-year period (1999–2018)
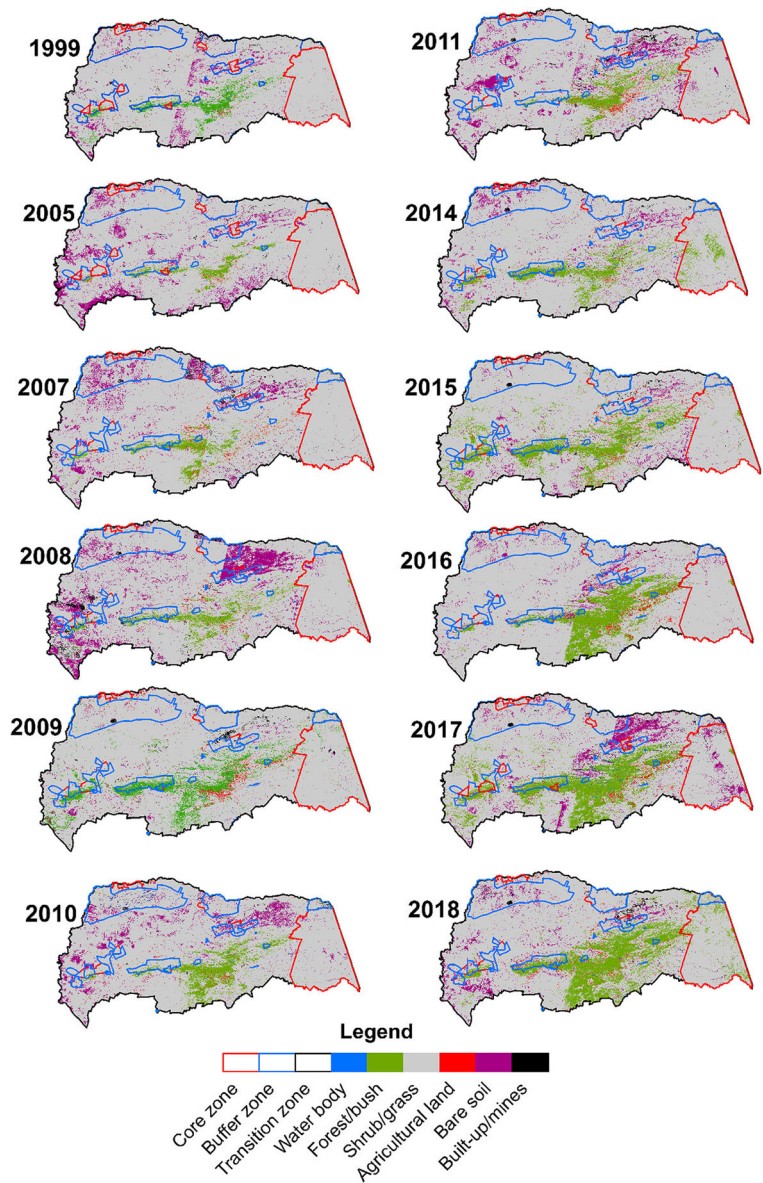
result of conversion from shrub/grass. These conversions explain the considerable decline of shrub/grass between 1999 and 2018, with comparable decline rates before and after the proclamation of the VBR. After the proclamation of the reserve, forest/bush extent increased significantly mainly due to conversion from shrub/grass land, which loses net area of 244.4 km^2. Agricultural land also showed an increase after the proclamation as a result of conversion mainly from shrub/grass; however, the increase was relatively small. Bare soil showed a substantial

net decline after the proclamation of the reserve, although some of the losses were compensated by conversion from shrub/grass lands.

