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(Research Article)

Characterization of land use dynamics from 1997 to 2017 in the baya river basin (East of the Ivory Coast)

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Abstract

The landscapes of the baya watershed have evolved under the direct and indirect effect of climatic and anthropogenic factors during episodes of drought and the advent of arboriculture as well as the agrarian reforms that have affected the country since the early 1980. in this context, this study assesses the dynamics of land use over the entire watershed (6325.48 km2) between 1979 and 2017 using satellite data (Landsat images). The methodology relies on the use of remote sensing and GIS to analyze the dynamics of the major land cover classes in the study area. These classes concern agricultural plots, natural vegetation, bare soils, water surfaces and urbanized areas. The supervised classification approach of Landsat TM satellite images from 1997, 2007 and Landsat 8 from 2017 made it possible to characterize the vegetation cover with cartographic accuracies of 98% and 97% respectively. Following this treatment, it appears that forest (44.97%) and fallow land (33.41%), which were the most represented vegetation types in the basin in 2007, experienced a significant regression between 2007 and 2017 in favor of crop classes (42.58%) and bare soils or urban areas (13.15%). The regression of plant formations is due to rapid urbanization and the expansion of agricultural areas, in particular the search for fertile land with still traditional cultivation techniques

Keywords : Caractérisation; Dynamics of land use; Baya watershed; Eastern Côte d'Ivoire

1. Introduction

The Baya watershed is one of the major basins located in eastern Côte d'Ivoire. Due to its location and the excellence of its land suitable for commercial agriculture (Judge, 2019), it experienced a significant demographic expansion between the 1980s and 2000s, which led to landscape transformations (Mangoua, 2013). The Baya watershed, dedicated to agriculture, is subject to various forms of attack due to the interaction between various climatic conditions and the human impact on vegetation and soil cover (N'Guettia, 2023). The main objective of this study is to analyze the évolution of land use in the Baya watershed during the years 1979 to 2007 and 2017. Knowledge of land use is very important information for the characterization of a region and for the development of plans for better land management Biga et al. (2020). It provides an illustration of the continuous confrontation between society and its environment (Belghiti et *al.*, 2014), expressing at a given moment a state of these relations which involve structures changing in time and space. It involves the use of remote sensing data, together with high-resolution satellite imagery (Diallo et *al*., 2025), to finely track the dynamics of land use and, subsequently, environmental pressures. In order to meet the objective of this work and thus allow a good under standing of the evolution of the landscape in the region, we will first present the studied area and the methodology applied before proceeding to the analysis of the dynamics of the land use through the spatial changes and the observed trends.

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2. Materials and Methods

2.1. Study area

The Baya watershed is located in eastern Côte d'Ivoire between longitudes 2°38' and 3°33' W and latitudes 6°35' and 8°26' N. It covers an area of approximately 6,324 km2 (Figure 1). The population of the basin is estimated at 267,263 inhabitants with an increase of 2.8% of the population (INS, 2014). From a soil point of view, this basin is covered with ferralitic soils occupied by cash and export crops (coffee, cocoa, cashew) and food crops (Yves et al., 1995). The main geological formations encountered can be grouped into three large lithological ensembles (Youan Ta et al., 2015).

A Tarkwaian and volcano-sedimentary ensemble consisting mainly of Shale, Amphibolite and Metadolerite. From a hydrogéologiques point of view, there are two types of aquifers in the study area. These are the aquifers of alterites, the aquifers of cracks and fractures. This hydrogeological framework means that water resources are mainly used for drinking water supply and for hydroelectric production, hence a basin characterized mainly by rainfed agriculture subject to climatic hazards (http://www.water.gov.ma/). Climate governs the spatial and temporal distribution of water resources (Figure 1) and thus influences land use, particularly in agricultural and forestry areas. It is distinguished on the basin by a wet season, from October to April, during which 90% of rainy episodes take place, and a dry season, from May to September (Mangoua, 2013).

