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Research Article

Landsat Imagery Monitoring and Quantification of the Land Cover Changes in the Kan Watershed at Tiébissou (Center of Côte d'Ivoire)

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Abstract The purpose of this study is to characterize and quantify the evolution and changes in land cover of the Kan watershed at Tiébissou between 1988 and 2015. It is based on the exploitation of Landsat 5 TM and Landsat 8 OLI images, submitted to a string of processing from ENVI 4.5, ARCGIS 10.0 and EXCEL 2010. Diachronic land cover analysis revealed six classes in the Kan watershed: water bodies, habitats, farming, dense forest, degraded forest and savannah. From 1988 to 2015, dense forest, habitats and farming grew respectively by 6.20%, 1.80% and 0.52% while savannah and degraded forest shrank by 6.83% and 1.62% respectively. Water bodies remained virtually stable. The largest changes occurred in the savannah (36.11%) while the least important changes were in the water bodies (0.20%). Degraded forest, dense forest, farming and habitats changed by 26.31%, 22.30%, 11.77% and 3.32% respectively. Dramatic changes have also occurred within each land cover classes at varying proportions.
Keywords *GIS; Kan watershed; Land cover; Progression; Regression; Remote sensing*

1. Introduction

The precious and vital natural resources for human survival, such as water, vegetation, are increasingly threatened by scarcity and disappearance for demographic, economic and climatic reasons.

In Côte d'Ivoire, land cover change has become unprecedented in recent decades. Vegetation cover is the perfect illustration of this change. The area of dense forest, which was 15 million hectares at the beginning of the century and 12 million at Independence, was only 6 million hectares in 1975 and about 2.5 million hectares in 1990 (Aubreville, 1959; SODEFOR, 1996). The main offending agents in this case are agriculture and logging. Côte d'Ivoire is expected to lose all of its national forest cover by 2034 (Durrieu de Madron et al., 2015) if no action is taken to improve its management.

While some biophysical features of the territories are considered virtually stable on a human scale (geology, modeling, hydrographic network geometry, soil cover), others are likely to change more rapidly and significant changes may occur. These changes affect large areas in a few years. The most dramatic changes are of anthropogenic origin (land use, deforestation and exploitation of natural resources, expansion of urban agglomerations).

The Kan watershed is an agricultural area located in the center of Côte d'Ivoire, which experienced the long and severe drought of the 1970s. This drought has had a negative impact on natural resources in general, and more specifically on water resources, including water availability, soil productivity, food security, and in turn on human well-being. The palpable impacts of this drought were, among other things, the exposure of agricultural activities to the problem of inter-annual and inter-seasonal availability of water resources (surface and groundwater); the intermittence or even the complete drying up of the groundwater catchment works (wells), and the drastic decline of the regime of the small tributaries of the Kan stream, or even their fragmentation and almost total drying up during the exceptionally dry years. This last situation causes the limitation of the cultivable surfaces which are reduced for the most part to the zones of lowlands whose humidity drastically decreases. To better understand the changes to the surface condition of the Kan watershed, a follow-up study is needed. The purpose of this study is to characterize and quantify, from multidate images, evolution and changes in land cover between 1988 and 2015. The aim is to perform a diachronic analysis of land cover from 1988 to 2015 from Landsat images; to evaluate the evolution of different categories of land cover classes highlighted in the watershed, and to spatialize and quantify all of these changes.

The advent of space-based Earth observation techniques facilitates the mapping and monitoring of surface conditions in many previously inaccessible regions (Green et al., 1994; Mas, 2005; Shalaby and Tateishi, 2006; Jovanović et al., 2015; Rajasekhar et al., 2017; Boussaada-Maabdi et al., 2017). The possibility offered by remote sensing space to access an overview of large areas recurrently is therefore a major asset for the production of land cover maps.

