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Land use/land cover patterns and challenges to sustainable management of the Mono transboundary biosphere reserve between Togo and Benin, West Africa

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ABSTRACT

The Mono Transboundary Biosphere Reserve (RBTM) has significant resources but faces many threats that lead to habitat fragmentation and reduction of ecosystem services. This study, based on satellite image analysis and processing, was carried out to establish the baseline of land cover and land use status and to analyze their dynamics over the period 1986 to 2015. The baseline of land cover established six categories of land use including wetlands (45.11%), mosaic crops/fallow (25.99%), savannas (17.04%), plantation (5.50%), agglomeration/bare soil (4.38%) and dense forest (1.98%). The analysis of land use dynamics showed a regression for wetlands (-23%), savannas (-16.06%) and dense forest (-7.60%). On the contrary, occupations such as mosaic crops/fallow land, urban agglomerations/bare soil and plantation increase in area estimated at respectively 128.64%, 93.94% and 45.23%. These results are of interest to stakeholders who assess decisions affecting the use of natural resources and provide environmental information essential for applications ranging from land-use planning, forest cover monitoring and the production of environmental statistics.

Keywords: Land use, baseline, spatial dynamics, environmental statistics, ecological monitoring.

INTRDUCTION

In recent decades, sub-Saharan Africa has experienced major environmental problems, including deforestation reflecting the conversion of forest to non-forest lands. Vegetation cover conversions and changes in land use patterns are identified as the major drivers of global environmental change (Minta et al., 2018; Zoungrana et al., 2018). These conversions, including changes of forest and /

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or woodlands to agricultural lands, have negative effects on climate, terrestrial carbon stores, and loss of biodiversity (Muriuki et al., 2011; Dube and Mutanga, 2015; Sibanda et al., 2018). They also result in the fragmentation of wildlife habitats and disruption of ecological and hydrological processes (Liu et al., 2008). In other cases, conversions have resulted in increased land surface temperatures and soil erosion, decreased evaporation rates and precipitation, and changes in rainfall patterns (Bounoua et al., 2002).

These observations are true in areas of high population density marked by contrasting climatic conditions and high demand for arable land. These characteristics are observed in the Mono Transboundary Biosphere Reserve (RBTM) located in the Dahomey corridor on the southern border between Benin and Togo (Kokou et Sokpon, 2006). This area is rich in plant and animal resources associated with different multi-functional ecosystems (Kokou et Sokpon, 2006; Adjonou et al., 2017). These ecosystems are unique habitats in the heavily anthropized region and are the last refuge for different type of wildlife in the Guineo-Congolese zone sheltering species such as hippopotamus, buffalo, small antelopes, monkeys, reptiles threatened with extinction. For example the red-bellied monkey (*Cercopithecus erythrogaster erythrogaster* Gray) is endemic to the area (Hougbédji et al., 2012; Agbessi et al., 2017).

However, many factors threaten biodiversity within and around this reserve. These include the uncontrolled exploitation of forest resources, fragmentation of habitats, pollution and changes in climatic parameters (Avakoudjo et al., 2014; Kpedenou et al., 2016; Akobi et al., 2018). These factors put great pressure on the dynamics of land cover and land use. Considering and mastering these factors will allow the effective conservation of the RBTM ecosystems and associated biodiversity. Unfortunately, the RBTM ecosystems, their dynamics, habitats and land-use patterns in the area are poorly documented (Bouko et al., 2007). In addition, there is no reference situation based on scientific data in terms of land use on the reserve. This information is needed to ensure sustainable management of the RBTM.

In the RBTM landscape, studying the nature, extent, and structure of land conversions, allows understanding the changes in forest cover and their consequences to be evaluated in order to develop sustainable strategies for biodiversity conservation. Land cover dynamics and land use are essential inputs for establishing a reliable environmental database for applications ranging from the production of environmental statistics, monitoring of forest cover, identification of biodiversity conservation sites, assessment of land degradation index and modeling of spatial dynamics for making future projections (Oloukoi et al., 2006; Bouko et al., 2007; Padonou et al., 2017). Based on remote sensing technologies and satellite data coupled with field investigations, this paper is aimed at: (i) establishing a land cover and a land use baseline for the RTBM, and (ii) analyzing the dynamics of land-use patterns in the period 1986 to 2015 in this area allowing to evaluate different trends in the evolution of the natural landscape.

MATERIALS AND METHODS

Study area

The RTBM is located on land at the southern border between Benin and Togo. It is located between 6 ° 8 '52.8 "and 7 ° 3' 41.8" North latitude and between 1 ° 24 '18.2 "and 1 ° 30' 0.0" East longitude (Figure 1) and covers 345.22 km². The reserve is located in the dry dahomey corridor characterized by mosaics of dense semi-deciduous forests, guinean savannas, marshy meadows, marshes, mangroves and water plans, crops and fallows mosaics in the Dahomey Gap (Kokou et Sokpon, 2006).

According to the Köppen-Gieger, climate classification system, the RTBM is characterized by a humid tropical climate with a succession of four seasons per year, two dry seasons the first from November to March and the second from July to September and two rainy seasons from March to July and from September to November. Annual rainfall varies between 850 mm and 1250 mm with a monthly average maximum of about 222.57 mm during the long rainy season and 88.30 mm during the short rainy season (October). The average maximum temperature is 31.25 °C between December and April, and the minimum temperature is 28 °C between July and September.