2.2. Study data

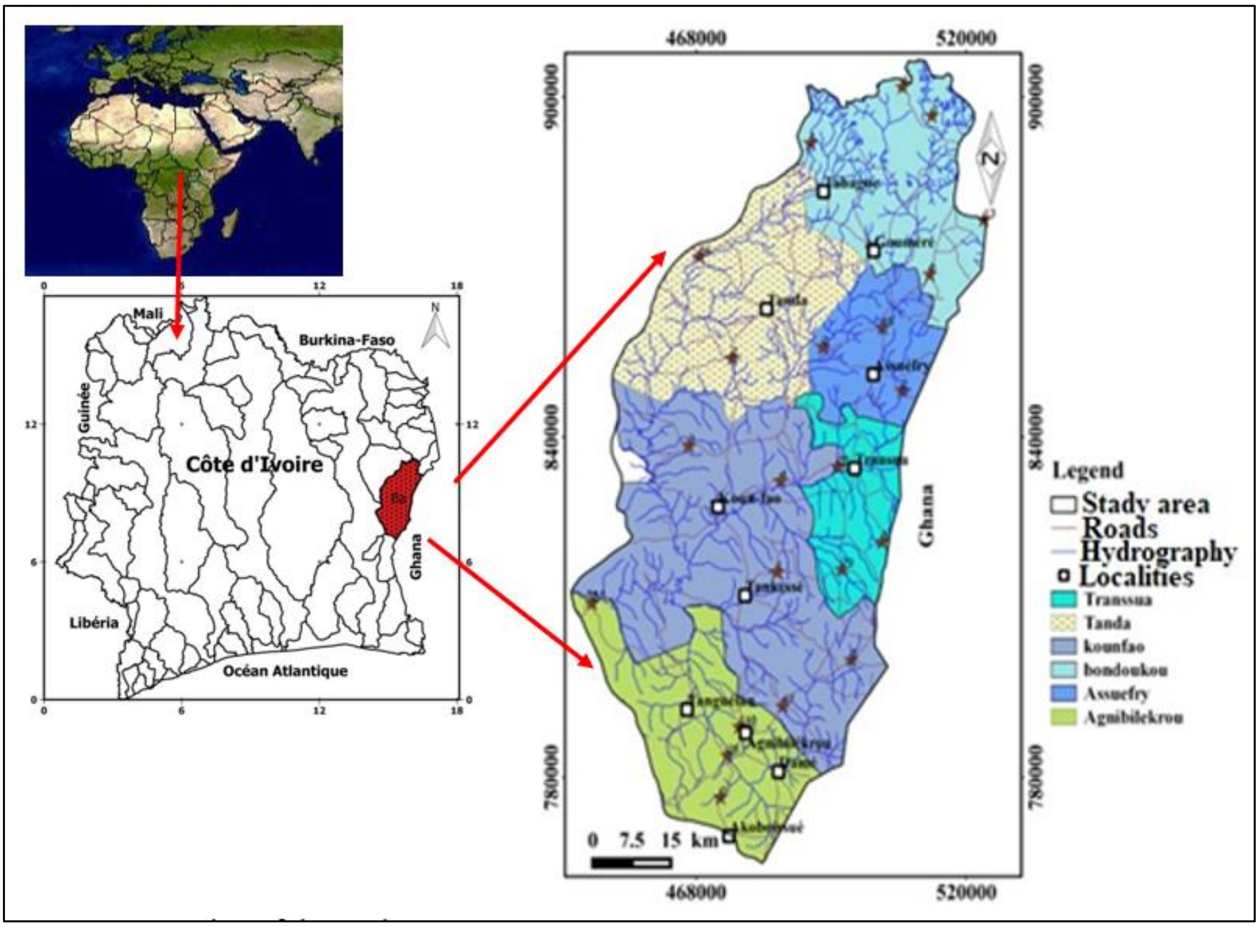

Figure 1 Location of the study area

The methodology used in this work is based on the use of satellite data and field observations. These data were then integrated and analyzed using remote sensing tools and Geographic Information Systems (GIS) to map the study area. Two scenes covering the basin. These are the scenes p195r54 and the scenes p195r55 was produced after the mosaicing of the scenes p195r54 covering the northern part of the basin and the scenes p195r55 covering the southern part of the study area.

