Land use analysis of the N'ZI watershed (Côte d'Ivoire) using multi-date and multi-source satellite data

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October 16, 2022

Abstract

The uncontrolled rapid population growth in our regions and strong industrialization are putting pressure on natural resources, accelerating climate change and desertification. This study aims to follow the evolution of land use in the N'ZI watershed. Three images from Landsat 4 & 5 (1986), Landsat 7 (2000), and Landsat 8 (2020) made it possible to carry out this study. Remote sensing and geographic information systems (GIS) have been used to monitor land cover as a whole. The software Envi 5.1 and ArcGIS 10.4.1 have made it possible to do various treatments. The supervised classification method was used in this work in addition to the calculation of the spectral indices. The land-use analysis showed the changes that took place during the periods 1986-2000, 2000-2020, and 1986-2020. The results of this analysis showed regression of water surfaces (-64.95% and-52.47%) over the period (2000-2020 and 1986-2020) on the other hand, there is a great increase in bare-ground dwellings (373.63%) and low-cover soils (10.60%). These progressions are at the expense in particular of forests (-86.93%), savannas (-3.97%), and agricultural areas (-9.30%) between 1986-2020.

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Abstract

The uncontrolled rapid population growth in our regions and strong industrialization are putting pressure on natural resources, accelerating climate change and desertification. This study aims to follow the evolution of land use in the N'ZI watershed. Three images from Landsat 4 & 5 (1986), Landsat 7 (2000), and Landsat 8 (2020) made it possible to carry out this study. Remote sensing and geographic information systems (GIS) have been used to monitor land cover as a whole. The software Envi 5.1 and ArcGIS 10.4.1 have made it possible to do various treatments. The supervised classification method was used in this work in addition to the calculation of the spectral indices. The land-use analysis showed the changes that took place during the periods 1986-2000, 2000-2020, and 1986-2020. The results of this analysis showed regression of water surfaces (-64.95% and -52.47%) over the period (2000-2020 and 1986-2020) on the other hand, there is a great increase in bare-ground dwellings (373.63%) and low-cover soils (10.60%). These progressions are at the expense in particular of forests (-86.93%), savannas (-3.97%), and agricultural areas (-9.30%) between 1986-2020.

Keywords: Land use, multi-date satellite data, N'ZI watershed, Côte d'Ivoire.

Introduction

The forest resource of Côte d'Ivoire was estimated at 16 million hectares in 1900, the country's forest cover was only 7,850,864 ha in 1986 and 3,401,146 ha in 2015(BNETD and Tera, 2016). The country lost a total of 78% of its crop cover, because, the expansion of agriculture occupies 62% of the Ivorian territory (BNETD and Tera, 2016). Forest area has fallen to more than 2 million hectares today (Koné et al., 2021; Assoma et al., 2021). Studies (Kouassi, 2010) on the N'ZI catchment area indicate a real decline in clear forests and forested savannah by more than 14.95%, Dense forests probably decrease by 1.93%, and shrub and/or grassland savannah by less than 15.15%.

The forests are composed of degraded secondary forests around the N'ZI River in particular (17% degraded forest, 10% light forest, and 3% gallery forest) (Noho et al., 2018). The watershed of the N'ZI River constitutes a feeding zone between the savannah and forest areas. This basin was the loop of cocoa and coffee between the period 1960-1980 (Brou et al., 2005). The population explosion in the study area has grown rapidly from 900,000 inhabitants to 3,030,381 inhabitants (INS, 2014), consisting of anthropogenic causes and rural land tenure have created great pressure on resources, in particular land degradation, thus leading to the abandonment of land to other sources of income. In the search for information leading to the abandonment of land to other more productive regions, remote sensing and geographical information systems (GIS) have been chosen to monitor the evolution of land use in the N'ZI watershed, to inform public opinion. Remote sensing is a powerful tool for providing quantitative spatial information to assess land use changes. This tool allows the measurement of the different forms of landscape change according to the level of land use and the temporal dynamics of these changes (Dietzel et al., 2005). However, quantitative analysis of landscape changes is fundamentally dependent on available geographic data, including spatial data (cartographic, photographic, or satellite) and the spatial resolution of the data used. Then, visualization of land cover and land use in the N'ZI watershed, based on satellite data, could be a primary means of understanding changes in land use and decision-making, to the extent that it has expected benefits.

Changes in soil surface classification methods and criteria vary from author to author (Hoang et al., 2009). These methods fall into three processing techniques: visual interpretations, pixel-based methods, and object-based approaches (Desclée et al., 2006). Today, the main classification methods used are supervised and not supervised.(Achbun et al., 2011). In this work, the aim is to use the supervised classification method to characterize the dynamics of land use, then quantify the changes in land use, to identify their evolution in the watershed of the N'ZI.