One of the ecological peculiarities of the area is the meeting of different ecosystems, marine, terrestrial and lagoonal. The Mono River is the main river around which the reserve is built. Topographically, the Mono River cuts through the Continental Terminal geological Formation and flows into a wide alluvial valley. Because of the diminishing slope of the river bed, (0.06 to 0.4 m/km), the Mono describes large meanders through flood plains before joining the lagoon system near the coast. The littoral part of the reserve consists of two low sandbanks separating the sea from the mainland.

Regarding the cultural and social aspects, the area shelters a population of about two million inhabitants about 80% of which live on small-scale farming, small-scale fishing and the exploitation of wood and charcoal, and so depend largely on the provision of ecosystem services to the surrounding areas (World Bank, 2017). This area with a high population density, resulting from different waves of migration, is characterized by ethnic and cultural tensions that are reinforced by the poverty of the region.

Methodological steps

Data sources

Two data sources were used to establish the MTBR baseline and the analysis of land-use unit dynamics. These include two Landsat satellite images (TM (1986) and ETM + (2000)) and a Sentinel 2A satellite image (2015 is considered the reference year). The scenes were chosen during the dry season when cloud cover is reduced to a minimum because of phenological phase variations of vegetation (Clerici et al., 2007). Satellite images have also been used with cartographic data consisting of a georeferenced digital layers of Togo and Benin mainly comprising roads, administrative units and localities in both countries. GPS data from the field and Google Earth Pro were also used to complete the information.

Data processing and analysis

Satellite image processing

- Several steps were followed during the processing of satellite images (Figure 2): **Pre-treatment of images:** Firstly, the radiometric correction of Landsat TM, ETM + and Sentinel 2A images was used to correct any atmospheric bias and to change from a pixel value to a digital count as a reflectance value. This operation is completed by mosaicing the two Sentinel 2A image scenes to obtain a single scene that can be used to extract the study area more easily;
- **Color composites:** after several combinations, the color composition of bands 4-5-7 was chosen for the TM and ETM + images and the 4-3-2 bands for the Sentinel 2A image, because it presents the best discriminations of land cover types (Sarr, 2009). This operation is completed by selecting training sites. This involved identifying and delineating about 100 plots representing all types of land cover on the TM and ETM + color compositions of the 4-5-7 bands and the 4-3-2 bands of the Sentinel 2A image. These sites were chosen according to their spatial distribution;
- **Classification and accuracy assessment:** it consisted in transforming the images into a thematic map. The spectral properties were used to classify the different objects of the image into thematic classes. To do this, the

supervised classification was adopted (due to a good knowledge of the study area) using the maximum likelihood algorithm that was used for the 1986, 2000 and 2015 images from the colored composition chosen for this purpose. Finally, the accuracy of the classifications obtained was evaluated using a confusion matrix or contingency table obtained from field truth data (collected using GPS) and a representative of each occupation class. soil class;

- **Validation of the classification:** two classification validation indices were calculated; this includes the overall accuracy (characterizes the proportion of well-ranked pixels, calculated as a percentage and the Kappa index (characterizes the ratio between the well-ranked pixels and the total pixels surveyed (Skupinski et al., 2009). In addition to these indices, the field truth data were used for validation.

Dynamics of land cover and land use analysis

In order to better characterize the dynamics of land use and the transitions between the different thematic classes from one year to the next, a quantitative analysis was carried out. Through a post-classification comparison, the quantitative analysis of changes over the study period was carried out to identify the different changes in land cover and land use classes. It produces a change detection matrix resulting from the comparison between the pixels of the classifications between two dates (Girard et Girard, 1999). This analysis is done by calculating the rate of change (Rc) commonly used in land-use change studies (FAO, 1996; Achard et al., 2002).

This rate is evaluated using the following formula: **Rc = [(S2 / S1)1/d - 1] x 100** (*where: Rc = rate of change (%) ;* ***S1*** *= area of the class on the date d1 ;* ***S2*** *= area of the class on the date d2 (d2 > d1) et* ***d*** *= number of years between the two dates*). Positive values indicate "progression" and negative values "regression". Values close to zero indicate that the class is relatively "stable".

The average annual rate of forest degradation (Kamungandu, 2009) is evaluated from the formula: ARD **= (S2/S1)/d x100** (*where: ARD = average annual rate of degradation (%);* ***S2*** *= Total area of lost forest ;* ***S1*** *= Initial area of forest and* ***d*** *= number of years between the two dates*).

The development of the transition matrix made it possible to highlight in a condensed way the different forms of conversion undergone by the units of soil occupation between two dates d1 and d2, and to describe the changes that occurred (Schlaepfer et al., 2002). It is obtained by superposing the land use maps of 1986, 2000 and 2015, made possible by the "Intersect polygons" algorithm of the Geoprocessing extension under ArcGIS 10.0.

The analysis of the evolution of the trajectories of changes in the units of occupation of the soil is based on three main scenarios. These are "modifications" and "conversions" of the units that oppose "unchanged" situations. "Modification", means the changes occurring within the same category of land use, for example shrub savannas which becomes shrub steppe or vice versa. Whereas "conversion" is the transition from one category to another, for example forest lands to cultivated areas. The term "unchanged" refers to all classes that remained in the same class between the two dates of the study, that is, not affected by the conversions.