2. Materials and Methods

2.1. Presentation of the Study Area

The study area is a part of the Kan watershed that represents a sub-watershed of the N'zi. It is an agricultural territory located in the center of Côte d'Ivoire between longitudes 4°01' and 5°24' west and latitudes 6°51' and 7°41' north (Figure 1). It covers an area of 2,086.31 square kilometers. The Kan watershed is part of the transition zone between the Southern Forest and the Northern Savannah. Its diet is of the equatorial type of attenuated transition or Baouléen climate characterized by a rainy season from March to October and a dry season from November to February. The average rainfall is between 1,000 and 1,200 millimeter and the average temperature is 30°C. Relief is slightly uneven with some plateaus whose average altitude varies between 200 and 300 meters. Geology is essentially granites and shales. Watershed soils are moderately and / or weakly desaturated ferralitic types with the addition of ferruginous tropical soils and clay or sand-humus or hydromorphic soils near streams and in shallows (Perraud, 1971). These soils are very conducive to agriculture which make the departments that make up the watershed (Tiébissou, Sakassou, south extreme of Bouaké and north-east of Yamoussoukro) a predominant area of agropastoral activities.

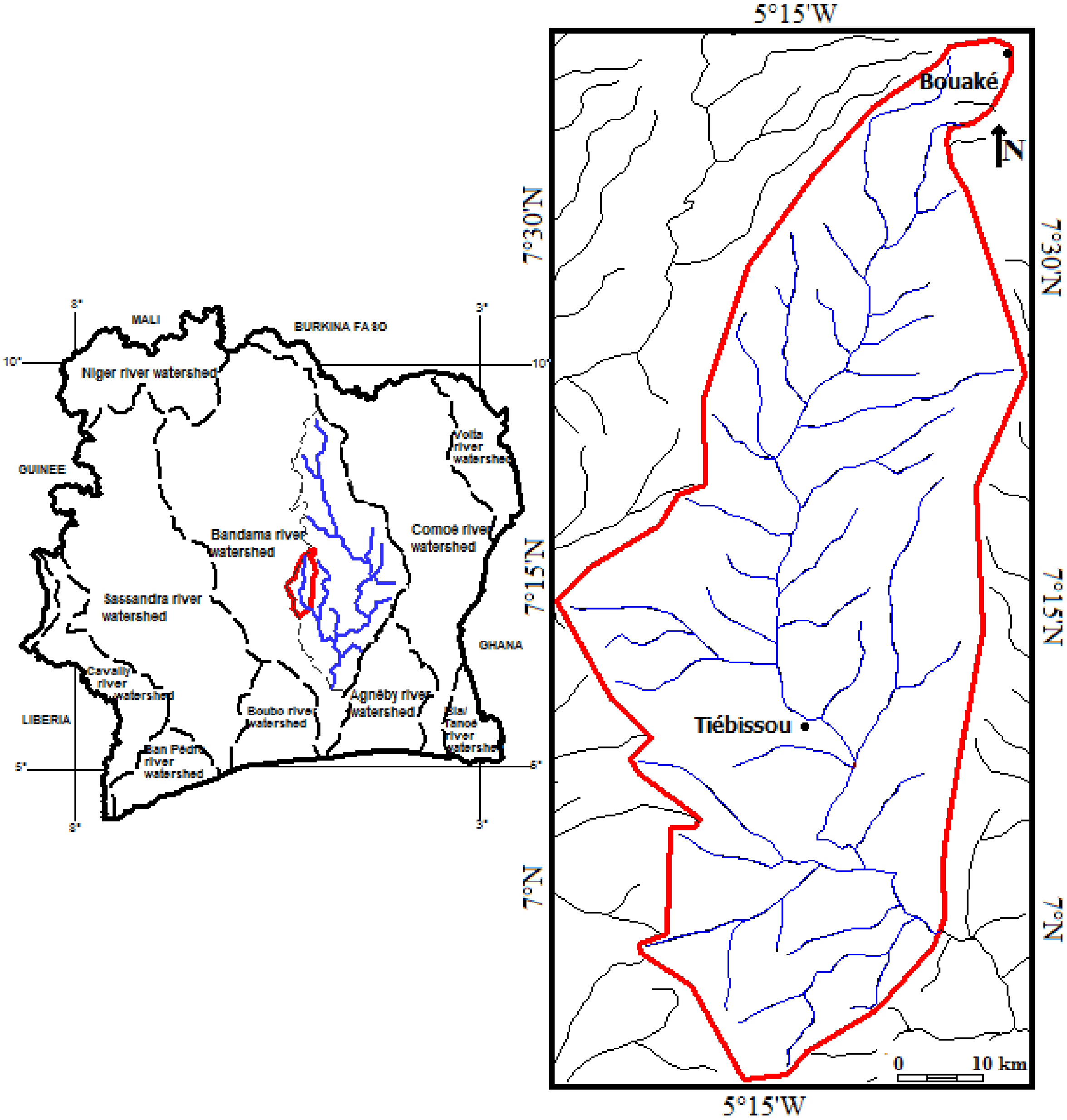

Figure 1: *Location of the Kan watershed*

2.2. Data and Software

The preferred sources of information used for mapping purposes to monitor dynamics of changes in the surface states of the natural environment are satellite images. They consist of Landsat 5 TM Scene 197-55 of December 23, 1988 and Landsat OLI Scene 197-55 of January 16, 2015 (Table 1). The choice of these images is dictated by the fact that they are a source of important information, downloadable for free on the NASA website (https://earthexplorer.usgs.gov/). Moreover, these images are adapted to the study of the evaluation of the occupation of the ground. The spatial resolution of these (30 meters) makes it possible to identify and characterize the different components of the landscape (Gracu, 2014).

