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Original Research Article

Assessment of land use and land cover changes from 1979 to 2017 and biodiversity & land management approach in Quirimbas National Park, Northern Mozambique, Africa

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A B S T R A C T

National parks are established with the aim of guaranteeing and protecting natural biodiversity and ecosystems, in a multi-level and integrated approach. Biodiversity conservation, management of protected areas and sustainable development with strategies targeting rural populations are current challenges in Africa, in the context of exponential human population growth, overexploitation of natural resources, forest destruction and climate change. The Quirimbas National Park (QNP) has been suffering from severe and constant threats originating from different sources and changes in land use and land cover. These changes, and in the context of global climate change, pose permanent challenges to the managers of this conservation area of Mozambique. The research aimed to analyze the historical and recent LULC over the last 38 years, to provide consistent and scientific information for decision making on biodiversity conservation approaches; to identify the main changes and their impacts on the ecosystem to implement/develop appropriate mitigation strategies. A combined and integrated methodological approach has been developed from satellite imagery analyzes of Landsat 2 and 5 MSS (Multispectral Scanner); Landsat 5 TM (Thematic Mapper), Landsat 8 OLI (Operational Land Imager), and fieldwork (field observation and communities and QNP staff meetings). The results show that the overall map classification obtained was between very good and excellent: 1979 - Kappa 71.84%, Overall Accuracy 86.55%; 1989 - Kappa 83.49%, Overall Accuracy 93.01%; 1999 - Kappa 85.03%, Overall Accuracy 90.07%; 2009 - Kappa 79.57%, Overall Accuracy 86.42%; 2017 - Kappa 80.24%, Overall Accuracy 86.95%. For 38 years, the QNP lost about 301,761.7ha, corresponding to 41.67% of the total QNP coverage land. The main causes are associated with intensive agriculture, human settlements, population growth, illegal exploitation of forest resources and miners inside of the Quirimbas National Park. The impact extends from territory reduction and fragmentation to vegetation and animal biodiversity loss, human-wildlife conflicts, habitat connectivity loss, species isolation and scaring, and basic resources scarcity for the community's livelihoods.

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1. Introduction

Biodiversity conservation, management of protected areas, and sustainable development with strategies targeting rural populations are current challenges in Africa, in the context of exponential human population growth, overexploitation of natural resources, forest destruction and climate change. However, the alternatives will introduce resource management measures that address environmental issues in an integrated and large-scale manner, based on the needs of rural communities, considering ecosystem and biodiversity balance and systematically assess and monitor them.

The level and intensity of use and exploitation of natural resources, especially forest, land, water, animal diversity, vegetation in the world has led to significant changes on the environment and degradation of resources with serious consequences in the reduction of ecosystem services, reduction of resources and weak food production.

Africa, a continent with an estimated forest area of 675 million hectares, corresponding to 17% of global forests, lost about 4 million hectares between 1990 and 2000, and this number reduced to 3.4 million between the years 2000–2010. The rest of the world continents, which represented the other 83%, lost about 8.3 million between the years 1990–2010, and 5.2 million in the years 2000–2010 (FAO, 2011; UNECA, 2011).

Regarding the land, Africa is responsible for 27.4% of land degradation, and it is estimated that almost 500 million hectares are practically degraded. In those 500 million hectares, 14% of the land degradation is a result of vegetation removal, 13% overexploitation, 49.5% overgrazing and 24% agricultural practices. Moreover, about 72% (Burkina Faso), 72% (Ethiopia), 63% (Lesotho), 60% (Mali), 40% (Sudan), 45% (Chad), 29% (Morocco), 28% (Zimbabwe), 27% (Namibia), 26% (Tanzania), 22% (Botswana), 19% (Malawi), 18% (Africa do Sul), 9% (Angola), 9% (Zambia), 6% (Mozambique) of the population live on degraded lands (UNEP, 2011; FAO, 2011; UNECA, 2011).

The land use and land change (LULC) constitutes a challenge for the territory or land management, ecological and sustainable development (Rawat et al., 2013), and has been reported by several studies (Mei et al., 2016; Yang et al., 2015; Beuchle et al., 2015; Yuan et al., 2005; Abd El-Kawy et al., 2011; Dewan and Yamaguchi, 2009; Gremychi, Gwyn, Bénié, Formaggio and Fahl, 2014; Halmy et al., 2015), indicating the significant differences in land surface objects or phenomena over time. The process of detecting changes in objects' characteristics can provide insight into the forms and types of systematic interactions between anthropogenic and natural issues (Berberoglu and Akin, 2009; Rawat et al., 2013; Belal and Moghanm, 2011).

The main causes of land change (LC) have been associated to anthropogenic factors such as fires, territory fragmentation, agricultural (intensification of agriculture), livestock, buildings, infrastructure, deforestation, urbanization (Halmy et al., 2015), mining industry (Mei et al., 2016), as well as natural phenomena (flooding and erosion) (Hazarika et al., 2015).

Knowledge of LULC over a time horizon can be of great importance in the context of preparing concrete local, regional and national land management measures and can be used to reverse land use issues, illegal occupations, habitats destruction, ecological and natural resource deterioration, loss of biodiversity (Anderson et al., 1976), evidence of the biodiversity conservation plans (Fuller et al., 1998) and modeling the climate and biogeochemistry of the world (Zhu and Woodcock, 2014).

The application of remote sensing techniques using satellite image has become an important tool for the management and monitoring of areas and spaces over time (Halmy et al., 2015).

This technique provides economically viable multispectral and multitemporal data, and this information is aggregated into an extremely important dataset for assessment and analysis of the state, health, and resources of ecosystems (Weng, 2002), mapping and monitoring coastal resources (Devi et al., 2015). It also provides useful and important information to analyze processes and patterns of change in ecosystems at different scales (Yang et al., 2015; Chen et al., 2012; Devi et al., 2015).

Perfectly understanding the state and dynamics of ecosystems is crucial to address a global and integrated strategy, especially in the regions where the main economic base or community's livelihood are natural resources and land, such as Africa, particularly Mozambique. In addition, it is crucial in the climate change context, whose impacts threaten ecosystems, condition species movement, alter the structure and functioning of ecosystems and condition the life and mobility of human populations (IPCC, 1996; 2014).

The scientific studies on land use and land cover change in Mozambique are still very incipient, available scientific reports address issues of mangroves cover changes (Ferreira et al., 2009; Shapiro et al., 2015), ecosystem services and biodiversity as a consequence of land cover changes (Niquisse et al., 2017), land cover changes detection in the Limpopo river basin (Pereira, 2004), understanding land use, land cover and woodland-based ecosystem services change in Mabalane (Zorrilla-miras et al., 2017). This scenario reveals the importance and urgent need of further studies in different areas in Mozambique to provide useful and timely information for better understanding land use changes.

In this context, population growth and spatial mobility in rural areas have been growing significantly, having jumped from 12.1 million (1980) to 16.1 million (1997–2.2% per year growth), 20.5 million (2007–2.4% per year growth) and 28.9 million (2017–3.5% per year growth). These figures show that Mozambique is one of the three African countries with the highest annual growth rates, after Equatorial Guinea and Niger with 3.8% per year growth (INE, 2017; World Bank, 2017). This mobility, which look is justified by the search for basic life conditions and resources, conditions the resources available for use and land exploitation (Ferrão, 2010). Sometimes exploitation is conducted in an unruly, disordered way, consequently enabling actions leading to land cover changes (LCC).