2.3. Methods

2.3.1. Unsupervised and supervised classifications

The unsupervised classification was an intermediate step and made it possible to better and more easily interpret the radiometric reality to the thematic reality (Kone et *al.,* 2007 ; Diallo et *al.,* 2019). Eight thematic classes were defined at the launch of the unsupervised classification. From the results of the unsupervised classification and the type of land use on the ground was made on the basis of the training plots. The supervised classification algorithm chosen is the "maximum likelihood" considered as one of the most efficient algorithms in the production of thematic maps in the field of land use (Diallo et *al.,* 2025).

Indeed, the classification supervised by the maximum likelihood was used, because it allows a good distinction of the themes of land use. This method is based on the probability that a pixel will belong to a given class (Djohy et *al.,* 2016). The colored composition ETM+7(R), ETM+5(V), ETM+3(B) was used for the classification.

2.3.2. Cartographic precision

The overall accuracy of the classification or Kappa Coefficient (CK) is valid when this value approaches 100%. The CK translates the ratio between the total number of well-classified pixels and the total number of pixels in an image (Benmessaoud et *al.,* 2008). It takes into account errors of omission. These two parameters make it possible to better appreciate the classification carried out.

2.3.3. Land use between 2007 and 2017

The balances of the evolution of the land-use units were calculated using the software Envi 4.7; i.e. V.2007 and V.2017, the proportion of a land-use unit respectively in 2007 and 2017. The variation TV is the area of a land use unit between two dates is given by equation 2 and FIG. 2 summarizes the supervised classification.

$$\text{TV} = \frac{(\boldsymbol{V1} - \boldsymbol{V0})}{\boldsymbol{V0}} * 100$$

TV: Rate of vegetation change between the two observation dates ;

V0: the proportion of the land cover class taken in the initial state ;

V1: the proportion of the land cover class taken in the final state.

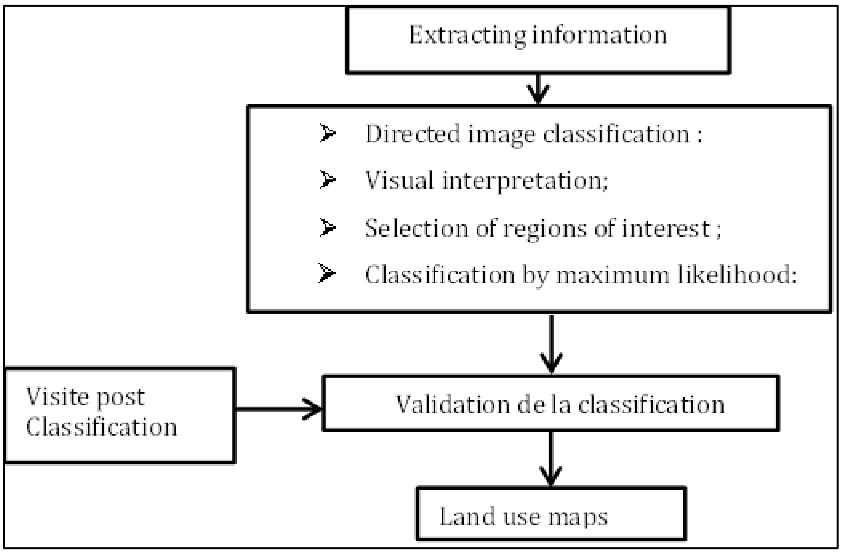

Figure 2 Simplified Methodological Scheme of Supervised Classification (N'go, 2015)

3. Results

3.1. State of land use in 1997, 2007 and 2017 in the Baya river basin

Land use maps from 1997 to 2017 were used to characterize changes in vegetation cover and anthropogenic activities in the Baya watershed.

3.2. Discrimination of types of land use by colored compositions

The color composition ETM+5/ETM+4/ETM+7 (FIG. 32) is the one which has allowed a better discrimination of the types of land use. It was possible to distinguish on this composition, various colorations that highlight the types of land use. The major colors in this image are represented by yellow, black and cyan indicating urban areas and bare soils. Bright magenta indicates wetlands like forest. Also, the mosaics of red-green, green-blue colors indicate crops and fallow land. Finally, black indicates the reservoirs and streams.