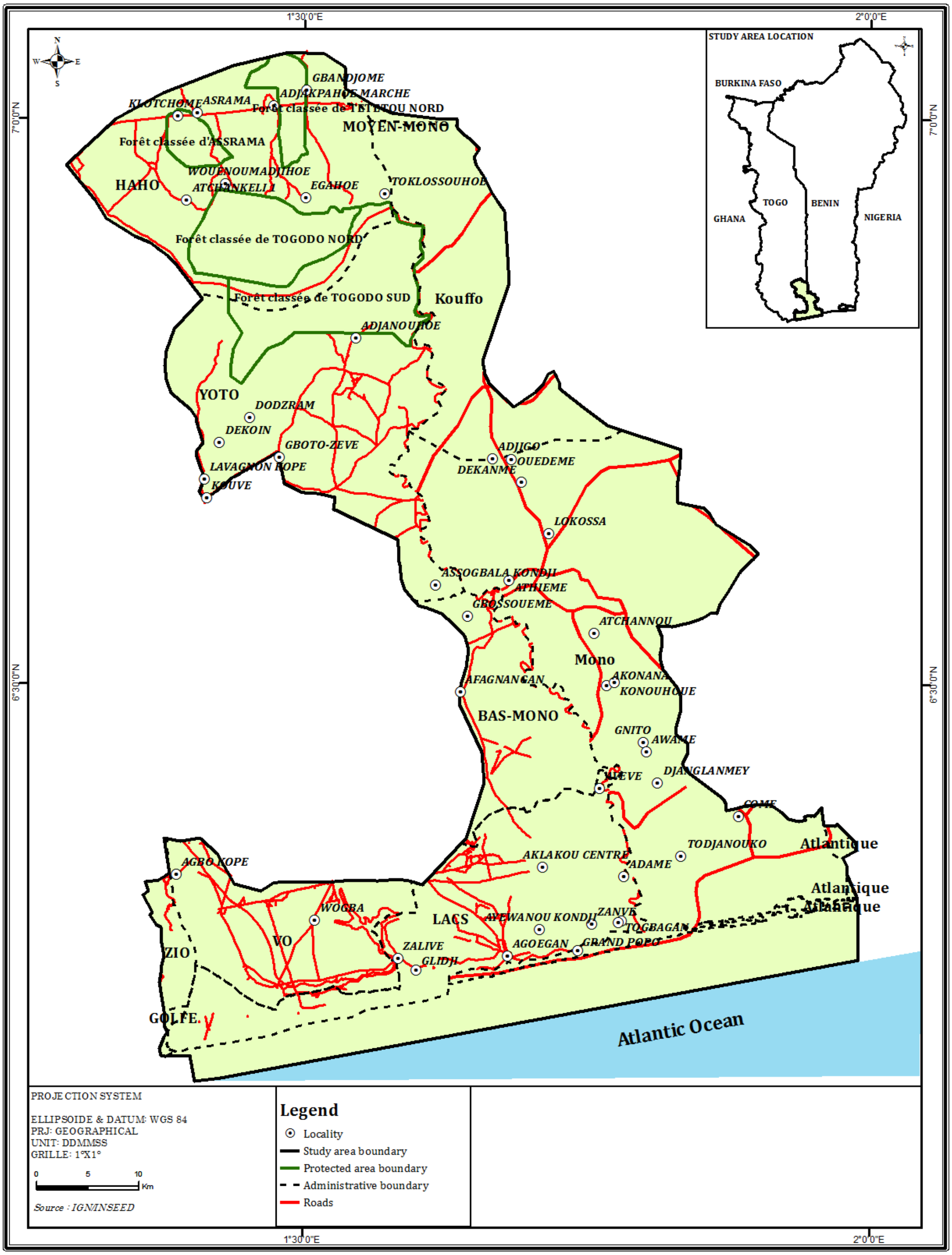

Figure 1: Location of the Mono Transboundary Biosphere Reserve.

RESULTS

Land cover in the Mono transboundary biosphere reserve: baseline in 2015

The results of the processing of Sentinel 2A satellite images for year 2015 to establish the baseline situation of the Mono Transboundary Biosphere Reserve (MTBR) are obtained with an overall accuracy of 89.84% and an estimated Kappa index at 0.88. Thus, six (06) main units of land cover are defined. These include (Table 1, Figure 2):

- **Closed forest :** they are composed of dense semi-deciduous forests, dry dense forests, open forests and forest galleries covering 6 835 ha (1.98%); these forests are in the form of fragmented islands dispersed in the reserve and the most important fragments in terms of surface area are observed in the Togodo protected area complex in Togo; the forest galleries identified sometimes appear very dense but narrow on both banks of rivers, notably the forest gallery along the Mono river and the other riparian forests on the banks of other rivers;
- **Savannas:** these are tree and shrub savannas with a large proportion relatively well preserved in the Togodo protected area. They occupy 58 919 ha, i.e. 17.0% of the reserve;
- **Mosaic of crops and fallows:** they consist of areas of crops and areas previously cultivated and abandoned or invaded by exogenous species. These mosaic of crops and fallows are found throughout the area and occupy 89 848 ha representing 25.99% of the reserve;
- **Wetlands:** the wetlands include mangroves, floodplain savannas dominated by *Mitragyna inermis*, marshy meadows and bodies of water. They are located in Togo in the Lama, Mono, Haho, Zio floodplains in Togo and in the Mono, Ouémé, Couffo and Zou depressions in Benin. The vast majority of wetlands and their associated plant communities are located in the southern half of the reserve and cover 155 944 ha or 45.11% of the reserve; Within these wetlands, mangroves that constitute particular ecosystems occupy 83 ha (0.02% of reserve);
- **Plantations:** these are forest tree plantations of teak (*Tectona grandis*), *Khaya senegalensis* and *Eucalyptus* sp., palm (*Elaeis guinensis*) and coconut (*Cocos nucifera*). These plantations cover 19 028 ha (5.50%); forest plantations are plots of variable size (1 ha to a few 2 ha) scattered throughout the reserve. Regarding palm plantations, their cultivation is much practiced in this area and they sometimes occupy large areas approaching hundreds of hectares, like the industrial palm plantation located near Lokossa in Benin and the palm plantation around Kouvé in Togo. Coconut plantations are found mainly in the southern part of the reserve along the coastline in both Togo and Benin;
- **Urban agglomerations and bare soil:** this unit includes towns, villages and areas with very low vegetation cover, including quarries (sand and gravel) and rocky outcrops. Densely populated urban agglomerations, are concentrated in the southern part of the reserve along the coast. Some big villages are found in the center of the reserve. They occupy 15 148 ha or 4.38% of the reserve.