The LULC changes in the buffer zone showed an increase in water body (net change = 6.5 km^2) before the proclamation due mainly to conversion from shrub/grass land but declined (net change = −3 km^2) after the proclamation. Similar to the case in the core zone, forest/bush declined prior to the proclamation of the reserve but increased considerably afterwards (net change = 112.8 km^2), with most of the increase being due to
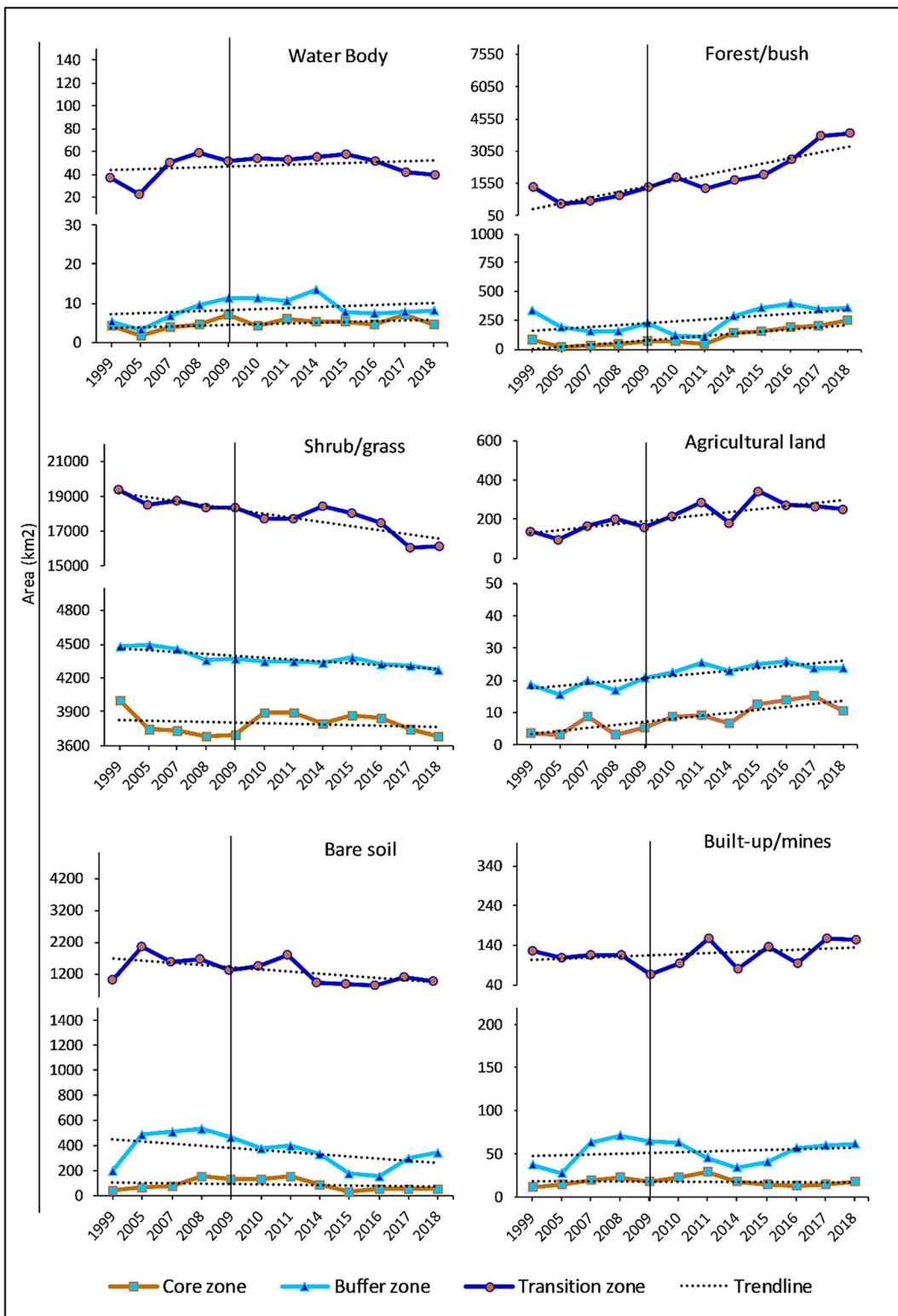
Fig. 8 Land use–land cover trends of the VBR between 1999 and 2019. The vertical line drawn at 2009 marks the proclamation year of the VBR