Northern Mozambique, mainly Cabo Delgado Province (CDP) is a resource-rich area, possessing enormous animal and vegetation biodiversity, including extensive forest areas. The survival of urban and rural communities has been dependent and related to the main services that the regional ecosystem has provided from regulation to support and production services (agriculture, livestock, fishing, water, forest). But the continuity of these services in serving the local populations is increasingly compromised due to the high level of pressure that this ecosystem has been facing in the last 15 years. Nonetheless, biodiversity is at the top of the main elements to suffer severe reductions in number and from fragmented locations in the coming times.

To ensure the protection and conservation of species, habitats, resources and reduce human-wildlife conflicts, the Mozambican government established a biodiversity conservation protected area, Quirimbas National Park. Since 2002, it has been facing serious management problems, loss of biodiversity, forest reduction and land invasion by local communities for traditional farming practices, resource exploitation (wood, fuel), construction. The demand for land and alternative resources for survival, driven by high rates of population growth, unemployment, and poverty is the great threat to Quirimbas National Park.

Faced with this scenario, there is a lack of scientific information deeply addressing the social and environmental dynamics that have occurred in recent times. The information on the impacts of these dynamics on habitats, biodiversity, and communities is still nonexistent.

On that topic, associated to the climate change context, where the consequences reach different scales, level, and magnitudes (IPCC, 1996; 2014), it is necessary to gather information on LULC that allow to analyze carefully the scenario and enable the implementation of effective land use plans for community, habitats, biodiversity conservation, mitigation and local adaptation policies on food security, water, food, resources exploitation in Quirimbas National Park.

The objective of the paper is to analyze the historical and recent LULC over the last 38 years, to provide consistent and scientific information for decision making on biodiversity conservation approaches; to identify the main changes and their impacts on the ecosystem to develop appropriate mitigation strategies.

2. Materials and method

2.1. Study area

Quirimbas National Park (QNP) is a biodiversity conservation area of Mozambique, one of the five biodiversity areas established by the government after independence from Mozambique on June 25, 1975 (Fig. 1). QNP is in the Province of Cabo Delgado (PCD), Northern Mozambique, created with an intrinsic goal for valorization and protection of the Cabo Delgado biodiversity (MITADER, 2012). This protected area was created at the request of communities that at the time suffered severely from attacks by and conflicts with animals, due to the sharing of basic resources such as water, land and food.

It covers an important area of the PCD, considered as an eco-region of the Inhambane and Zanzibar Mosaic, housing enormous biological diversity both marine and terrestrial, a significant part of which is considered endemic of Northern

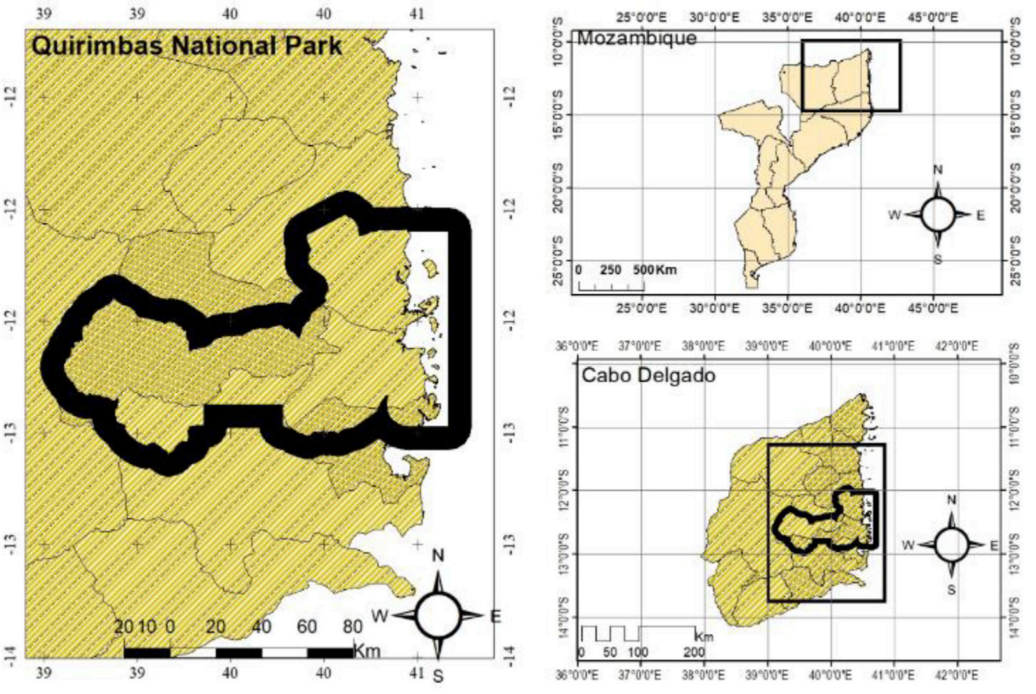

Fig. 1. Quirimbas national park, Cabo Delgado and Mozambique.

Mozambique (MITADER, 2012), such as *Nothophryne unilurio* (Conradie et al., 2018); *Hexalobus mossambicensis, Vismianthus punctatus, Gardenia transvenulosa, Zanthoxylum lindense* (Timberlake et al., 2011).

The QNP comprises two main conservation areas (marine and terrestrial) and a buffer zone (Fig. 1 clearly illustrates the three areas: (1) right side (white) is the marine ecosystem; (2) left side is the terrestrial ecosystem, and (3) black area is the buffer zone). The marine ecosystem comprises an area of 1,185km2, and the terrestrial ecosystem an area of 5,984km2, while the buffer zone occupies an area of 1961 km^2 (MITADER, 2012).

QNP presents peculiar characteristics regarding other protected areas in the world, specific to the southern region of Africa. QNP is one of the few protected areas that has human populations within its borders. It is composed by seven partially integrated districts, namely Macomia, Metuge, Ancuabe, Montepuez and Meluco and two integrally associated districts, Ibo and Quissanga.

Quirimbas National Park has a population of 166.000 habs. 95.000 (57%) of them residing inside QNP and 71.000 (43%) living in the transition and buffer zone of QNP (MITADER, 2012). Being the third largest conservation protected area in Mozambique, it has a significant and important ecological, economic value, but it is facing multiple challenges, whether due to the poaching, deforestation, illegal exploitation of mining resources, hunting, uncontrolled burning, community invasion to exploit the basic resources for their survival. These factors contribute negatively to all aspects of biodiversity and resource conservation.

2.2. Data analysis

2.2.1. Fieldwork

Fieldwork was carried out from November 2016 to April 2017 in the Quirimbas National Park (Fig. 1). The main goal was to collect environmental and social data. Fifty control points – ancillary data was recorded (rivers, rocks, roads, forests, coastal areas, housing, mangroves, exposed soils), and three sessions meetings were held in the communities, and two with the QNP managers. This methodology approach allowed us to assess the important issues that determine and promote the dynamics of land use and land cover, to identify the different types of environmental issues and to register clearly the perceptions and needs of local communities on resources and land exploitation.

2.2.2. Image acquisition & digital processing

Regarding the remote sensing analysis, twenty satellite images were used corresponding to three main sensors Landsat 2 & 5 MSS (Multispectral Scanner), Landsat 5 TM (Thematic Mapper), Landsat 8 OLI (Operational Land Imager), distributed in four images by different years 1979, 1989, 1999, 2009, 2017. At the same time, an image from 1999 and another from 2017, taken outside the Quirimbas National Park were acquired. All images were obtained at no cost from the United States Geological Survey (USGS), archive https://ers.cr.usgs.gov/(Table 1). All used images were firstly pre-georeferenced for WGS 84/UTM zone 37N, and were processed by RGB colored composition, the mosaic techniques were applied, and a Quirimbas National Park cartographic map was used to make the clip to study area (Fig. 2) (see Table 2).