The vegetation cover (degraded magenta) of the study area is very important, but little varied between 1997 and 2007. Areas of forests (dark magenta), cultivated mosaics (light magenta) and bare cyan habitats or soils can be observed. In 2017, the analysis of the colored composition carried out on the same zone shows a very significant variation in the vegetation. You can see a significant disappearance of the yellow color with its variants, including green yellow, orange yellow. The mosaics of forests, crops or fallow crops observed in 1997 and 2007, have evolved to make way for forest complexes.

The cyan themes show the spatial distribution of urban areas and bare soils that progress and are concentrated mainly in large. agglomerations and a proliferation of small hamlets, especially in the Bondoukou and Agnibilékrou regions (Figure 4 (a, b, c).

There is also a decrease in wetlands. Crop and/or fallow areas have a light magenta hue. They have taken place gradually with the destruction of forest areas. In all the images, the change in vegetation cover can be observed in the space of 20 years. This degradation affects the different types of vegetation in the Baya watershed.

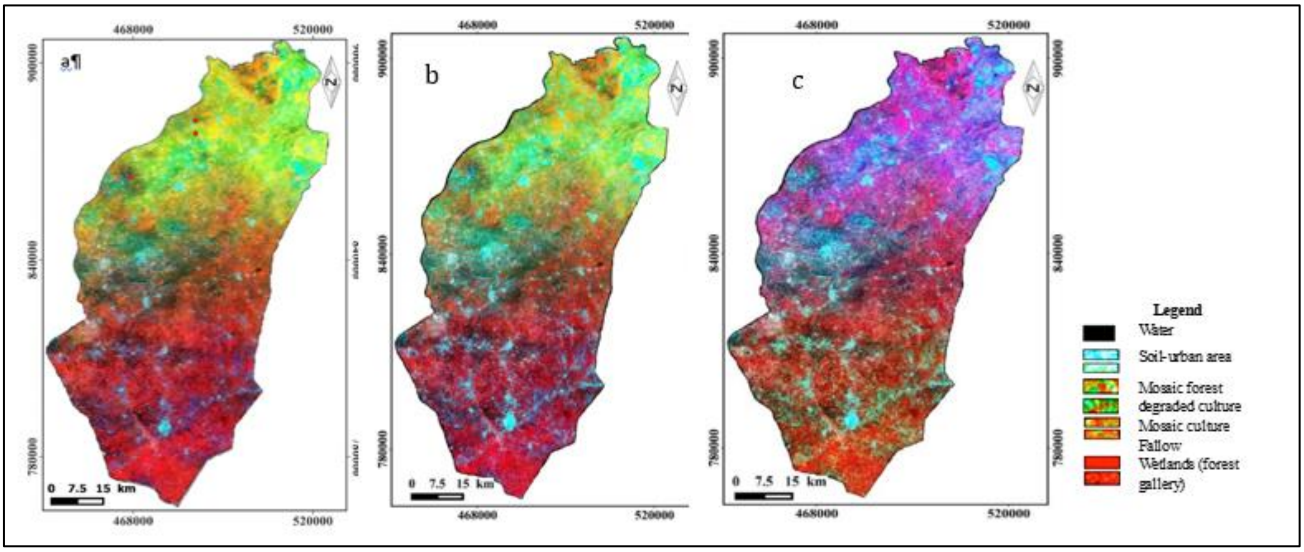

Figure 3 Colored composition of bands 5, 4 and 7 of the Landsat TM images from 1997 (a), Landsat TM+ images from 2007 (b) and Landsat 8 images from 2017 (c)

3.3. Supervised Classification

To better discriminate the different types of land use, a directed classification with field observation was carried out. This classification was carried out on the basis of 5 types of land use: forest, crops, fallow land, water and urban areas or bare soils. The confusion matrices (Table 1, 2 and 3) express the pixel rates of a class actually assigned to this class by the maximum similarity classification method. The different rates outside the diagonal reflect those of the poorly classified pixels, that is to say pixels that have been assigned to a class to which they do not belong.