Table 3 Linear regression results for LULC patterns in the core, buffer, and transition zones of the VBR

Land cover	Core zone			Buffer zone			Transition zone		
	Model	R^2	p value	Model	R^2	p value	Model	R^2	p value
Water body	$y = 0.1457x - 288.31$	0.2896	0.07*	$y = 0.2272x - 448.47$	0.1758	0.2	$y = 0.1175x - 186.44$	0.0095	0.8
Forest/bush	$y = 11.856x - 23{,}737$	0.7352	0.0004***	$y = 12.992x - 25{,}886$	0.4721	0.01***	$y = 169.94x - 339{,}900$	0.7383	0.0003***
Shrub/grass	$y = -10.92x - 26{,}330$	0.7648	0.0002***	$y = -6.0162x + 15{,}896$	0.1124	0.3	$y = -146.74x + 321{,}976$	0.6821	0.0009***
Agricultural land	$y = 0.2498x + 492.99$	0.0117	0.3	$y = 0.5894x - 1163.7$	0.7549	0.0002***	$y = 10.354x - 20{,}605$	0.6118	0.003**
Bare soil	$y = -1.3815x + 2865.5$	0.0285	0.6	$y = -8.6635x + 17{,}780$	0.1427	0.2	$y = -35.965x + 73{,}573$	0.2846	0.07*
Built-up/mines	$y = 0.0497x - 81.714$	0.0029	0.9	$y = 0.8714x - 1700.4$	0.1035	0.3	$y = 2.2947x - 4499.2$	0.1759	0.2

*$p \leq 0.1$

**$p \leq 0.05$

***$p \leq 0.01$

conversion from shrub/grass. Like in the core zone, comparable rates of decline in shrub/grass extents were observed before and after the proclamation. Agricultural land, bare soil, and built-up mines in the buffer zone had similar dynamics as were the case in the core zone in terms of change of direction. The transition zone experienced quite a substantial increase in forest/bush extent after the proclamation as a result of conversion from shrub/grass cover. Correspondingly, shrub/grass declined significantly, though it gained from conversions mainly from bare soil. Another notable dynamic in the transition zone was that agricultural land cover increased after the proclamation quite significantly by taking land mainly from forest/bush and to a lesser extent from bare soil. Bare soil in the transition zone declined by 363.3 km^2 after the proclamation, although it gained significantly large areas from shrub/grass land.

Discussion

Biosphere Reserves have continued to experience human-induced alterations that are affecting the natural environment (Taïta 2003; Béliveau et al. 2017; Von Thaden et al. 2018). Several assessments of land cover in different BRs have demonstrated unique land cover patterns (Chowdhury 2006; Clerici et al. 2007; Biswal et al. 2013; Sharma et al. 2016; Flores-Casas and Ortega-Huerta 2019). However, the lack of accurate spatial information on the effect of the proclamation of each BR on the specific zones and the potential threats to critical biodiversity in the core zone has been one of the major challenges. Such information is useful for improving management strategies.

The South African National Land Cover Maps were generated using an unsupervised classification technique to produce a map on a scale of 1:250000 and used 199 sample points to validate land cover within the boundary of the VBR region (Geoterraimage 2015). Though a recent South African National Land Cover Map was released in 2019, it followed largely similar classification methods and sampling protocols as the previous maps at the same scale. Furthermore, the frequency of the South African National Land Cover Maps is relatively low at an interval of ~ 5 years and therefore does not permit short-term tracking of land cover changes. Our study used high temporal LULC maps and provides a dependable classification based on a rigorous validation process involving 1015 sample points. This study captured the trend of the LULC

Table 4 Land cover change matrices in the core, buffer, and transition zones (km²) before and after the establishment of the Vhembe Biosphere Reserve (year 2009). Italicized values represent the area of land cover that remained unchanged, while the rest show area change from one class to another over time