Spatio-temporal dynamics of land cover in the reserve between 1986 and 2015

The evolution of the land cover units in the MTBR is established by the superposition of the maps of three different dates namely 1986, 2000 and 2015 and their respective statistics. Crossing this information shows that the area has undergone significant changes in land use over the 30- year period considered (Table 2, Figure 3).

- Closed forest and savannas showed declines in areas between 1986 and 2015, from respectively 7661 ha to 6835 ha (representing a regression rate of 7.61%) and 72 695 ha to 58 919 ha (a regression of 16.06%). The regressive dynamics observed with these two types of land cover is explained by the different forms of anthropic pressure that they have undergone in recent years;

- Wetlands including mangroves, marshy meadows and floodplain savannas have shown the highest rates of regression. They decreased respectively from 1 234 ha in 1986 to 83 ha in 2015, a regression rate of 93% for mangrove ecosystems, from 63 149 ha in 1986 to 6 766 ha in 2015, a regression from 88.90% for swampy grasslands and from 127 454 ha in 1986 to 105 233 ha in 2015, representing a 14.49% regression for flooded savannas. Contrary to this regression dynamics, water plans showed a change in their occupancy from 11 217 ha to 43 862 ha, an increase of 304.97% between 1986 and 2015;
- Zones with low vegetation cover (mosaics of crops and fallows, urban agglomeration/ bare soil) have indicated an increase in their area in different proportions. It can be deduced that the reserve undergoes an anthropization with an increase in cultivated areas at the rate of 128.64% and urban agglomeration/ bare soil areas at the rate of 94.93%. The increase in the area of plantations in the reserve (from 13 569 ha in 1986 to 19 028 ha or 45.23%) is mainly linked to the various reforestation initiatives carried out by different actors such as NGOs /Associations and the ministry in charge of forests but especially the enthusiasm of the people of this region about the restoration of vegetation cover and the need to meet the demand for wood products.

Trajectories of changes in land cover of the reserve between 1986 and 2015

Superposition of two land cover maps of the RBTM in particular from 1986 to 2000 and from 2000 to 2015 gives a matrix that reflects the evolution of the trajectories of the different classes between the two dates considered.

Changes between 1986 and 2000

The matrix of changes in land cover-land use shows that 4351.41 ha (56.80%) of forest (estimated at 7661 ha in 1986) do not undergo noticeable change during the period 1986 to 2000. Of these forest areas, about 3,309.59 ha have been converted to other land uses, of which 293.13 ha are mosaic crops and fallows, and 119.97 ha are part of an urban agglomeration or bare soil (Table 3). Over the same period, 86,373.36 ha of a wetland area of 203,054 ha in 1986 (42.54%) remained unchanged, while 116,680.64 ha have changed occupancy categories. Forest plantations retained 4801.14 ha (35.38%) of their area, while 8 767.86 ha changed categories between 1986 and 2000.

Overall, as shown by the change data for the period 1986 to 2000, 49.26% of the reserve has not undergone major change, which corresponds to 170 293.86 ha out of 345 722 ha. The remaining area of 175,428.14 ha (50.74%) has undergone changes in occupancy categories. These changes are related to modifications in land use or to conversions to other forms of land use. The changes have mainly occurred in wetlands, particularly between floodplain savannas with *M. inermis*, marshy meadows and water plans. Of all the forms of land use in the reserve, high rates of change have occurred in mangroves (86.9%), closed forests (76.28%) and water plans (71.2%). On the other hand, the lowest rate of change is observed in forest plantations with 1.47%.

Changes between 2000 and 2015

The superposition of land cover maps from 2000 to 2015 indicates that 3131.01 ha of closed forest remained without major changes, while in the savannas, the area without changes over the same period is estimated at 20,812.59 ha. For these forests, it is noted that a large area is converted to other forms of land use, especially urban agglomerations and bare soil (Table 4). Thus, 3,992.04 ha of closed forest and 20,897.55 ha of savannas are converted to inhabited areas or areas devoid of vegetation such as bare soil. Similary, with these two forms of land use, an estimated 7,526.43 ha is converted to crop lands and fallows.

With regard to wetlands, it is noted that 49,724.01 ha are conserved without major change during the period 2000 to 2015. For these types of land use, a trend towards urbanization is also observed. As a result, an estimated 14,242.59 ha is converted to inhabited area and bare soil.

It is noted that the highest rates of change are recorded respectively in inhabited areas and bare soil (91.40%), wetlands (89.55% for marshy meadow, 89.45% for flooded savannahs with *M. inermis),* plantations (73.78%) and closed forest (72.49%). Water plans are the least affected land cover and the rate of change is estimated at 3.49% (Table 4).