Table 1
Details of satellite images.

Description	Year	Scene ID	Rad. Resolution (m)	Path/Row	Spectral Band Used	Spectral Bands (μm)
Remote Sensing Data						
Sensor/Landsat 2	27/08/1979 03/12/1979	MSS	60	176/068 176/069 177/068 177/069	B4, B5, B6, B7	0.5–1.1
Sensor/Landsat 5	09/05/1989 16/05/1989	TM	30	164/068 164/069 165/068 165/069	B1, B2, B3, B4, B5, B6, B7	0.45–2.35
	05/02/1999 14/02/1999 29/06/1999		30	164/068 164/069 165/068 165/069	B1, B2, B3, B4, B5, B6, B7	0.45–2.35
	23/05/2009 16/05/2009		30	164/068 164/069 165/068 165/069	B1, B2, B3, B4, B5, B6, B7	0.45–2.35
Sensor/Landsat 8	09/07/2017 30/06/2017 23/12/2017	OLI-TIRS	30	164/069 164/068 165/069 165/068	B1, B2, B3, B4, B5, B6, B7	0.43–12.5

For LULC classification all the reflective bands were used, excluding the thermal bands. Topographic maps from 2010 (scale 1:800000) of northern Mozambique, obtained from the National Institute of Geology, were used to generate the land use and cover maps.

2.2.3. Pre-processing

2.2.3.1. Radiometric and geometric corrections. Due to technical circumstances of the sensors, platforms, as well as the state of the atmosphere, earth rotation and terrain effects, the images obtained by sensors can be subject to errors and distortions. These distortions can be assessed as less significant or significant according to analyzes that can be performed. If appropriate methods of removing distortions are not applied, it can significantly affect the results and conclusions (Jia and Richards, 2006; Rahman and Dedieu, 1994).

For good image analysis, two main corrections are necessary: radiometric and geometric correction (Zhu, 2017; Goslee, 2011; Rani et al., 2017; Rahman and Dedieu, 1994; Hansen and Loveland, 2012), useful and particularly important when it is intended to make comparisons of information or multiple data over time (Hansen and Loveland, 2012). Usually, radiometric corrections apply to the removal or reduce the atmosphere and sensor noise, haze removal, correction of data loss and missing lines due to a solar position, satellite calibration (Lyapustin et al., 2012; Hilker et al., 2012).

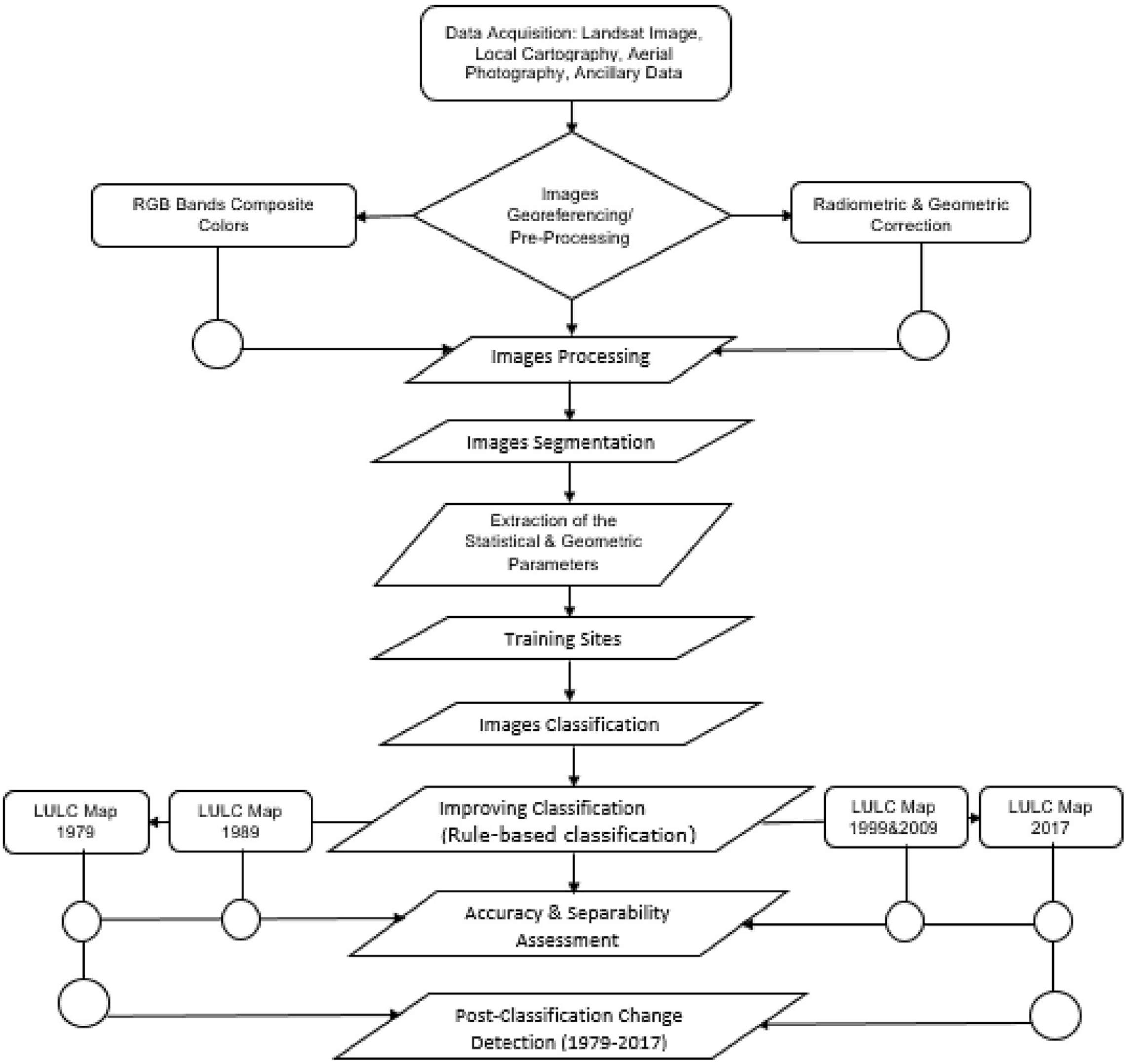

Fig. 2. Flowchart of Quirimbas national park land use and land cover/change detection.

Table 2
Land cover classification criteria.

Variables	Description
Human Settlements	Characterizes lands/locales with housing and community, public and private infrastructures
Vegetated	Describes lands with different types of vegetation (forest, mixed forest lands (dry, dense, open and closed), scrub and others).
Non-Vegetated	Characterizes lands with no differentiated vegetation

On this study, all images obtained from the U.S. Geological Survey (USGS) between 1989 and 2017 were level 2, which means that they were fully corrected (Zhu, 2017). It was necessary to make the geometric and radiometric corrections of the images obtained in 1979. The radiometric corrections applied were the top of atmosphere reflectance, surface reflectance, brightness temperature, haze and cloud mask using Semi - Automatic Classification (QGIS Desktop v.2.18.13) and the ATCOR (PCI Geomatics v.2017) (Zhu, 2017).