The matrices obtained show overall cartographic accuracies of 98.6% ; 99.12% and 98.47% for Landsat 7 TM+ of 1997, 2007 and Landsat 8 ETM for 2017 with respective KAPPA coefficients of 0.981, 0.988 and 0.980. The values in bold in the diagonal (Table 1, 2 and 3) correspond to each type of land use with well-classified pixel rates. The fallow class has the best accuracy rate in 1997 with 100% pixel well ranked. Next are the forest, bare soil/habitat and crop classes (Table 2). In 2007, the crop, urban or bare soil and water classes had the best mapping accuracy rates of 99.42%, 99.27% and 99.97% respectively.

On the other hand, the rate of cartographic accuracy recorded in the forest class, although important, remains the lowest with 97.31%. This low rate records a confusion of 2.65% with the fallow class. With regard to the confusion matrix from the Landsat 8 image of 2017 (Table 3), the best mapping accuracy rates were observed at the fallow class (99.76%), forest class (99.23%), habitat/bare soil class (100%). The culture class displays the lowest rate of well-ranked pixels with (95.57%). This low rate recorded a confusion of 1.02, 1.29 and 1.96% respectively with the forest, water and habitat/bare soil class. The fallow class has the best accuracy rate in 1997 with 100% pixel well ranked. Next are the forest, bare soil/habitat and crop classes (Table 2).

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Table 1 Confusion Matrix of the Supervised Maximum Likelihood Classification from the Landsat TM (1997) image of the Baya Basin

Theme (in %)	**Waters**	**Fallow land**	**Forests**	**Cultures**	**Habitat/ Sol nu**
Waters	98.11	0.00	0.20	0.00	0.12
Fallow land	0.00	100	0.07	0.00	0.00
Forests	1.05	0.00	99.59	0.11	0.00
Cultures	0.00	0.00	0.14	97.47	0.84
Habitat/ Sol nu	0.84	0.00	0.00	1.26	98.95
Total	100	100	100	100	100

Overall accuracy = (12471/12648) 98.6 %, Kappa coefficient = 0.9818

Table 2 Confusion Matrix of the Supervised Maximum Likelihood Classification from the Landsat TM (2007) image of the Baya Basin

Theme (in %)	**Waters**	**Fallow land**	**Forests**	**Cultures**	**Habitat/ Sol nu**
Waters	99.66	0.00	0.00	0.13	0.00
Fallow land	0.22	99.42	2.65	0.00	0.00
Forests	0.00	0.16	97.31	0.03	0.03
Cultures	0.11	0.00	0.00	99.27	0.00
Habitat/ Sol nu	000	0.42	0.04	0.56	99.97
Total	100	100	100	100	100

Overall accuracy = 2007 (11377/11478) 99.12%; Kappa coefficient = 0.98

Table 3 Confusion matrix of the supervised classification by maximum likelihood from Landsat 8 (2017) image of the Baya basin.

Theme (in %)	Waters	Fallow land	Forests	Cultures	Habitat/ Sol nu
Waters	98.05	0.00	0.08	1.29	0.00
Fallow land	0.00	99.76	0.00	0.16	0.00
Forests	1.38	0.00	99.23	1.02	0.00
Cultures	0.00	0.00	0.62	95.57	0.00
Habitat/ Sol nu	0.57	0.24	0.08	1.96	100
Total	100	100	100	100	100

Overall accuracy = 2017 (9470/9617) 98.47%; Kappa coefficient = 0.9802

3.4. Assessment of land use between 1997, 2007 and 2017

Compared to 2007 and 1997, 2017 (Figure 4) saw a wide variety of vegetation units. The evolution of different vegetation cover units between 1997 and 2017. This figure shows a continuous evolution of the bare habitat-soil classes from 1997 to 2017. The culture class, on the other hand, experienced a drastic fall from 1997 to 2007 and a galloping increase from 2007 to 2017.In addition, the forest and fallow classes experienced a reduction in their areas between 2007 and 2017. Proportions of land-use units are reported (Table 4). From 2007 to 2017, the forest increased from 2842.06 hectares to 1386.91 ha, corresponding to a deforestation rate of 21.93%. Crop classes showed an exponential change from 10.28% to 42.62%, i.e. a change rate of 314%.