Table 1: *Landsat Images of the study area*

Satellites	Sensors	Path	Row	Dates of acquisition
Landsat 5	TM	197	055	23/12/1988
Landsat 8	OLI	197	055	16/01/2015

These images are submitted to a string of appropriate processing from the software ENVI 4.5, ARCGIS 10.0 and EXCEL 2010.

2.3. Methods

The evolution of land cover classes and the detection of changes in the surface state of the Kan watershed are highlighted on the multidate satellite images through a string of treatments illustrated in Figure 2.

Orthorectified images of the study area taken in the dry, cloudless season are of acceptable radiometric quality. The preliminary treatment from the ENVI 4.5 software consisted of the extraction of the study area. The actual processing combined NDVI, PCA and color compositions to produce derived images for good spectral discrimination of different types of land cover in general, and in particular vegetation cover (N'Da, 2007). The development of the different classes of land occupation consisted in the creation of the training plots (ROIs) for the establishment of the land cover map based on the difference of spectral signatures of the objects on the ground. The method uses the maximum likelihood classification. This classification is evaluated by the various performance tests (kappa index, confusion matrix). A 3 × 3 median filter is applied to the cards to reduce intra-class heterogeneity by eliminating isolated pixels. The thematic validation to verify the credibility of the result consisted of a visual analysis by comparison between the resulting image of the classification and the basic image (color composition).