2.2.4. *Image processing*

2.2.4.1. Image classification. The image classification was done using Object-Based Image Analysis (OBIA). OBIA is a classical and updated, high-resolution multispectral satellite image classification technique that allows detailed analysis of the objects on the surface under study (Ma et al., 2017; Blaschke et al., 2014).

A simulation of unsupervised classification using PCI Geomatics was done simply to assess the class or category type and information provided by the classifier. Practically, supervised classification (Object-Based Image Analysis) using PCI Geomatics, v.2017, was used.

The OBIA analysis was based on (1) Multispectral Image Acquisition. (2) Atmospheric Correction. (3) Conversion from GeoTIF (TIF) files to PCIDSK (PIX). (4) Image Segmentation. To select the best parameters to be used in the segmentation process, different Scales (SC), Shape (SP), and Compactness (CP) were performed, and finally, the following parameters were proposed: $SC = 30$; $SP = 0.5$; $CP = 0.5$. (5) Extraction of the statistical and geometric characteristics (statistical channels were the mean and standard deviation. Geometrical parameters were Compactness, Elongation, Circularity, Rectangularity). (6) Selection of Training Sites (Table 4). For each image, more than 300 samples were selected, distributed in (1) Vegetated; (2) Human Settlements; (3) Non-Vegetated. The samples were statistically significant, according to the criteria proposed by (Jia and Richards, 2006). (7) Classification. For the classification process, the algorithm and binary classifier SVM (Support Vector Machines) was used (Lu and Weng, 2007).

2.2.4.2. Accuracy assessment. Accuracy was evaluated based on the detailed analyzes of the classified images from 1979, 1989, 1999, 2009 and 2017 and finally the confusion matrix approach was applied. The confusion matrix rule allowed us to evaluate the overall accuracy, kappa coefficient, commission errors, omission errors, producer's and consumer's accuracy (Liu and Yang, 2015). The classification validation was done analyzing about 30% of the samples of each class of the LULC maps from 1979, 1989, 1999, 2009, 2017 (Table 4), and supported by ground truth reference data and google earth professional maps.

Table 3
IUCN protected area management categories (Dudley, 2008).

Category	Description
Ia Strict Nature Reserve	Strictly protected for biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
Ib Wilderness Area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
II National Park	Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational and recreational visit opportunities.
III Natural Monument or Feature	Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/Species Management Area	Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
V Protected Landscape or Seascape	Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected Areas with Sustainable Use of Natural Resources	Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

Table 4
Number of Sample Training and Validating Objects used on LULC Classification Process.

Year	Sample Training/Validating Objects		
	Vegetated	Humans Settlements	Non-Vegetated
1979	888/328	0/0	0/0
1989	955/271	475/116	0/0
1999	457/157	485/120	325/119
2009	450/158	414/148	406/111
2017	463/141	387/119	359/108
Total	**3213/1055**	**1761/503**	**1090/338**

2.2.4.3. Land use and land change analysis. Detection of changes was done using the post-classification method. Considered efficient, because it allows a greater objects detection and changes variation occurred (Fig. 2). The maps of LULC (1979–2017) have been compared two by two over the years, and maps of the changes that occurred over the last 38 years have been produced comparing the LULC maps of 1979 and 2017, using PCI Geomatics Matrix Analysis. The map overlay method was applied resulting in the bidirectional cross matrix acquisition.

3. Results

3.1. Classification accuracy assessment

Accuracy assessment result for QNP shows that, for 1979, Overall Accuracy was 86.55% with Kappa equal to 71.84%. For 1989, Overall Accuracy 93.01%, Kappa equal to 83.49%. In 1999, Overall Accuracy was 90.07%, Kappa equal to 85.03%. In 2009, the Overall Accuracy was 86.42%, Kappa equal to 79.57%. Finally, INE, 2017, the Overall Accuracy was 86.95%, Kappa 80.24% (Table 5). For this accuracy classification assessment, the results show a slight variation of the accuracy and kappa from 1979 to 2017. However, both metrics ware considered statistically significant, above the minimum required for the accuracy assessment.

For the accuracy assessment of the map of the area outside QNP the results show that in 1999, Overall Accuracy was 92.18% and Kappa equal to 78.57%. For 2017, Overall Accuracy was 88.61% and Kappa equal to 76.96% (Table 6).

As shown in Tables 5 and 6, producer accuracy is a metric that indicates the accuracy of the map from the maker's viewpoint (producer's). This metric measures how often the terrain/ground attributes or characteristics under analysis are declared correct on the map. User accuracy is a reliability metric and measures how often the classes defined on the map under analysis are present on the ground/terrain.

3.2. Quirimbas National Park land use and land cover (1979–2017)

According to the LULC map from 1979, Quirimbas National Park presented a uniform distribution of vegetation, and it is not possible to accurately identify land cover changes occurring in this period (Fig. 4). Nevertheless, it was possible to detect the presence of the two types of vegetation (1) dense and closed located in the Center, North and East of the QNP, and (2) dry and open forest, located from Center to West (Fig. 4). As it is evident, in the East region some places present similar information as dry forest land. However, this is a coastal zone, but because some ground objects may have similar spectral characteristics to a dry forest, it may have caused the assignment of that category by the classifier (Fig. 4).

The categories that were not identified in 1979 were detected in 1989 (Fig. 5). All LULC categories under analysis were found between 1999 and 2017. The land cover changes in the Quirimbas National Park probably had an impact and becomes more evident from 1980 (Fig. 5). In 1979, the presence of human settlements was insignificant, increasing quantitatively and qualitatively INE, 2017 (Fig. 8).

Table 5
Classification accuracy - QNP (1979–2017).

LULC Category/Classes	1979 (%)		1989 (%)		1999 (%)		2009 (%)		2017 (%)	
	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
Vegetated	90.23	76.22	92.04	98.12	96.97	88.76	87.50	86.42	84.02	90.26
Human Settlements			95.49	82.40	90.77	91.15	90.63	79.18	96.86	91.50
Non-Vegetated					81.37	90.54	87.50	90.71	80.66	77.73
Dry Vegetation	84.60	94.05								
Overall Accuracy	86.55		93.01		90.07		86.42		86.95	
Kappa Statistic	71.84		83.49		85.03		79.57		80.24	
Quantity Disagree %	6.49		4.45		3.12		4.20		2.84	
Allocation Disagree %	6.90		2.55		6.79		9.36		10.19	
95% Conf. Interval-	88.55		94.21		91.54		88.08		88.64	

Table 6
Classification accuracy — outside QNP (1999 and 2017).

LULC Category/Classes	1999 (%)		2017 (%)	
	Producer's	User's	Producer's	User's
Vegetated	92.92	97.72	89.17	95.05
Human Settlements	91.19	93.54	90.90	73.91
Non-Vegetated	86.86	59.50	84.58	78.98
Overall Accuracy	92.18		88.61	
Kappa Statistic	78.57		76.96	
Quantity Disagree %	4.20		4.29	
Allocation Disagree %	3.60		7.08	
95% Conf. Interval-	93.57		90.31	

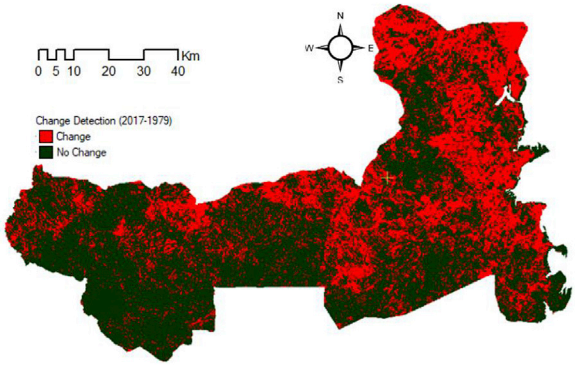

Fig. 3. Change detection (2017–1979).