Similarly, urban areas and bare soil increased from 717.68 to 931.83 hectares, an increase of 15.9 per cent. There was also a slight increase in water areas, from 0.02% in 2007 to 4.78% in 2017. The order of predominance of units is defined by secondary forest or gallery (44.97%), fallow (33.41%), urban areas-bare soil (11.34%), crops (10.28%) and water (0.02%). As for the satellite image taken in 2017 in the basin, it shows a significant variation in vegetation cover compared to that taken in 2007 and 1997. The order of predominance of units is as follows : crops (42.58%), fallow forest (22.27%), forest (21.93%), urban areas and bare soils (13.15%) and water (0.07%).

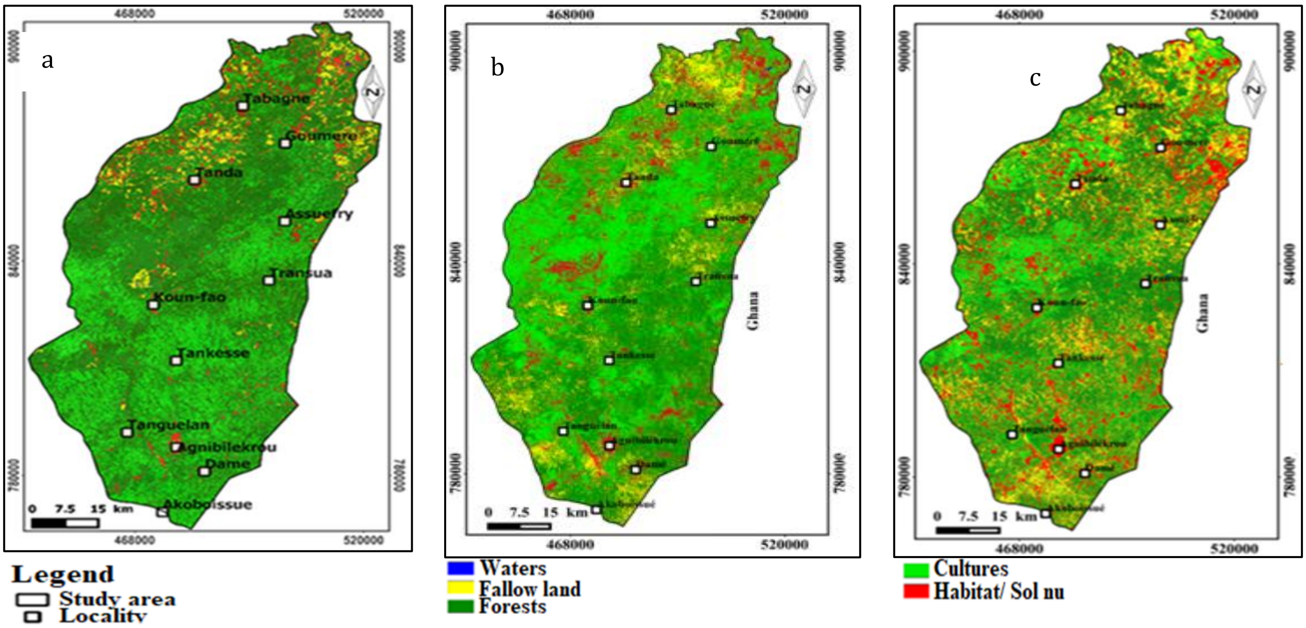

Figure 4 Land use in 1997 (a), 2007 (b) and 2017 in the Baya

Table 4 Land cover classes in 1997, 2007 and 2017

Classe	State in 1997		State in 2007		State in 2017	
Units	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
Waters	8.02	0.13	2.3	0.02	4.71	0.07
Fallow land	2100.78	33.21	2112.96	33.41	1408.86	22.27
Forests	1879.71	29.72	2842.06	44.97	1386.91	21.93
Cultures	1949.68	30.82	650.48	10.28	2693.17	42.58
Habitat/ Sol nu	387.3	6.12	717.68	11.34	831.83	13.15
TOTAL	6325.48	100	632.48	100	6325.48	100

3.5. Summary of land use between 1997 and 2017

The regressive trends of land-use units in the 1997-2017 chronicle concern forest and fallow land with respective proportions -51% and -33%. These differences in area are very significant in the old loop of the cocoa coffee binomial of the basin, circumscribed in the localities of the South from Akobouassué to Tankessé and the new zone of cultivation of the cashew precisely in the localities of Tanda, Gouméré and Tabagne ; however, the differences in progressive areas are of 16%, 314%, and 105% and concern islets of plots which are observed scattered over the whole basin. These are bare habitats/soils, crops and water surfaces respectively.