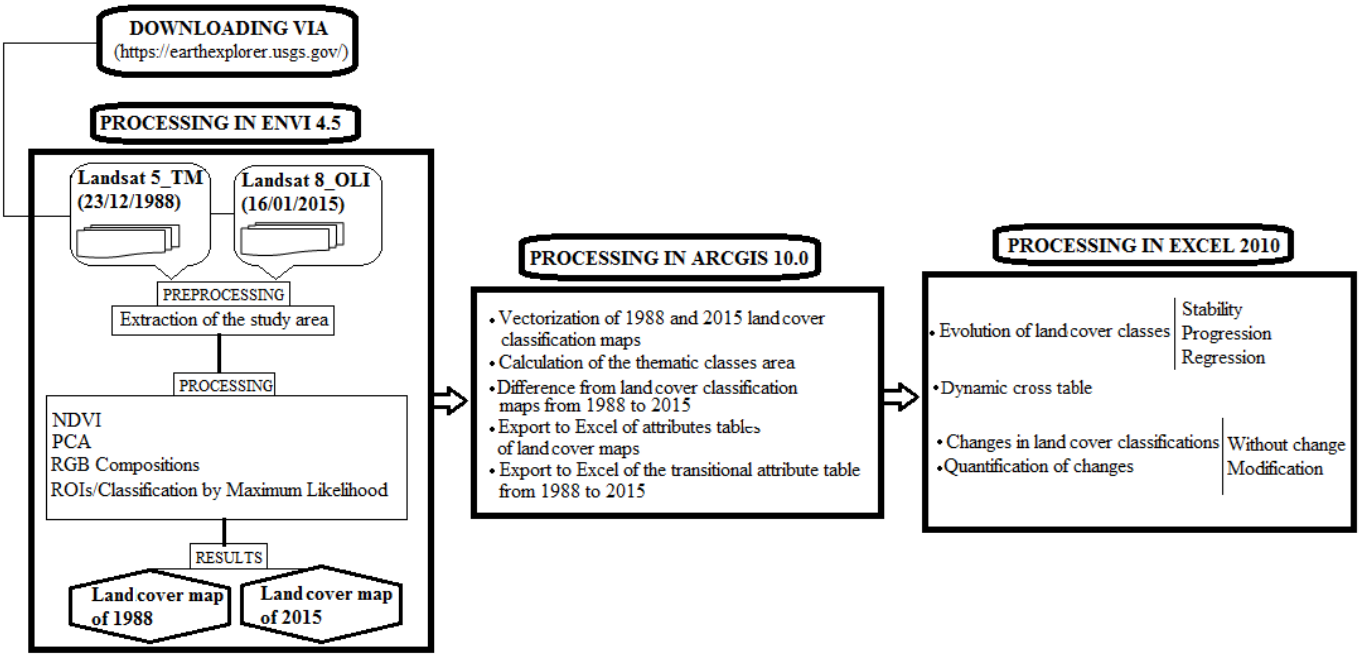

Figure 2: *Flow chart of satellite image processing*

The evolution of each land cover class is reflected in the relationship between the same class from 1988 to 2015. This relationship makes it possible to extract the "stable" or invariant areas characterized by values close to zero. "Regression" zones that indicate a loss of class surface and are characterized by a negative value. "Progression" zones of the class that translate a surface gain characterized by the positive value.

The changes in land cover are evidenced from the difference in land cover classification maps (Gupta et al., 1985) from 1988 to 2015 on ArcGIS 10.0. The resulting attribute table or transition attribute table that contains the number of pixels that have changed or not between the two dates is exported to Excel 2010 to highlight these different changes in land cover classes and to quantify them. Changes are characterized by a change or conversion of some or all of one class to another. Otherwise, the class remains stable or "unchanged".

3. Results and Discussion

3.1. Diachronic Analysis of Land Cover in the Years 1988 and 2015

The different colored compositions, the ACP and the NDVI made it possible to highlight six classes of occupation of the ground which are the water bodies, the habitats, the farming, the dense forest, the degraded forest and the savannah. Figures 3a and 3b show respectively the land cover maps from the supervised classification of the years 1988 and 2015.