The needs by the land use are preferential in the North and East (close to coastal region), as well as inside of QNP and buffer zone. The verified human settlements are associated with the lands occupied by private dwellings, public and private facilities. Non-vegetated land are associated with agricultural, abandoned and deforested land.

The Non-vegetated land category has been growing since 1980, slightly proportional to the emergence of human settlements (Fig. 5). These may have natural and anthropogenic causes. In Most of the region, non-vegetated lands had anthropogenic issues, highlighted by the need of land for agriculture practice, coal production, infrastructures, private and public business, wood needs for small and medium scale commerce. In The west and south regions, non-vegetated land is related with natural factors, such as dry and hard or rocky land and rainfall frequency.

The great and direct dependence on forest and ecosystem services, the economic income that the forest resources provides around the Quirimbas National Park, including through the strong actions of exploitation of artisanal mining resources practiced by local communities, small illegal companies combined with the emergence of companies that look for natural and mineral resources inside of QNP and buffer zone are considered the main causes of the vegetation loss in Quirimbas National Park.

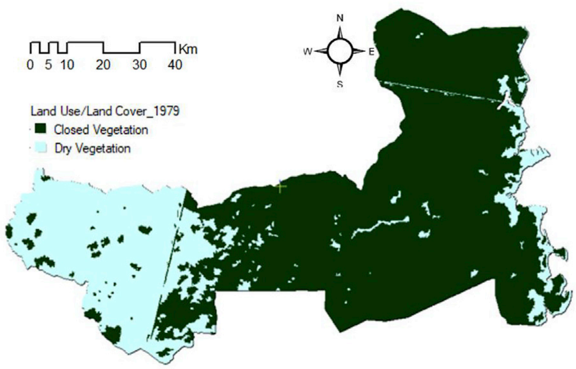

Fig. 4. Land use and land cover for 1979.

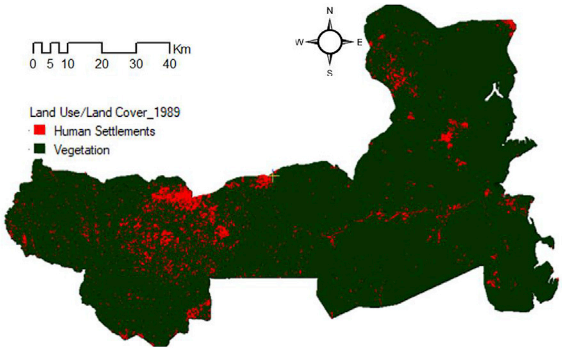

Fig. 5. Land use and land cover for 1989.

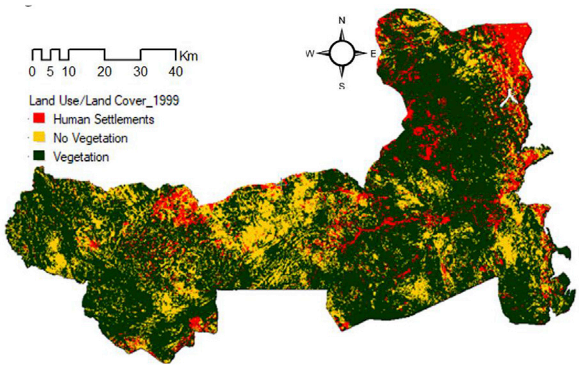

Fig. 6. Land use and land cover for 1999.

3.3. *Quirimbas National Park: social and environmental dynamics*

The study shows that in 1979, QNP had an estimated vegetated land area of about 723,907.1 (ha), representing approximately 100% of the coverage. In 1989, it lost about 5.7% of the vegetation, the area which was occupied by human settlements. In 1999, it had 493,971.7 (ha), reducing vegetation coverage by 31.75%. In this case, areas occupied by human settlements represented about 9.71% of the loss and 22.04% became non-vegetated areas (Table 7, Fig. 9).

In 2009, human settlements grew by 12.40%, and non-vegetated land increased to 24.61%. On that year, the vegetation had an area equal to 455,870.3 (ha), representing a vegetation decrease of 37%. INE, 2017, QNP, presented a vegetated area equal to 422,145.4 (ha), non-vegetated land equal to 200,499.3 (ha), and 101,260.6 (ha) of human settlements. However, the vegetation decreased by 41.67%, with 27.69% attributed to non-vegetated lands and 13.98% to the human settlements (Table 7, Fig. 9).

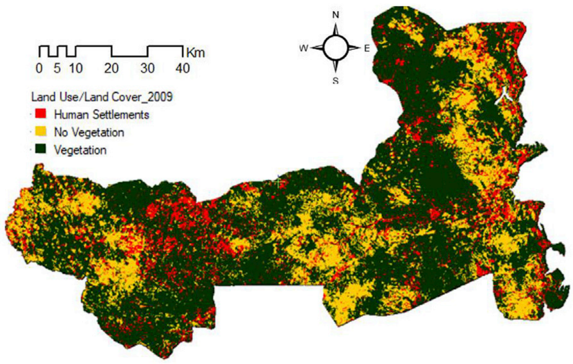

Fig. 7. Land use and land cover for 2009.

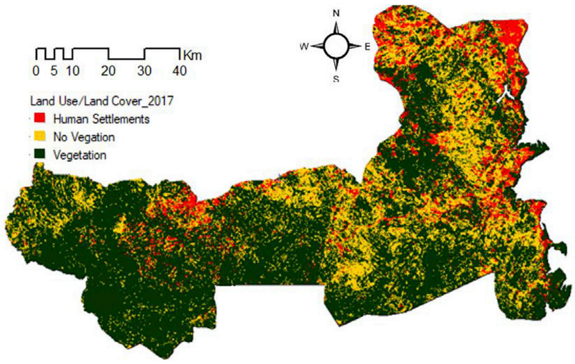

Fig. 8. Land use and land cover for 2017.

Table 7
Land cover changes – QNP (1979–2017).

Categories	1979		1989		1999		2009		2017	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Vegetated/Forest Land	723,907.1	100	682,616.1	94.29	493,971.7	68.23	455,870.3	62.97	422,145.4	58.31
Non-Vegetated Land	0	0	0	0	159,573	22.04	178,205.7	24.61	200,499.3	27.69
Human Settlements Land	0	0	41,289.91	5.70	70,360.74	9.71	89,829.63	12.40	101,260.6	13.98
Total	723,907.1	100%	723,906	99.99%	723,905.4	99.98%	723,905.7	99.97%	723,905.3	99.88%

Rapid growth rates were found in the non-vegetated land category, growing to 159,573 (ha), from 1989 to 1999. The human settlements also showed a rapid growth rate, reaching 41,289.91 (ha) in 1989.

Non-vegetated lands are a category that, from 1999, showed a significant increase in occupied area. Human settlements grew proportionally to the non-vegetated lands. Despite the considerable decline in vegetation year after year, the human settlements showed a non-linear decreasing growth tendency. From 1989 to 1999, human settlements obtained a growth rate of 4.01%, and from 1999 to 2009, that rate was equal to 2.69%, and from 2009 to 2017, equal to 1.58%.

Also, comparing the periods between 1979 and 2017, we verified that the vegetation was drastically reduced from 1989 to 1999, with a rate equal to 25.96%. The range where the vegetation suffered the slightest reduction was between 2009 and 2017, losing about 4.66%. Overall, Quirimbas National Park lost every 10 years approximately 10.42% of the vegetated lands, corresponding to 74.431,1 (ha), and the vegetation has not recovered over the years.