4. Discussions

The classification method supervised by the maximum likelihood algorithm was applied to Landsat 7 satellite images from 1997, 2007 and Landsat 8 satellite images from 2017 in the Baya watershed. The cartographic precision obtained is 98.6% (1997); 99.12% (2007) and 98.47% (2017) with Kappa Coefficients (CK) of 0.981, 0.988 and 0.980 respectively. These values suggest that the classifications performed are reliable and acceptable. Biga et *al.,* (2020) Dialo et *al.,* (2025) interprets the values of the kappa coefficient from 1 to 0.81 as excellent and good. Moreover, these cartographic details are in line with the range of values obtained by some authors, notably Aké (2010) and N'go (2015) with cartographic details of 90% and 83.24% respectively. These results revealed an increase in cultivation areas and a decrease in natural plant formations. Cette régression de la végétation aux profits des zones anthropisées est devenue de plus en plus récurrente. These results are consistent with observations by Koffi (2016) in d'Azagny, southern Côte d'Ivoire, Kpedenou et al. (2016) in southeastern Togo, Millogo et al*.* (2017) in the province of Bam in Burkina Faso, Mamane et al*.* (2018) in the total wildlife reserve of Tillabéry in Niger of Biga et *al.* (2020). The regressive trends of land use units in the 2007-2017 chronicle concern forest and fallow land with a respective proportion of -51%, and -33% to the detriment of crop classes (314%) and urban bare soil (16%). The extension of cultivation areas synonymous with regression of plant formations and fallow land is also supported by the work of certain authors such as Adjonou et al. (2010), Koumoi et al. (2013) and Djohy et al. (2016).

For these authors, agricultural activities could be the major causes of vegetation degradation. The same observation was made by Sudhakar et al. (2017) respectively in Benin and Sri Lanka. For the latter, this deforestation is linked to the marked increase in agricultural land and urbanization. In addition, the introduction of arboriculture into the Ivorian economic system, such as rubber, cashew and Tecks, has helped regenerate vegetation in some localities (Djohy et al., 2016). Also, the widespread poultry areas in the area have contributed to a significant reduction in forest areas. Woodland is the most represented vegetation in the basin with an increase of nearly 314% in their area in 10 years. Then, urbanization with its corollary of electrification and subdivision has led to the loss of agricultural land and an increase in bare areas or 16% of the total area of the Baya basin as indicated by Dialo et *al.* (2025) in the Djiby basin.

Water surfaces in the Baya catchment area have increased slightly during this decade. They increased from 0.02% in 2007 to 4.78% in 2017, a rate of change of 205%. This gradual trend in water surfaces would indicate a recovery in rainfall at the basin level. Indeed, a study (Ouattara, 2018) on the regression of the number of rainy days between 1970 and 2000 indicates a positive slope of about 0.38 and 0.18 respectively for the Ferkessédougou and Bondoukou stations.

5. Conclusion

At the end of this study, it appears that image processing techniques and GIS have made it possible to characterize the dynamics of land occupation and use between 1997 and 2017. The changes in land use in the Baya basin were highlighted using Landsat TM (2007) and Land SAT 8 (2017) satellite image processing combined with field observations. The results of the dynamics of land use show a regression of the forest (-51%) and fallow land (-33%) on the one hand and an increase in cropping areas (315%), bare habitats and soils (105%) and water surfaces (16%) on the other hand. The decline in plant formations is due to the expansion of agricultural areas, particularly the search for fertile land and still traditional farming techniques, urbanization and demographic expansion.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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