Table 1: Land cover in the Mono Transboundary Biosphere Reserve in 2015.

Class of land cover/land use		**Area (Ha)**	**Percentage (%)**
Closed forest (semi-deciduous dense forest, dry dense forest, open forest and forest gallery)		6 835	1.98
Savannahs		58 919	17.04
Mosaic of crops/fallows		89 848	25.99
Wetlands	Floodplain savannas with *Mitragyna inermis*	105 233	30.44
	Marshy meadow	6 766	1.96
	Mangroves	83	0.02
	Water plan	43 862	12.69
Plantations		19 028	5.50
Urban agglomerations/bare soil		15 148	4.38

Table 2: Variation in areas of land cover units in the reserve between 1986 and 2015.

Classe d'occupation		**Area in 1986 (Ha)**	**Area in 2015 (Ha)**	**Variation of areas between 1986 - 2015 (Ha)**	**Rate of change between 1986-2015 (%)**
Closed forest		7 661	6 835	-8.26	-7.61
Savannas		72 695	58 919	-137.76	-16.06
Mosaic of crops/fallows		40 696	89 848	491.51	**128.64**
Wetlands	Floodplain savanna with *Mitragyna inermis*	127 454	105 233	-222.21	-14.49
	Marshy meadow	63 149	6 766	-563.83	**-88.90**
	Mangrove	1 234	83	-11.50	**-93.00**
	Water plan	11 217	43 862	326.45	**304.97**
Plantations		13 569	19 028	5459	**45.23**
Urban agglomeration/ bare soil		8 048	15 148	71.01	**94.93**

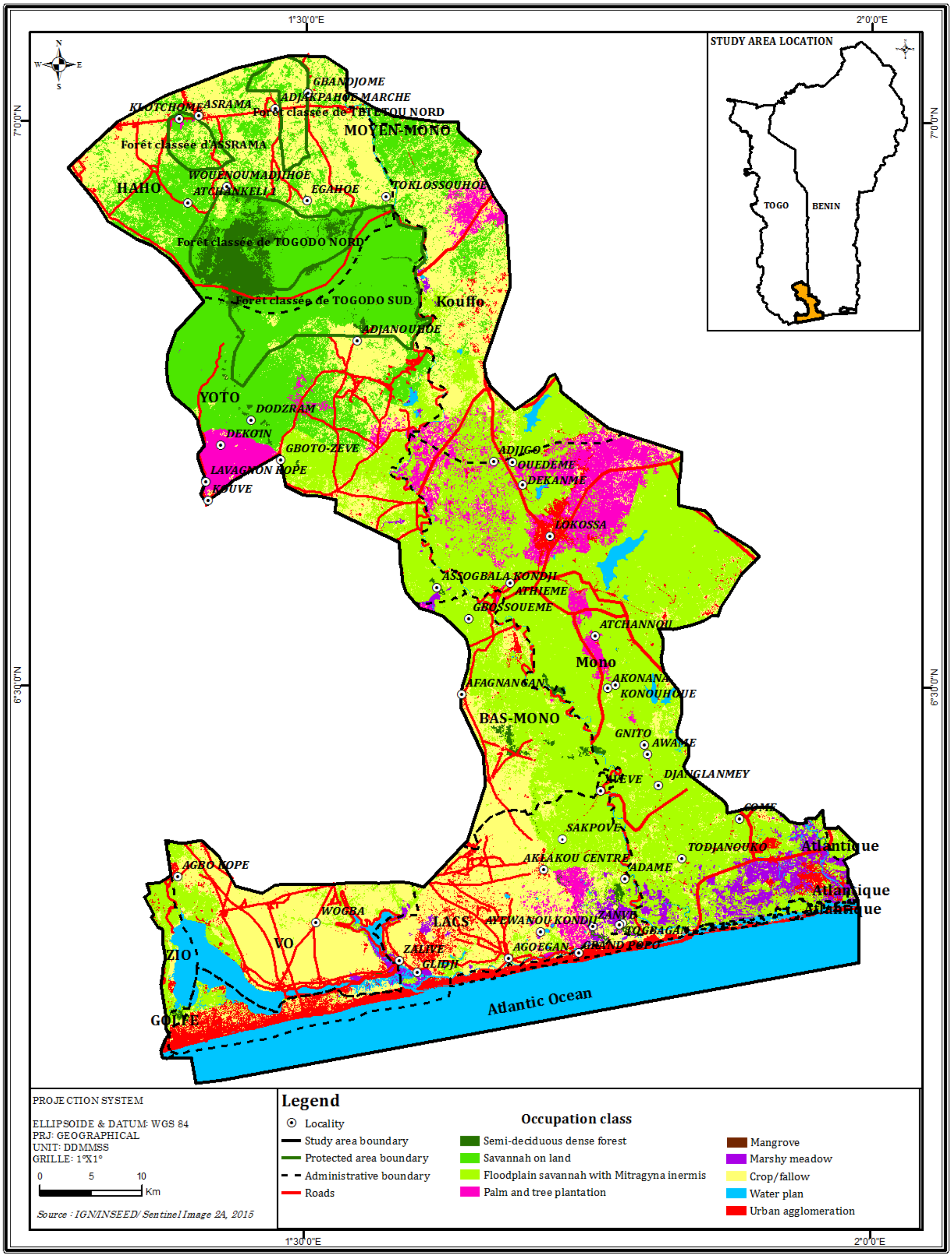

Figure 2: Reference situation of land cover/land use in the Mono Transboundary Biosphere Reserve in 2015.