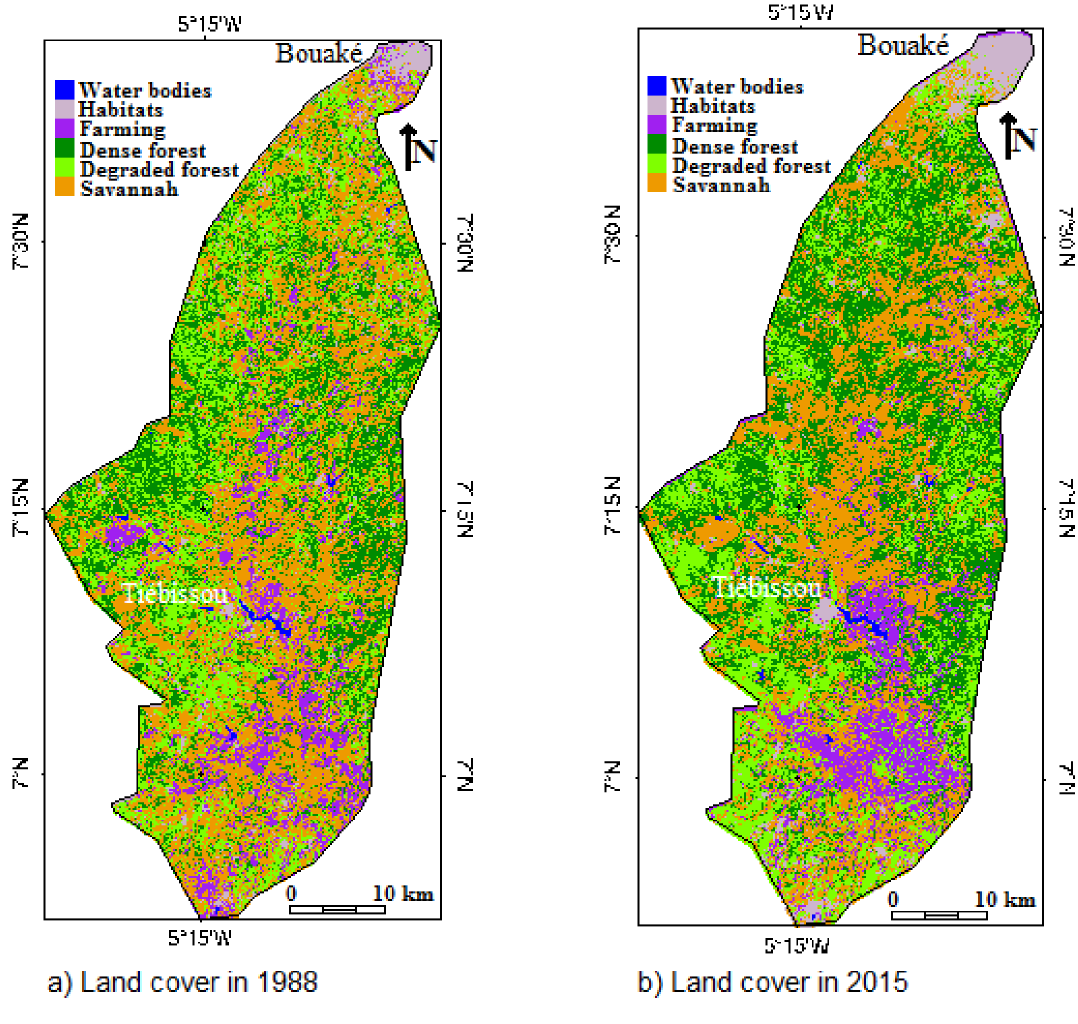

Figure 3: *Kan watershed land cover maps, 1988 (a) and 2015 (b)*

The spatio-temporal variation in the percentage of class sizes is shown in Figure 4.

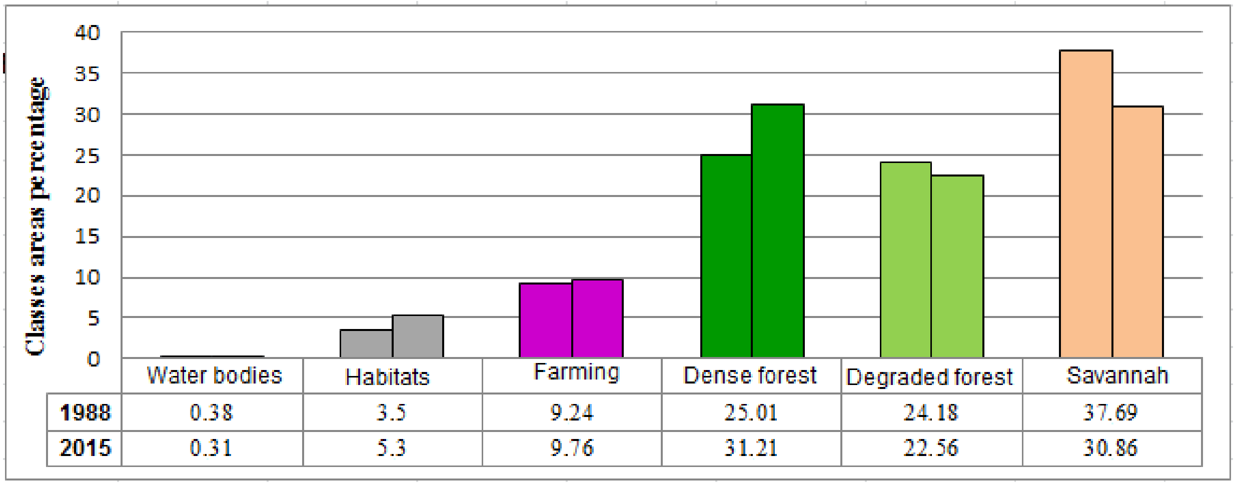

Figure 4: *Spatio-temporal variation in percentages of land cover classes sizes from 1988 to 2015*

The state of land cover in 1988 revealed a high proportion of savannah (37.69%) and a small proportion of water bodies (0.38%). The areas occupied by dense forest, degraded forest, farming and habitats vary respectively by 25.01%; 24.18%; 9.24% and 3.5%.

Compared with the year 1988, the highest proportion of land cover in 2015 is represented by dense forest (31.21%) and the lowest proportion (0.31%) is accounted for by water bodies. savannah, degraded forest, farming and habitats occupy respectively 30.86%, 22.56%, 9.76% and 5.3% of the total area of land cover in 2015.

3.2. Analysis of Changes in Land Cover from 1988 to 2015

Table 2 shows the evolution of land cover from 1988 to 2000.