The districts that are part of the QNP have grown significantly. The population of the Quissanga district increased from 34,328 habs in 1997 to 50,174habs INE, 2017, increasing 31.1% over the last twenty-one years. In the Macomia district in 1997 the population was 69,973 habs, having increased in 39.9% by 2017, its current population being equal to 116,405 habs. In the Ancuabe district, data indicate that the population in 1997 was 87,243 habs, reaching about 164,114 habs INE, 2017, showing a 46.9% growth. The population of the Metuge district in 1997 was 42,935 habs, and INE, 2017, it was equal to 89,122 habs, having grown by 46.9%. The district of Montepuez in 1997 had a population equal to 147,181 habs, growing to 261,535 habs INE, 2017, showing a growth of about 51.9%. The district of Meluco had, in 1997, a registered population of 23,912 habs, increasing 35,6% by 2017, when its population was of 37,130 habs (INE, 2017).

The population increased significantly, and If we consider that the districts partially inserted in the terrestrial site of the Quirimbas National Park (Montepuez, Macomia, Ancuabe, Pemba-Metuge, Meluco) represent the minimum of 10% of the resident population inside the Park, plus 100% of the Quissanga district, then currently, QNP has about 117,000 habs. The

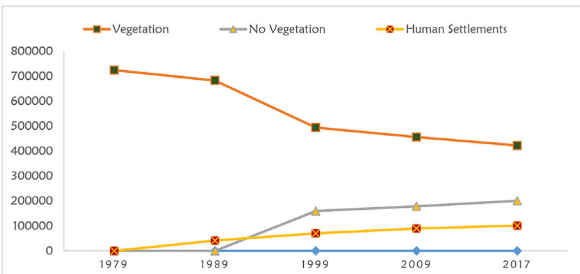

Fig. 9. Land cover changes – QNP (1979–2017).

movement and land occupation, in the QNP, has been happening in an unregulated and uncontrolled way. The key factor for the land choice by communities is the existence of basic conditions and resources (rivers, natural wells, food, suitable land for agriculture, easy access roads, close to local marketing centers, hospitals, schools).

As the population grows, the clusters are becoming evident, as the rural populations tend to move away from the greater concentration. This mobility obviously requires the choice of a new land for construction, agricultural practice, forest resources collection for coal production and domestic materials (Fig. 10).

The abandonment of non-productive agricultural land, usually caused by insufficient water and low levels of precipitation, is frequent. Every year, hundreds of families abandon their lands, migrating to other regions with typical conditions for practicing agriculture. Use of fire to clean lands and the process of deforestation has been regularly and intensively adopted by the communities inside Quirimbas National Park.

The remnant of vegetation and the maintenance of ecological services and functional processes engaged in a natural biodiversity protection perspective poses challenges for the public private sectors and community managers.

Nevertheless, if assertive management measures are introduced, Quirimbas National Park can prevent further forest destruction and increase the vegetated land in more than 100,000 (ha). However, if appropriate measures are not taken, QNP will gradually go from a natural ecosystem to a modified ecosystem with a high level of degradation.

3.4. LULC impacts for biodiversity, community, and habitats

According to the fieldwork and the analysis of satellite images, it is clear that the geospatial dynamics that have occurred in the last 38 years in the Quirimbas National Park have brought profound changes and transformations in the human populations organization, to the quality, and amount of landscape available for habitat protection, species perpetuation and conservation of local biodiversity, particularly in the Quissanga district, in the area towards the Meluco district, and north of Quirimbas National Park (Macomia district - Mucojo), as well as close to the south of QNP (Ancuabe and Metuge district) (Fig. 10).

Based on the fieldwork survey, the natural resources available for the community's livelihoods are increasingly far away from the village settlements. The water quality and availability are a concern that has become more pronounced in the last 10 years.

Rivers and water resources sources have reduced their support capacity, being dry most of the year, mainly the Messano and Montepuez river that crosses the Quirimbas National Park.

Uncovered lands, caused by numerous anthropogenic actions, condition the processes of vegetation species recolonization, as well as the connectivity process of important areas to biodiversity safeguard (mainly from Mucojo to Bilibiza). They interfere in the species mobility, specifically the animals that need slightly bigger land for survival. The scaring of large animals, and systematic accidents grew considerably in the last 12 years. Conflicts between humans and animals were more reported, due to the sharing of resources, whose availability and quality resource reduced.

Currently, the communities living inside of the Quirimbas National Parks found that sightings of emblematic animals, such as elephants, lions, leopards, hyenas, have reduced significantly compared to 9 years ago. These animals have reduced in numbers and distributed in a fragmented way.

Based on QNP staff and community leaders, the mobility of the populations inside of the QNP, associated to the discovery of new lands, created opportunities for deforestation and slaughter of animal species through the hunting of medium-sized animals (eg herbivores, rodents) for commerce and food.

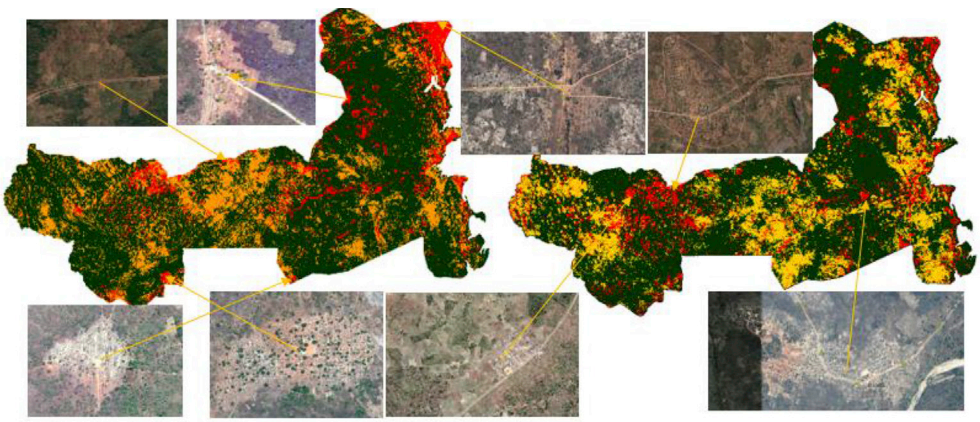

Fig. 10. Different types of LULC -QNP.

4. Discussion

4.1. Classification accuracy assessment

According to the results presented (Tables 5 and 6), the classification was statistically significant. According to Lands & Koch (1977) Kappa values = 20% (poor rating); 20% < Kappa = 40% (reasonable rating); 40% < Kappa = 60% (good rating), 60% < Kappa = 80% (very good rating), Kappa = 80% (excellent rating) (Park and Harari, 2005; Jia and Richards, 2006). In this study, Kappa coefficient was used as an accuracy measure of the LULC map of the Quirimbas National Park (Hudson and Ramm, 1987; Congalton and Green, 1999). Authors Lunetta and Lyon (2004), understand that Kappa allows us to verify and test whether a given land use and land cover map generated from data and using remote sensing techniques and analyzes is very significant or not. Our Kappa for 1979 = 71.84% and Overall Accuracy = 86.55%; 1989 = 83.49% and Overall Accuracy = 93.01%; 1999 = 85.03% and Overall Accuracy = 90.07%; 2009 = 79.57% and Overall Accuracy = 86.42%; 2017 = 80.24% and Overall Accuracy = 86.95%, reveal that the accuracy presents a classification between very good and excellent.