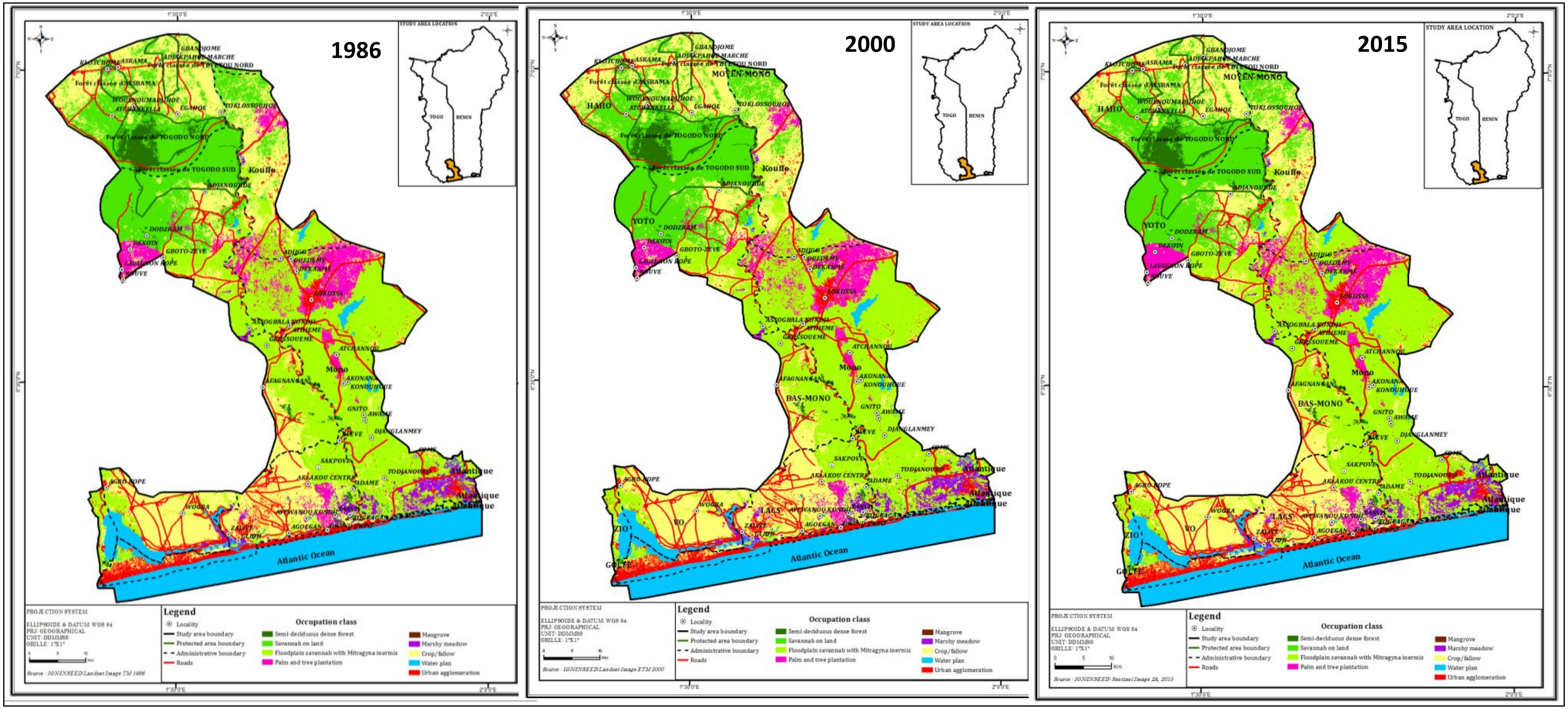

Figure 3: Dynamic of land cover/land use in the Mono Transboundary Biosphere Reserve from 1986 to 2015.

Table 3: Land occupancy changes matrix from 1986 to 2000.

1986 \ 2000	Closed forest	Savannas	Mosaic of crops/ fallows	Floodplain savannas with *M. inermis*	Marshy meadow	Mangrove	Water plan	Plantation	Urban agglomeration / bare soil
Closed forest	**4351.41**	762.21	293.13	4416.21	378.18	598.95	1.53	463.14	119.97
Savannas	3099.33	**37075.95**	7333.92	9052.02	5544.54	210.42	8.64	1132.29	1841.85
Mosaic of crops/ fallows	1767.69	4108.59	**28390.32**	7802.28	908.1	95.76	2.07	3307.32	5591.52
Floodplain savanna with *M. inermis*	3680.46	1384.11	2790.45	**39273.93**	1464.66	1201.86	305.64	4792.41	1081.35
Marshy meadow	809.01	3370.32	851.49	10028.07	**6321.15**	1179.54	36.27	16.29	1187.91
Mangrove	375.3	320.04	643.14	3205.62	503.37	**656.64**	5.94	230.85	428.13
Water plan	67.86	0.45	11.25	979.38	301.41	24.57	**40121.64**	4.14	401.67
Plantation	1450.08	516.87	3431.34	9458.55	358.92	339.48	0.09	**4801.14**	878.94
Urban agglomeration / bare soil	2745.81	5942.61	11284.65	33738.21	2241.18	414.18	239.22	1902.87	**9301.68**
Total classes (Km^2)	**18346.95**	**53481.15**	**55029.69**	**117954.27**	**18021.51**	**4721.4**	**40721.04**	**16650.45**	**20833.02**
Change in classes (Km^2)	**13995.54**	**16405.2**	**26639.37**	**78680.34**	**11700.36**	**4064.76**	**599.4**	**11849.31**	**11531.34**
Rate of change in classes (%)	**76.28**	**30.68**	**48.41**	**66.70**	**64.92**	**86.09**	**71.17**	**1.47**	**55.35**

Table 4: Land occupancy changes matrix from 2000 to 2015.