Table 2: *Evolution of land cover in the Kan watershed from 1988 to 2015*

Years	Water bodies	Habitats	Farming	Dense forest	Degraded forest	Savannah
1988	0.38	3.50	9.24	25.01	24.18	37.69
2015	0.31	5.30	9.76	31.21	22.56	30.86
Evolution (1988-2015)	-0.07	1.80	0.52	6.20	-1.62	-6.83
Difference area	-1.34	37.53	10.77	129.39	-33.77	-142.58
Term	Regression	Progression	Progression	Progression	Regression	Regression

The Table 2 shows that land cover classes have evolved differently from 1988 to 2015. The savannah and degraded forest have strongly decreased (negative value of evolution) whereas the dense forest, the habitats and the farming have strongly progress (positive value of evolution). The water bodies remained practically stable (value of the regression statistically zero).

The evolution of land cover in the Kan watershed from 1988 to 2015 is illustrated in the graph (Figure 5).

The analysis of the evolution of land cover from 1988 to 2015 shows that the proportion of water bodies has hardly changed (around 0.07%). The latter has remained virtually stable. The dense forest, habitats and farming grew with respective proportions of 6.20%, 1.80% and 0.52%. Savannah declined sharply (6.83%) from 1988 to 2015, compared to the degraded forest which declined slightly (1.62%).

Figure 5: *Evolution of land cover from 1988 to 2015*

3.3. Detection of the Changes Made in the Different Classes of Land Cover from 1988 to 2015

This progression or regression of land cover classes has undoubtedly led to changes in the different classes presented in Table 3.

An analysis of Table 3 shows that all the land cover classes in the Kan watershed underwent more or less significant changes from 1988 to 2015. The total area of land cover is estimated at 1092.07 km² against 994.24 km² of the unmodified area, a percentage of 52.34% against 47.66%. The most important changes occurred at the savannah level with an area of 394.35 km², or 36.11%. The 394.35 km² of savannah have been converted to 40.40% in dense forest, 30.51% in farming, 20% in degraded forest, 9.05% in habitats and 0.04% in water bodies. The least significant changes affected the water bodies with an area of 2.18 km², or 0.20%. The classes of degraded forest, dense forest, farming and habitats changed with respective proportions of 26.31%, 22.30%, 11.77% and 3.32%.

The most dramatic changes in each land cover class (Table 3) are as follows:

- Farming: 70.95% of the area converted to savannah;
- Degraded forest: 67.03% of the area converted into dense forest;
- Dense forest: 65.74% of the area converted into degraded forest;
- Water bodies: 51.42% of the area converted into savannah;
- Habitats: 43.18% of the area transformed into savannah;
- Savannah: 40.40% of the area converted into dense forest.

Table 3: *Changes made in the different land cover classes from 1988 to 2015*

Land cover in 1988	Modified land cover classes from 1988 to 2015		Changes in each land cover class from 1988 to 2015		
	Modified areas (km²)	Percentage	Classes	Areas (km²)	%
Farming	128.52	11.77	Degraded forest	8.03	6.25
			Dense forest	14.34	11.16
			Habitats	14.68	11.42
			Water bodies	0.28	0.22
			Savannah	91.18	70.95
Degraded forest	287.31	26.31	Farming	6.09	2.12
			Dense forest	192.59	67.03
			Habitats	16.14	5.62
			Water bodies	0.18	0.06
			Savannah	72.31	25.17
Dense forest	243.50	22.30	Farming	4.79	1.97
			Degraded forest	160.08	65.74
			Habitats	6.98	2.87
			Water bodies	0.13	0.05
			Savannah	71.52	29.37
Habitats	36.21	3.32	Farming	7.94	21.93
			Degraded forest	6.24	17.22
			Dense forest	6.30	17.40
			Water bodies	0.10	0.27
			Savannah	15.64	43.18
Water bodies	2.18	0.20	Farming	0.15	6.89
			Degraded forest	0.32	14.60
			Dense forest	0.33	15.05
			Habitats	0.26	12.03
			Savannah	1.12	51.42
Savannah	394.35	36.11	Farming	120.32	30.51
			Degraded forest	78.88	20.00
			Dense forest	159.33	40.40
			Habitats	35.68	9.05
			Water bodies	0.14	0.04
Modified tatal area	1092.07	52.34			
Kan watershed area	2086.31	100			
Unmodified area	994.24	47.66			