It is our understanding that a better classification could be achieved. However, a set of additional procedures should be introduced, such as increasing the number of sample sizes collected for classification, to consider image quality and resolution, image size and shape, and additional information about the sensors.

4.2. LULC, impacts and social & environmental dynamics

On that research, three land cover changes categories were under analysis in the last 38 years. In 1979, only one category was detected (Fig. 4, Table 7). We understand that the non-detection of the two categories (human settlements and non-vegetated), was associated (1) the fact that the vegetated lands dominates and are distributed uniformly throughout the Quirimbas National Park, making it impossible to identify and collect sufficient ground samples for classification, (2) it is considered that the image quality and spatial resolution was a decisive factor, since it did not allow us to distinguish accurately the different objects types on the image. Image quality and resolution are discussed by the authors (Wang et al., 2006; Xia and Chen, 2015; Fisher et al., 2017; Fu et al., 2017), and findings clearly show that the differences are remarkable and significant between a high-resolution and low-resolution image, and that has an impact on the accuracy of the classification of land use (Fisher et al., 2017).

There was no record with clear evidence of the emergence of human settlements and non-vegetated lands before 1979. The research showed that the community's notable mobility and appearances of human settlements and non-vegetated lands in the Quirimbas National Park may have begun after 1979 (Fig. 5). It is likely that this mobility, until 1995, is motivated by the combination of several factors: historical and cultural, associated with colonial and civil wars, as well as traditional nomadism and socioeconomic needs.

figures (3)–(8) and (10) illustrate combinations of different forms and types of land use and landscape changes. The rapid growth of human settlements and non-vegetated land since 1989 (Fig. 5), gives evidence of how rural population growth and local needs are closely related to the exploitation of land and natural resources. However, it is not conclusive that the exponential population growth in the Quirimbas National Park, associated with the community's direct dependence on local natural resources, are the only promoters of the changes that have occurred from 1979 to 2017. Similar studies developed in Africa (Wingate et al., 2016; Mundia and Murayama, 2009; Padonou et al., 2017; Akinyemi, 2017) confirm that resources exploitation, agriculture, population growth, built-up, are considered the main carriers landscape change. However, we associate with the identified promoters the governmental fragility in the application of the biodiversity conservation and natural resources exploitation laws, control, monitoring and non-implementation of territorial planning and human settlements programs.

The vegetation reduced about 41.67%, in 38 years (Fig. 3, Table 7). Meanwhile, the population continues to grow year after year. This trend of human population growth and disorderly mobility inside Quirimbas National Park tends to put pressure on this ecosystem and direct QNP to unsustainable levels, with irreversible consequences.

The reports are incipient in Africa and elucidate similar cases. On that issue, it was not possible to identify any report carried out in conservation and protected areas that pointed to a drastic vegetation reduction of more than 40% throughout history. Similar cases have been widely reported by research conducted outside protected areas and urban centers (Käyhkö et al., 2011; Beuchle et al., 2015; Grecchi et al., 2014; Dewan and Yamaguchi, 2009). It is true that studies of land use and land cover carried out in conservation areas identify problems of deforestation, illegal land occupation, communities invasion, especially for the agricultural practice (Payés et al., 2013; Dimobe et al., 2015; Scharsich et al., 2017; Estes et al., 2012). However, when quantifying the impacts, the conclusions focus on reducing forests to a worrying state, but at sustainable levels and with lower deforestation rates (Scharsich et al., 2017).

We understand that we are likely to be facing an emerging case on the African continent, which should require a new paradigm of natural resource management, conflict resolution, community involvement and protected area management.

4.3. Mitigation and management strategy

According to our analysis and understanding, QNP has lost its status as Category II “National Park” according to the overall classification of protected areas proposed by IUCN (see Table 3). Dudley (2008), refer that National Parks are generally large-scale areas with the core goal to protect natural biodiversity, based on the ecologic structure and environmental processes, to promote environmental education, scientific, tourism, cultural development and process regulation. These areas are not intended to implement management systems to promote and guarantee the sustainable use and exploitation of natural resources by the communities. The presence of human population and settlements are discouraged. Buildings, public infrastructure constructions, people's movements with visible impact are not allowed, except for tourism and visitation proposal (Dudley, 2008).

The presence of huge numbers of villages, and accentuated territory fragmentation in the Quirimbas National Park do not give a guarantee that the current implemented model or strategy can succeed in continuing to protect biodiversity, landscape, and habitat.

In this section, we intend to discuss some alternatives that can be immediately discussed and implemented to reinforce and guarantee the continuity of forest or vegetation remnants, animal biodiversity, habitat and safeguard the local community's interests.

The rural community inside of the Quirimbas National Park has always depended on the resources that QNP provides. The community will continue to explore the QNP's resources, biodiversity will continue to decline, habitats will continue to fragment, and tourism may decline.

It is necessary to understand the dynamics and address the issue of natural resource management, biodiversity, habitat, from the perspective of sustainability and shared benefits.

The effective mitigation process should analyze and be based on the following assumptions:

(1) What alternatives is it possible to offer to the resident community inside of QNP, (2) What approach can ensure the effective participation of the community in the process of inclusive management of natural resources, (3) What solutions need to be explored to reduce deforestation? (4) What ecological possibilities must be tested to recover the fauna and habitat, (5), Which mechanisms exist to exploit tourism.

Given the scenarios, the identified problems, and the QNP's management system fragility, we proposed the following approaches:

a) **Community Education to Promote a Change in Behavior**: The community living inside QNP has not yet realized the concept of the national park, protected area, protection of natural resources, biodiversity and habitat. A concerted effort is needed and introducing sturdy programs of environmental education.

Implementing formal education there is a safe alternative, but also regular training, campaigns, systematic community activities, competitions, including the women's empowerment and family planning, can be fundamental to raising the awareness of rural communities.

b) **Resize/Re-dimensioning**: Assign new boundaries, excluding all possible villages and problematic regions that have contributed significantly to the landscape deterioration. If this is not possible (even knowing about future risks and the problems of that alternative), the number of villages should be limited for those located in sensitive regions of great ecological importance. During that process, a set of actions should be conducted, such as census of flora and fauna, precise identification of permanent and temporary sources of water, dambos, wetlands, identification of human settlements, accurate identification of animal corridors, human-animal conflict sites, areas prone to forest/vegetation illegal logging, agricultural regions, areas prone to poaching, socio-economic surveys of key communities within Quirimbas National Park, sites of economic interest for the local communities, main access routes. All this information must be considered.

The yellow areas on the maps (Figs. 6–8, 10) contain important information and should be considered useful for management, as we know they are abandoned or deforested areas, or areas that are disturbed by other anthropogenic actions that can be perfectly recovered with the local community's efforts.

c) **Re-categorize/Re-qualify**: Reclassification process means assigning another category to the Quirimbas National Park for an inclusive and sustainable management of natural resources, habitat protection, biodiversity, and more effective and better adjusted to the current scenario resource valorization. However, categories V or VI proposed by IUCN may be appropriate.

Another category, such as the Biosphere Reserve proposed by UNESCO, may be alternative, but, regarding this category, and in line with socio-economic conditions, ecosystem pressure, as well as regional characteristics, this category should only be implemented if effective management measures and proposed reforms are introduced.

d) **Natural Corridor/Compensation Area**: The study focuses on a territory connectivity perspective, to allow integrated and large-scale biodiversity management, prevent fragmentation and isolation of habitats, as well as serve as a refuge for species whose territory in QNP is threatened and that need slightly larger areas. More forest/vegetation destruction is expected soon in QNP if concrete actions are not directed. It is our understanding that the establishment of a compensation area or natural corridor equal to or greater than the total area destroyed in the Quirimbas National Park may be a functional alternative for species protection if all ecological and conservation aspects are safeguarded.