2015 / 2000	Closed forest	Savannas	Mosaic of crops/ fallows	Floodplain savanna with *M. inermis*	Marshy meadow	Mangrove	Water plan	Plantation	Urban agglomeration / bare soil
Closed forest	**3131.01**	2940.39	228.15	3745.8	775.71	300.96	83.16	543.69	3992.04
Savannas	3686.13	**20812.59**	7298.28	21321.0	6690.06	2027.07	174.69	6010.11	20897.55
Mosaic of crops/ fallows	457.02	1096.29	**35503.2**	5465.16	1989.0	928.62	25.11	6847.74	18413.91
Floodplain savanna with *M. inermis*	1799.28	11491.65	3402.9	**5903.19**	7322.22	1457.01	457.47	1240.92	8051.13
Marshy meadow	393.84	9608.04	256.68	1210.68	**2486.88**	162.18	248.13	31.23	695.07
Mangrove	1074.42	8335.53	2795.13	3187.17	3788.37	**886.14**	288.99	671.22	4914.90
Water plan	17.73	47.79	20.07	668.61	165.96	27.0	**40447.8**	3.06	581.49
Plantation	769.5	58.37	1197.63	14104.17	46.71	403.29	6.93	**5567.94**	4432.59
Urban agglomeration / bare soil	55.8	509.31	1271.61	369.09	535.14	176.76	180.09	319.5	**5831.73**
Total classes (Km²)	**11384.73**	**65298.96**	**51973.65**	**55974.87**	**23800.05**	**6369.03**	**41912.37**	**21235.41**	**15765.92**
Change in classes (Km²)	**8253.72**	**44486.37**	**16470.45**	**50071.68**	**21313.17**	**5482.89**	**1464.57**	**15667.47**	**61978.68**
Rate of change in classes (%)	**72.49**	**68.13**	**31.69**	**89.45**	**89.55**	**86.09**	**3.49**	**73.78**	**91.40**

DISCUSSION

The processing of Landsat (TM (1986) and ETM + (2000)) and Sentinel 2A (2015) satellite images and other geographic information's allowed to establish the baseline of the study area for a better knowledge of land use patterns, ecosystems and habitats. The method used to analyze the transition modalities between the different dates is based on post-classification processing. This approach appears to be a robust method with respect to variations in image quality (Lefèvre et al., 2002 ; Rigollier et al., 2004; Corgne, 2014). Thus, in the context of this study, it allowed to perform an analysis of images from different sensors (Landsat and Sentinel 2A). The results obtained provide sufficient evidence that satellite data and remote sensing are tools for mapping land cover transformations by providing spatially explicit information (Cabral and Lagos, 2017; Hagensiekera et al., 2017; Ramachandrana et al., 2018).

The analysis of land cover and its evolution dynamics allow to understand the biophysical and anthropic processes which direct the quantitative and qualitative evolution of landscapes in a general way and natural resources in particular, including vegetation cover, water and soils (Davranche et Taïbi, 2015). But this analysis also seeks to understand and highlight the factors, both natural and anthropogenic, that cause these processes. Thus, the analysis of the dynamics of change in land cover units in the RBTM revealed the different evolutionary processes that took place in the landscape during the period 1986 - 2015. These changes mainly concern the regression of closed forest and wooded savannas, while low-cover soil occupancy (mosaics of crops and fallows and urban agglomerations / bare soil) have shown a gradual increase in their areas. These results are consistent with those of Avakoudjo et al. (2014) in the W National Park and its periphery in north-western Benin, which show a continuous regression of forests in favour of fallows, bare soil and settlements based on diachronic studies.

This shows that the RBTM is characterized by high pressures on the dynamics of land use. It must be noted that the phenomenon of ecosystem degradation has become more pronounced from 2000 to 2015 with a greater anthropization of forest domains and wooded savannas and their conversion to cultivated areas, inhabited areas / bare soils. The factors most commonly cited as having contributed greatly to reductions in forest areas and savannas are agricultural practices, logging, charcoal production and wildfires. The manifestations of these factors are more and more felt with the ever-increasing population of the area, thus increasing resource needs and accentuating pressure on land (Adjonou et al., 2013). Conversions of natural forests into agricultural and non-vegetated areas observed in the RBTM are common and support earlier work on changes in land use (Ouedraogo et al., 2010; Houessou et al., 2013; Brandt et al., 2014; Faye et Cheikh, 2016; Konko et al., 2018a). This trend in reduced natural vegetation cover in West Africa is an urgent environmental concern as it leads to soil and ecosystem degradation (Avajoudjo et al., 2014; Faye et Cheikh, 2016; Zoungrana et al., 2018). It is to address these concerns that in recent decades conservation science has increasingly incorporated work on changes in land use as simple processes, reduced to the manifestation of an irreversible transition from one state to another (Mertens and Lambin, 2000).