1. Presentation of the study area

Figure 1 shows the geographic location of the study area. The study area is a sub-watershed of Bandama. It is drained by the N'ZI River and its tributaries, located between longitudes 3°49'-5°22' West and latitudes 6°00'-9°26' North. It covers an area of 35076.4 km², about 10.88% of the national territory. And the N'ZI river runs about 600 km long today. The watershed of the N'ZI is composed of 80 sub-prefectures and is limited to the north by the department of Ferkessédougou, to the south by the departments of Tiassalé and Divo, to the east by the department of Daoukro, and to the west by the department of Béoumi. The N'ZI watershed is generally dominated by a fairly monotonous relief (Perraud, 1971), the altitude of which varies from approximately 668 m in the north to less than

130 m in the south. The main soil types are medium-saturated (North) and strongly-saturated (Central and South) ferritic soils (Monnet, 1972; Koudou *et al*., 2016). Due to its elongated geographical configuration, the N'ZI watershed (Figure 1) is representative of the major climatic groups of Côte d'Ivoire. The central part of the basin is characterized by a humid tropical regime. The south of the basin is characterized by an equatorial regime.

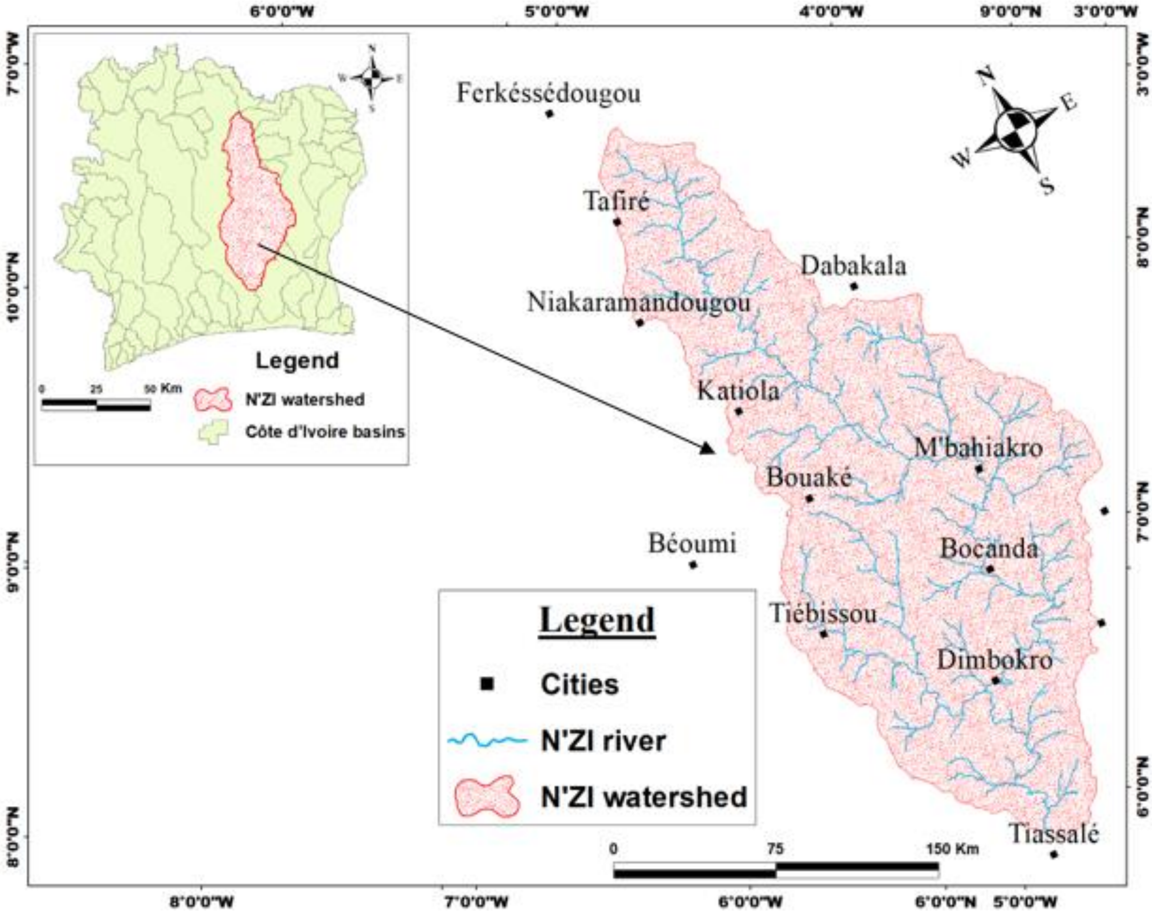


Figure 1: Presentation map of the N'ZI watershed

2. Material and Methods

2.1. Data used

Three multi-date satellite images are used in this work to study the evolution of the basin's land use. These are images from Landsat 4 TM from 1986, Landsat 7 ETM+ (Enhanced Thematic Mapper plus) from 2000, and Landsat 8 OLI from 2020. The study area is covered by the scenes that are: 196-054, 196-55, 196-056, 197-053, 197-054, and 197-055. They can be downloaded on: http://earthexplorer.usgs.gov, 30 m spatial resolution. Cartographic data on the evolution of the vegetation of Côte d'Ivoire at the scale of 1: 200,000, from the Remote Sensing Mapping Center (BNETD, 2016) were used.