			Water body	Forest/ bush	Shrub/ grass	Agricultural land	Bare soil	Built-up/ mines	Total
Core zone		2009							
	1999	Water body	*3.9*	0.1	2.1	0	0.1	0.1	6.2
		Forest/bush	0.6	*40*	25.6	1.1	0.3	0.1	67.6
		Shrub/grass	3.2	23	*4156.9*	3.5	103.1	28.5	4318.3
		Agricultural land	0.2	1	2.2	*0.2*	0.3	0.2	4
		Bare soil	0.6	0	3.7	0.2	*6.5*	2.6	13.6
		Built-up/mines	0.1	0	14.5	0.1	3.8	*2.5*	21
		Total	8.6	64.2	4204.8	5.1	114	34	4430.7
		Net change	2.3	− 3.3	− 113.5	1	100.4	13	
		2018							
	2009	Water body	*1.6*	1	5.4	0.1	0.4	0.2	8.7
		Forest/bush	0	*47.9*	14.3	1.3	0.7	0	64.2
		Shrub/grass	1.4	323.7	*3818.7*	7.5	28.2	25.1	4204.7
		Agricultural land	0	0.8	3	*0.9*	0.2	0	5.1
		Bare soil	0	5.5	90	0.1	*17.1*	1.2	114
		Built-up/mines	0.2	0.9	28.9	0	2.7	*1.4*	34
		Total	3.3	379.8	3960.3	9.9	49.3	27.9	4430.7
		Net change	− 5.4	315.7	− 244.4	4.8	− 64.7	− 6.1	
Buffer zone		2009							
	1999	Water body	*2.7*	0.2	0.8	0.1	0.2	0	4
		Forest/bush	2.6	*183.2*	201.6	3.5	3.3	0.1	394.3
		Shrub/grass	4.3	25.5	*3234.5*	8.6	336.6	52.6	3662.2
		Agricultural land	0.2	2.8	7.9	*6.7*	0.7	0.2	18.6
		Bare soil	0.2	0.2	116.5	0.7	*103.6*	5.7	226.9
		Built-up/mines	0.5	0.1	17.7	0.2	7.7	*3.3*	29.5
		Total	10.5	212	3579	19.9	452	61.8	4335.3
		Net change	6.5	− 182.3	− 83.1	1.3	225.1	32.4	
		2018							
	2009	Water body	*3*	3.1	2.1	0.1	0.7	1.6	10.7
		Forest/bush	0.2	*167*	31.1	4.3	9.2	0	211.8
		Shrub/grass	1.7	139.8	*3153*	15.2	248.5	19.8	3578
		Agricultural land	0.1	6.5	10.1	*2.2*	0.7	0.3	19.9
		Bare soil	2.5	8.3	252.3	0.8	*154.9*	33.1	452
		Built-up/mines	0.1	0	50.5	0.4	6	*5.1*	62.1
		Total	7.7	324.7	3499.1	23.1	420	60	4334.5
		Net change	− 3	112.8	− 78.9	3.2	− 32.1	− 2.1	
Transition zone		2009							
	1999	Water body	*29.3*	1.4	7.8	0.8	1.7	0.6	41.5
		Forest/bush	4.5	*929.234*	342.2	7.8	8.7	0.3	1292.6
		Shrub/grass	5.7	376.4	*16,631.1*	89.9	952.4	14.8	18,070.4
		Agricultural land	0.7	24.4	48	*62.5*	6.5	1.4	143.5
		Bare soil	11.3	6.2	689.8	1.9	*309.5*	26.7	1045.4

Table 4 (continued)