3.4. Discussion

The technique of classification of the occupation of the ground implemented, the evolution of the classes and the various changes made in these classes deserve to be discussed. As long as the spectral characteristics of objects on the surface of the soil observed change over time, the comparison of multitemporal images makes it possible to detect the existence of possible changes

(Guarguet-Duport and Girel, 1995). In the present study, the results of the changes show some imperfections, notably confusions between certain classes whose characteristics are very close together during the classification. These include habitats modification, habitats conversion to farming, water bodies and savannah. Some modifications are probable since this dynamic take place over a period of 27 years. Nevertheless, a ground truth deserves to be undertaken. These confusions are also observed in the case of the transformation of degraded forest into dense forest and / or savannah and vice versa. The Landsat TM and OLI images, taken in the savannah zone and in the dry period, the vegetation is mostly herbaceous and tends to dry (without chlorophyllous activity) to mingle with bare soil. The few semi-deciduous dense forests and scattered crop plants in the savannah do not facilitate the discrimination of these classes. This same remark was made by N'Da et al., 2008; Aahda et al., 2008; Soro et al., 2013.

The maximum likelihood-supervised classification technique, however, remains relatively reliable (Brou, 2005, Koudou, 2013, Soro et al., 2014, Havyarimana, 2015, Koffi-Didia and Coulibaly, 2017) and is considered very reliable performing in the case of land cover map development (Kouassi, 2007). However, the single multispectral classification is ineffective in achieving an indisputable mapping of land cover from images. It is therefore necessary to use different image analysis procedures (spectral, textural and mathematical morphology) (Noyola-Medrano, 2006). The difficulty of certain land cover classes to be discriminated more particularly in the countries of sub-Saharan Africa was also highlighted by Kayembe et al. (2009).

Notwithstanding some confusions in some classes, these images have somehow been able to reveal the general trend of the dynamics of land cover in the Kan watershed. The strong progression of the dense forest and sharp regression of the savannah is in agreement with the results of Soro et al. (2014) in the center of Côte d'Ivoire.

The increase in the area of farming and habitats is attributable to population growth in this predominantly agricultural region where human pressure is constantly causing anthropisation of natural areas. As for the progress of the dense forest, it is due to the reforestation policy implemented by the Ivorian state and the introduction in this part of the territory of new cultural practices (rubber, etc.).

The even insignificant regression observed at the level of water bodies is to be attributed to the combined action of water withdrawals in the various dams or reservoirs for agricultural development and the evaporation of these plans of water. This situation causes the splitting up of rivers and even their almost complete drying up in very dry years. According to Soro et al. (2014), there is a food deficit or a decrease in surface runoff.

These multiple evolutions and changes in the land cover classes of the Kan watershed reflect a considerable impact of human activity (bushfires throughout the dry season, urban sprawl supported by population growth, agricultural development, etc.) on land cover.

4. Conclusion

The study of land cover dynamics of the Kan watershed using Landsat TM and OLI imagery allowed us to monitor changes in each land cover class and to quantify their evolution. From 1988 to 2015 in the Kan watershed, the classes of land cover of dense forest, habitats and farming grew by respectively 6.20%, 1.80% and 0.52%. The savannah and the degraded forest have regressed. The regression was strongly felt in savannah (6.83%) and dense forest (1.62%). The water bodies remained virtually stable. In addition, all land cover classes in the Kan watershed have undergone more or less significant changes during this period. The total modified area of the land cover classes is estimated at 1092.07 km² or 52.34%, compared to 994, 24 km² of the total unmodified area (47.66%). The most important changes occurred in the savannah (36.11%) while the least important changes were in the water bodies (0.20%). Degraded forest, dense forest, farming and habitats changed with respective proportions of 26.31%, 22.30%, 11.77% and 3.32%.

Within each class, dramatic changes have occurred in different proportions:

- 70.95% of the farming were transformed into savannah;
- 67.03% of the degraded forest has been converted into dense forest;
- 65.74% of the dense forest has been converted into degraded forest;
- 51.42% of the water bodies were transformed into savannah;
- 43.18% of the habitats were transformed into savannah;
- and 40.40% of the savannah has been transformed into dense forest.

All these changes are due to the combined action of human activities supported by population growth and climate change.

The present study opens perspectives on the dynamics of the occupation of the soil in the years to come. It involves using predictive modeling, which is a projection technique on the future of a landscape, which takes into account all the socio-economic and biophysical factors that explain the changes observed in the occupation of soil in the future.

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