Contrary to the regressive dynamics of natural forest landscapes, increase in the area of anthropophilic landscapes is linked to the degradation of forests and savannas. The most dramatic increase is observed with size of water bodies having an estimated rate of 304.97% representing an increase in area of about 32 645 ha. This increase in the surface area of the water plans would be globally linked to the recurring flood phenomena that the area has known in recent years. The inter-annual rainfall variability would therefore be the main cause as we can have an increase in temporary water areas and floodplains because of a year of good rainfall.

The degradation of the environment resulting from the regression of natural forest landscapes is linked to the development of socio-economic activities (slash-and-burn agriculture, exploitation of timber, charcoal production mining, etc.) in a context of demographic pressure (Pale, 2000). Several authors have questioned population growth and certain modes of exploitation as the causes of ecosystem and land degradation resulting in the disruption of ecological balances (Konko et al., 2018b). This is a remarkable phenomenon in sub-Saharan Africa, where high population densities and the crisis of agricultural space lead people to seek new land (Abotchi, 2002). Indeed, the area of the reserve is marked by high population density estimated at 300 to 350 inhabitants / km² and the agricultural practices adopted by the populations lead farmers to exploit more fertile forest lands and marginal lands in wetlands (Adjonou et al., 2013). Thus, to meet the growing needs for land, people are exploiting fertile forest lands available in the protected areas. In a similar study conducted in Côte d'Ivoire, Kouassi (2014) argues that forest reduction can also be explained by the type of agriculture practiced. The author explains that predominantly agricultural areas where there is a continual search for more productive land, farmers abandon cultivated lands after one or two years of exploitation, to colonize new more fertile forest lands, leaving the former fallow to restore fertility.

Although changes in land use in the RBTM provide social and economic benefits at several levels, especially for the well-being of the population, it should be noted that land development is responsible for ecological degradation at different spatial scales. In this regard, it has been shown that the different phases of economic development (agricultural, industrial, etc.) affect different components of biodiversity over time. The agricultural phase tends, to eliminate the biodiversity of highly productive areas, while preserving the marginal areas (Pale, 2000 ; Davranche et Taïbi, 2015). But these biodiversity reservoirs are now threatened by recreational activities or residential spaces that are spreading to rural areas. Increasingly, land-use changes are taking place over large areas, to the detriment of residual biodiversity. This degradation usually results in the reduction of ecosystem services provided. A study conducted in the peripheral zone of the RBTM in 2016, shows that the populations perceive the decline in services provided by the reserve in the following proportions: 64.4% for wood energy, 54% for wood products, 44.4% for bush meat and 78.9% for agricultural products. For these populations, the different proportions of decline are related to the excessive extraction of forest resources, demographic pressure, and climate-related changes, particularly long periods of drought (GIZ, 2016).

However, it should be noted that despite the changes and conversions observed during the period of this study (1986 to 2015), the study area remained largely covered with natural vegetation and still has good potential for the conservation of biodiversity. The reserve is rich in plant and animal resources associated with a diverse multi-function ecosystem. Thus, the better preserved natural habitats consist of semi-deciduous forests, wooded savannas, flooded savannas and associated ecosystems, mangroves, etc.; some of these are still found in the Togodo protected complex, in the community forests (Akissa, Godje-Godjin) and in the lagoonal system along the coast of south-east Togo. The preservation of these habitats will allow the conservation of biological diversity (Abdourhamane et al., 2013; Faye et al., 2018) and also the reinforcement of the resilience of populations in facing the harmful effects of climate change. To this end, the development of the land use baseline in this study provides quantitative data and information (occupancy / use classes, area estimates) needed for good land use to describe and establish a quantitative link between human activities, their impact on the environment, and the geographical (spatial) dimension. Information on the dynamics of land use incorporating the temporal dimension is therefore of great importance to decision-makers who evaluate decisions on the use of natural resources and to the scientific community that discovers the causes and the effects of land use changes on the management of the natural resources of the RBTM.

Conclusion

The reference situation of the RBTM between Togo and Benin in terms of land cover and land use is established on a scientific basis using satellite images and other sources of geographical information. The results of this satellite image analysis allowed a better knowledge of the types of land occupancy, the ecosystems, the habitats and the dynamics of change in the RBTM. The analysis of the dynamics of change in land occupancy units revealed the different processes of evolution within the landscape during the period 1986 - 2015. These changes mainly concern the regression of natural ecosystems such as closed forests and wooded savannas whereas low-cover land occupancies (mosaics of crops / fallows and urban agglomerations / bare soil) have been gradually increasing. Despite the changes and conversions observed during the period of this study (1986 to 2015), the study area remained largely covered with natural vegetation and still has good potential for biodiversity conservation. The reserve is rich in important plant and animal resources associated with a diverse multi-function ecosystem. The preservation of these habitats will allow conservation of biological diversity but also the reinforcement of the resilience of the population in the face of the harmful effects of climate change. All the information generated by this study should be of interest to policymakers, NGOs and the scientific community who evaluate decisions on the use of natural resources. The study therefore provides information for applications ranging from land use planning, forest cover monitoring and production of environmental statistics.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

All authors contribute significantly to the present study and to the revision of the manuscript. KA: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, materials, analysis tools or data, wrote the paper ; IA-KB : conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, materials, analysis tools or data, wrote the paper ; KNS: conceived and designed the experiments, performed the experiments, materials, analysis tools or data, wrote the paper ; IR: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, wrote the paper; KVS: conceived and designed the experiments, performed the experiments; RG-K: conceived and designed the experiments, analyzed and interpreted the data; KK: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, wrote the paper.

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