		Water body	Forest/bush	Shrub/grass	Agricultural land	Bare soil	Built-up/mines	Total
	Built-up/mines	1	0.5	62.1	0.5	4.1	*5.6*	73.8
	Total	52.5	1338.1	17,781	163.4	1282.9	49.3	20,667.2
	Net change	11	45.5	− 289.5	19.9	237.6	− 24.5	
	2018							
2009	Water body	*28.3*	15.3	5.2	0.8	2.6	0.3	52.5
	Forest/bush	0.5	*1117.1*	175	36.4	8	0.2	1337.2
	Shrub/grass	7.8	2468.8	*14,480*	171.9	537.5	115.6	17,781.7
	Agricultural land	0.2	73.4	55.9	*27.9*	5.3	0.7	163.3
	Bare soil	2	59.9	819.4	10.3	*362.3*	28.9	1282.8
	Built-up/mines	0.6	1.1	35.4	1.3	3.8	*7.1*	49.3
	Total	39.4	3735.6	15,571.1	248.5	919.6	152.7	20,666.8
	Net change	− 13.1	2398.4	− 2210.6	85.2	− 363.3	103.4	

dynamics and assessed the effect of the proclamation of the VBR in 2009 on different LULC types. In addition, assessments were made to examine the threat that core protection zones are faced with by delineating imaginary buffers around them. Our study is the first to document the classification of LULC in the VBR using a supervised classification technique that produces comparable results across landscapes (Jia et al. 2014; Hackman et al. 2017).

The overall classification accuracy achieved in this study using Landsat image and corresponding Google Earth data acquired in 2018 was generally high (Table 2). Although waterbodies have been identified with high degrees of confidence due to their distinct spectral difference from the other land cover types, the accuracies of forest/bush and shrub/grass and to a certain degree agricultural land can be considered good in terms of producer's, user's, or both metrics. Bare soil and built-up/mines had the lowest accuracies mainly due to confusion with each other. Such confusions are expected since these land cover types can fundamentally consist of similar materials. For example, mining activities basically break down geological conglomerates into smaller particles including soil particles that can be considered bare soil if it is not vegetated. Similarly, built-up structures in rural communities such as those common in the study area were heterogenous from the mixture of domestic gardens and lawns found around buildings (Shackleton et al. 2015). We therefore regarded the classification approach and the Landsat data as suitable to assess LULC and associated dynamics in the three zones of the VBR. It is however important to note the difficulty in achieving good accuracy in discriminating bare soil and built-up areas among each other and from the other classes. Built-up areas pose a more serious threat to conservation interventions than do bare lands that can transform to natural vegetation under conducive climate scenarios. Confusing these two classes with other land cover types such as shrub/grass and agricultural land as observed in the present study (Table 2) can also have a detrimental management implication to the BR. One potential implication is that shrub/grass can be overestimated by false identification of built-up and bare land. Although false identifications might also occur due to confusion with forest (Table 2), this may not pose a serious concern to environmentalists provided that the forest falls under a natural vegetation category. Furthermore, the confusion between shrub/grass and built-up and bare land is not welcome, as it may worsen the predicted shrinking grassland ecosystems in South Africa (Mucina and Rutherford 2006). The 2018 LULC map showed the relative dominance of shrub/grass in the three management zones (Figs. 4 and 5). This is typical of the savanna biome, which has the largest spatial coverage (46%) in Southern Africa (Neumann and Bamford 2015; Guo et al. 2017). The forest in the VBR plays a significant role in preserving a wide variety of biodiversity and endemic species (Götze et al. 2003; Ofoegbu et al. 2017). However, a greater proportion (86%) of the forest/bush is found in the transition zone, possessing minimum legal protection. Because of continuous human activities in the transition zone, the