The selection of areas to be included in the natural corridor should be based on the following criteria:

1. Free or with a reduced number of human settlements;
2. It must allow perfect connectivity with the Quirimbas National Park and other conservation areas around;
3. Undisturbed vegetation and ecological conditions for species recovery and establishment;
4. Favorable habitats for conservation;
5. Sources of water;

The area required for this purpose is the link between Quirimbas National Park and, passing through the Nairoto and Mirate (Montepuez) up to the Niassa Hunting Block B.

To meet the criteria, a set of quick analyzes were developed using the Landsat 5 TM satellite imagery of 1999 and 2017 to verify if there were significant changes in the forest lands and human settlements over the past 12 years. An analysis involving Google Earth Pro 2018 was used to confirm and validate satellite imagery results and allowed us to observe in detail the proposed geographic region.

The results showed a significant area, equal to 388,390.05 (ha), larger than the total area destroyed in Quirimbas National Park. It presents a limited number of human settlements as shown in Fig. 11. The red clusters (Fig. 11) should not be truly

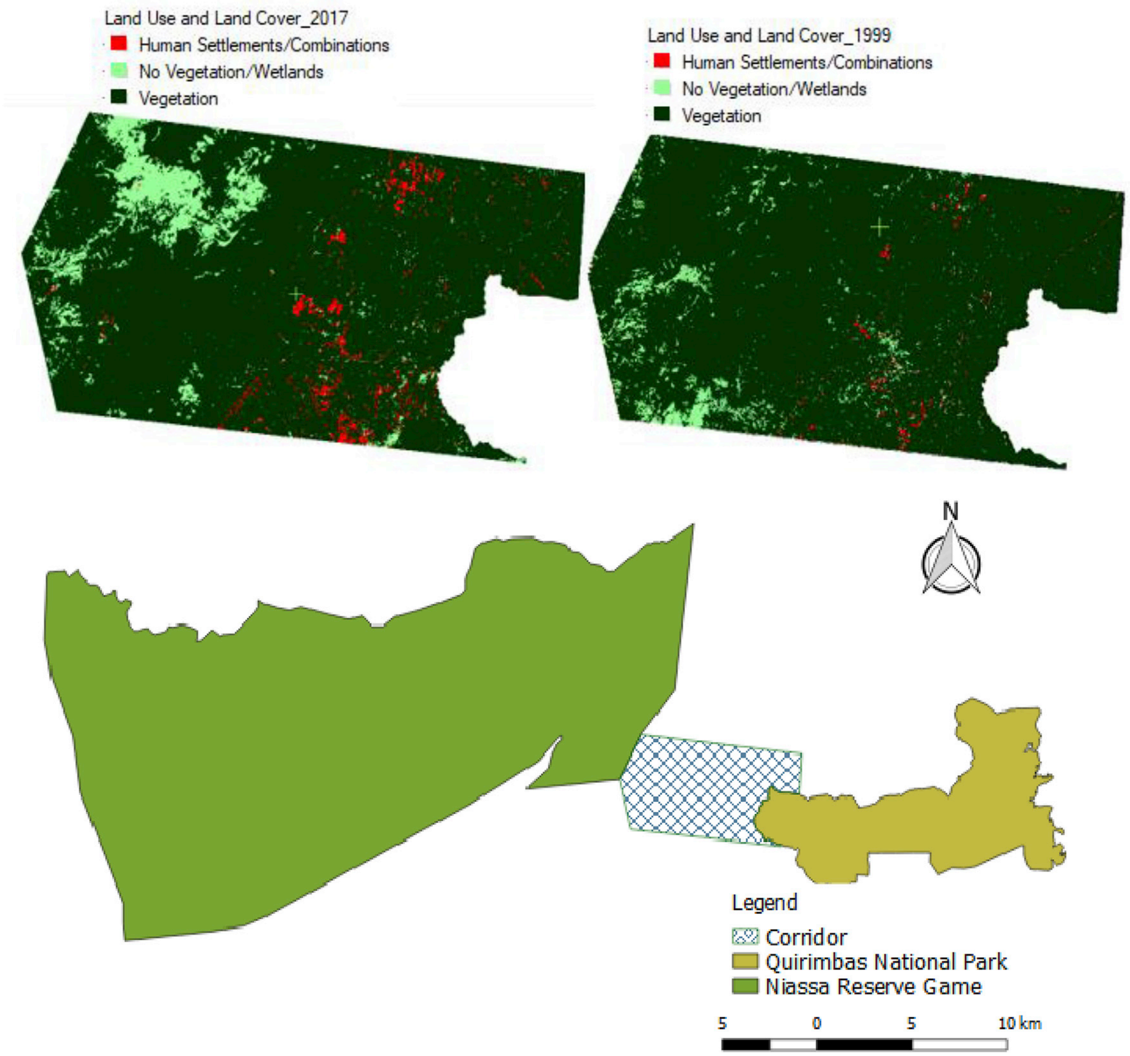

Fig. 11. Niassa and Quirimbas national park corridor.

considered as human's settlements but should be understood as combinations between cultivated areas, non-vegetated lands and abandoned lands, while light green clusters represent flooded areas and lands uncovered by natural processes.

The proposal should be complemented by precise baseline studies as well as multi-level analyzes such us political, economic, social, environmental and sustainability issues.

e) **Conservation Levels Approach**: Communities living inside the Quirimbas National Park cannot be neglected. They need and will need the natural resources for sustainability. However, it will be necessary to create levels of biodiversity protection and resources exploitation actions, based on:
   1. Level I - Exclusive and Fully Protected Zone
   2. Level II – Damping or Buffer Zone
   4. Level III - Zone of Use and Sustainable Exploration of Resources
f) **Conservation Management**: The management process for levels I, II should be the responsibility of the government. While level III should be fully managed by local communities. Government action will serve to regulate processes and oversee the programs and policies implementation.

5. Conclusion

According to the objectives and methodology proposed (remote sensing analysis, fieldwork, and literature review), this research provided a historical analysis of land use and land cover of the Quirimbas National Park useful to serve as a basis for future LULC analysis, as well as to guide the preparation of concrete local plans for the use and exploration of resources, area sustainability and the protection of forests and animals.

Quirimbas National Park has experienced unsustainable levels of threats and destruction of the territory, which hinder the management of natural resources and biodiversity conservation. On average, the results indicate that the Quirimbas National Park has lost around 10.42% of the vegetated lands every 10 years, corresponding to 74.431,1 (ha), and the vegetation has not recovered over the years. For 38 years, QNP has lost about 301,761.7 ha (ha) of vegetated lands. The main land change promoters are associated with the expansion of uncontrolled and disordered settlements, intensive agriculture, forest resources trade, uncontrolled fires, private and public infrastructures, trade and artisanal exploitation of mining resources. The impacts range from the fragmentation of the territory, isolation of habitats, reduction of native forest, death of animal species and conflicts. The recovery of the Quirimbas National Park and the reduction of deforestation levels should require a new paradigm for the management of natural resources, based on the re-dimensioning and re-qualification of the Park, creation of a compensation area or natural corridors, as well as the inclusive and community-centered management of natural resources.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2018.e00447.

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