natural forest is at risk of conversion into plantation forest or other land cover types, since local communities depend on the forest resources for their livelihoods (Ofoegbu et al. 2016; Bakali et al. 2017). It is interesting to see farming practices in close proximity to the core management zone of the VBR (Fig. 6), considering that this zone should enjoy the maximum protection, according to the BR guidelines (Van Wyk and Smith 2001; Hoffmann et al. 2017; Tiawoun et al. 2018). The fact that more of the farms are found in close proximity (0–5 km) to the core zone should raise the warning signs in the management of the VBR. An argument can be made that the large-scale modern farming activities are well managed and therefore minimize encroaching onto the core zone. Such management however may not offer an absolute guarantee against the loss of resources from the core zone. For example, the use of irrigation farming can disrupt hydrologic processes that the natural environment of the zone benefits from. Similarly, large-scale farming practices are often associated with utilization of growth-enhancing treatments such as pest controls that can have undetermined amount of detrimental effects on the ecosystem functioning of the core zone. The buffer zone is designated only for strict conservation practices to provide peripheral protection for the priority areas in the BR. However, the lack of such buffer zones around certain core zones creates a weak link that can encourage negative human influence in the core zone, thereby threatening the protection of biodiversity. It is unlikely for the core zone to be completely enclosed, since most parts of the buffer zone consist of pre-existing conservation sites that do not necessarily surround the core zone. Factors such as the spatial arrangement of zones and the effective implementation of management rules are linked to land cover changes in the BR (De la Rosa-Velázquez et al. 2017; Van Cuong et al. 2017). For this reason, special attention must be inclined towards the protection of core areas that are adjacent to the transition zone.

The land use–land cover dynamics depicts noticeable patterns in the three management zones with almost persistent increase in forest/bush cover after the proclamation of the VBR (Figs. 7 and 8). The fact that these increases were statistically significant (Table 3) and occurred mostly after the proclamation (Table 4) suggests a positive outcome in terms of vegetation increase. These increases match with the corresponding decreases in shrub/grass especially in the core ($r = -0.7393$; Fig. 9a) and transition ($r = -0.8918$; Fig. 9c) zones,

which might indicate success in influencing a healthy vegetation growth or natural regeneration of the flora through transformation of shrubs to foliage-richer bushy forms. Besides, forest/bush expanded by gaining a significant amount of area from bare soil in the buffer zone ($r = -0.7975$; Fig. 9b) and transition zones ($r = -0.6520$; Fig. 9d). While these observations are purely the result of interpretation of remotely sensed data, it is prudent to consider the potential causes of forest/bush cover increases in the VBR. Changes in land cover can potentially be tied to changes in climatic conditions. Particularly from 2014 to 2016, South Africa was faced with a severe drought event (Archer et al. 2017; Swemmer et al. 2018), which might have contributed to land cover dynamics. Withering of grasses and smaller plants caused by drought reduced competition between plants and the occurrence of wildfires, favoring of the expansion of drought-resilient trees and forb species (Hoffman et al. 2018; Swemmer et al. 2018). Furthermore, the dynamics in plantation forests found in the reserve could have resulted in the increase of the forest/bush class. For example, the latest South African National Land Cover Map showed that the commercial plantations occupy about 7% of the entire forest in the reserve (Geoterraimage 2020). If not well managed, plantation forests can threaten the fundamental principles of biodiversity conservation that BRs aim to achieve; as a result, the forest/bush increase observed in our study should be interpreted cautiously (Yang et al. 2016; Ntshuxeko and Ruwanza 2018; García-Barrios et al. 2020). Considerable decline in shrub/grass may well be consequences of woody plant encroachment, which are potentially caused by poorly managed farming and grazing activities, change in fire regimes, variations in rainfall patterns, and carbon dioxide emissions (Van Rooyen 2016; De la Rosa-Velázquez et al. 2017; Stevens et al. 2017; Luvuno et al. 2018). Woody plant encroachment is a common threat to large proportions of grassland and savannahs in South Africa (Ekblom et al. 2012; Stevens et al. 2016).

Despite the above promising LULC changes in vegetation, increasing agricultural lands in the three management zones even after the 2009 proclamation poses an environmental concern in the management of the VBR. The greater agricultural activity in the buffer and transition zones (as shown by the relatively high regression coefficients in Table 3) is indicative of the relaxed restrictions imposed on these zones. Other LULC types (water body, bare soil, and built-up/
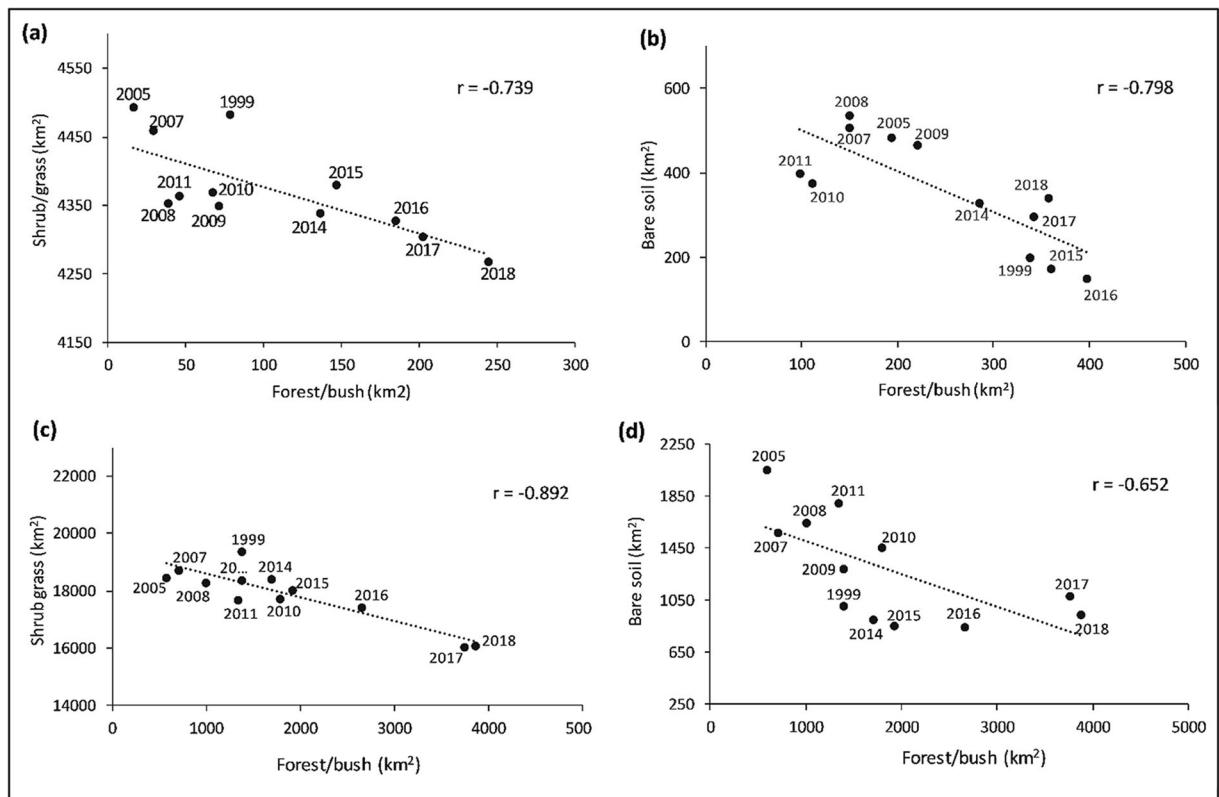
Fig. 9 a The correlation of forest/bush with shrub/grass in the core zone. **b** The correlation of forest/bush with bare soil in the buffer zone. **c** The correlation of forest/bush with shrub/grass in the transition zone. **(d)** The correlation of forest/bush with bare soil in the transition zone

mining) did not show clear decreasing patterns nor significant fluctuations across the study period particularly in the core zone (Fig. 8). It is unclear how much of the water bodies are categorized as natural. Considering the importance of irrigation to agricultural practices that appear to be existing in the area (Fig. 6b and c), it is logical to expect runoff harvesting mechanisms such as surface dams to support the irrigation systems. Implementing careful management of waterbodies for such economy-driven management should therefore keep the amount of water fairly unchanged within the same season as considered in the study. The somewhat constant spatial extent of bare soil particularly in the core zone compared with the decreases in the other two zones (Fig. 8) is surprising. We expected a significant decreasing trend in bare soil particularly after the proclamation. Although the core zone comprises of pre-existing Nature Reserves and National Parks before the designation of the VBR, incorporating them into the BR has reinforced the conservation status. The

expected revegetation and expansion of forest/bush can be said to be a consequence of the buffering effect provided by the BR system. Management strategies directed towards minimizing the collection of forest products play a significant role in maintaining the ecological significance of existing protected sites in the BR (Ofoegbu et al. 2016; Mphidi 2019). Persistence of bare soil in the buffer and transition zones over time can be linked to small-scale (and possibly) undocumented sand mining that may manifest spectrally as bare soil (Amposah-dacosta and Mathada 2017; Sengani and Zvarivadza 2019). This trend is likely to continue based on predictions that the grassland biome in South Africa is expected to change under increasing temperatures resulting from climate change effects (Mucina and Rutherford 2006; Buhrmann et al. 2016). Built-up/mining land cover type showed non-trending pattern and limited fluctuations over the study period particularly in the core zone. This is promising in that human activities have been constrained in the zone to avoid further

damage to the environment. In contrast, the high fluctuations of built-up/mining land cover in the buffer and transition zones indicate the need to prioritize protection in the zones. Even as this study identified a promising dynamic in LULC as displayed in the increasing trends of forest/bush and decline in bare soil, findings in other BRs reported similar trends. For example, Satish et al. (2014) reported that forest increased in the Nilgiri BR in India due to reduced deforestation rates after the establishment as a BR in 1986. Son et al. (2016) also identified a huge reforestation (41%) of the mangrove forest in the Can Gio BR in South Vietnam. While the effectiveness of each BR is strengthened by the common understanding of sustainable development, conflicting interests and management decisions even in the conservation sites located within the BR have implications on land cover.

Conclusion

This study aimed at assessing biodiversity protection around the core zone and tracking the spatio-temporal LULC dynamics in the three management zones of the VBR. The state of vegetation has improved in the VBR, since the proclamation as a BR in 2009. We identified potential threats on the core zone by delineating artificial boundaries around the zone, particularly from agricultural activities. These threats are indicative of the weak shielding effects of the buffer and transition zones. The assessment of LULC change showed that forest/bush increased after the proclamation while shrub/grass declined steadily in all the three management zones (core, buffer, and transition). Particularly during the period after 2009, forest/bush gained significantly by replacing shrub/grass area in the core and transition zones and bare soil in the buffer zone. Another noticeable change was seen in the overall decline in bare soil after 2009, most of which was converted to shrub/grass and forest/bush. Agricultural lands increased throughout the reserve especially in the period after the proclamation. On the other hand, water body and built-up/mines showed very slight increasing trends in the three management zones.

In spite of the threat to biodiversity conservation in the core zone and the possible effects of plant encroachment, the promising result of LULC change indicates possible achievement of the fundamental goal of protecting biodiversity through the BR program that is

being achieved in the VBR. To ensure effective conservation of biodiversity, special attention must be focused on regulating activities (such as agriculture), which can directly modify the physical environment. Furthermore, reviewing the spatial arrangement of the management zones is essential for protecting critical biodiversity. In line with the above findings, the management framework for BRs endorses a re-plan of the spatial arrangement of management zones according to the sustainable development plan, when it becomes a necessity to reinforce the protection of biodiversity in the core zone (UNESCO 1996). Finally, we emphasize the need for periodic monitoring of LULC changes in BRs for designing and implementing efficient zone-specific management strategies. Notwithstanding, there is a need for further studies on LULC, which will utilize improved data qualities. An example in this regard could be integrating high temporal resolution data such as moderate resolution imaging spectroradiometer (MODIS) with high spatial resolution data (e.g., Sentinel-2 Multispectral Imager and Landsat) to develop a more robust monitoring method.

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