2.2. Methods

The approach used to study changes in land use in the N'zi watershed is illustrated in Figure 2. The method adopted is divided into four phases. Phase one (1) consisted of downloads of data. The second (2nd) phase is devoted to pre-treatments. The third (3rd) phase is concerned with the treatment of satellite images. The fourth (4th) phase was dedicated to the analysis of the changes and the discussion.

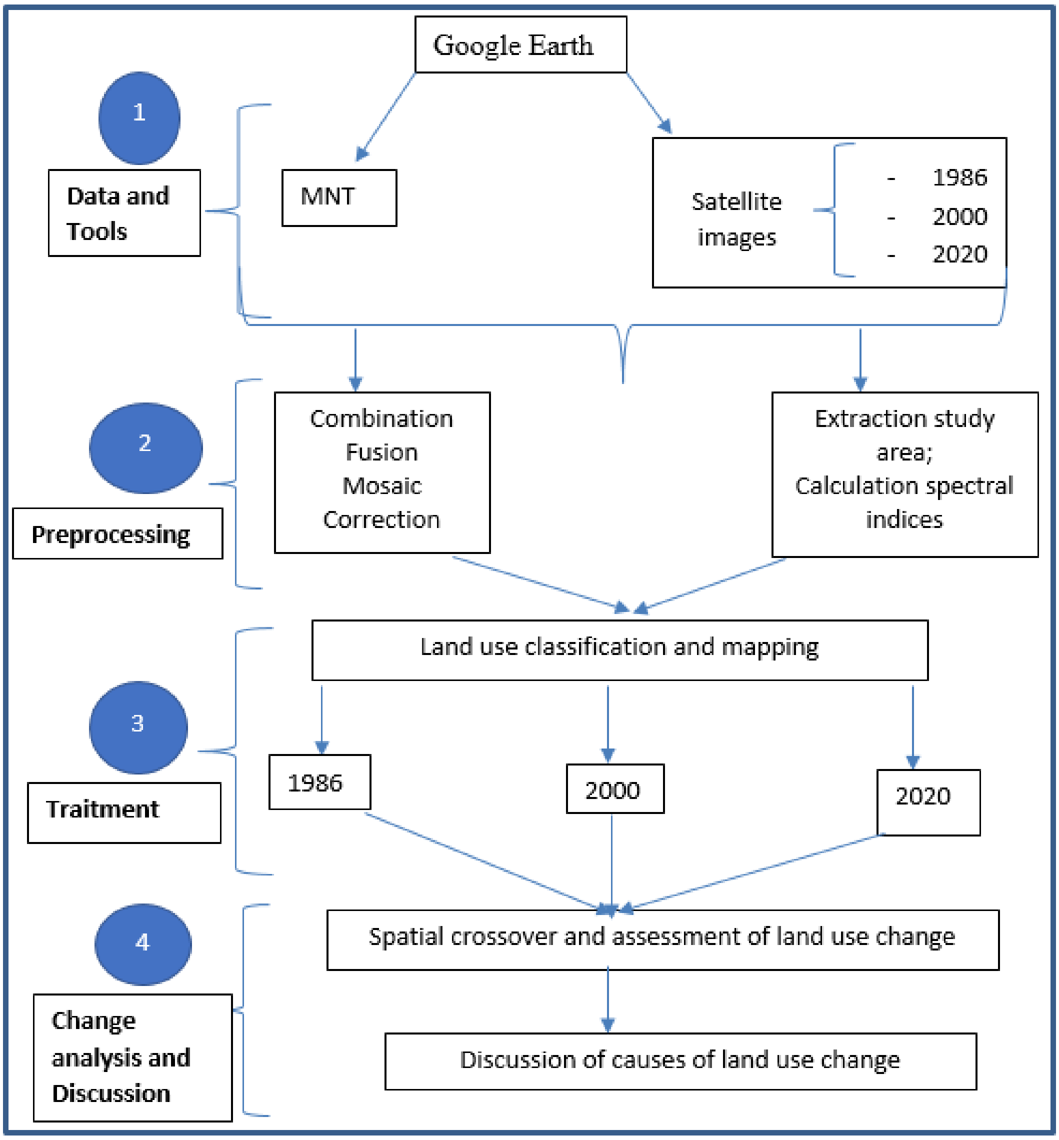


Figure 2: Organizational chart analysis of the evolution of land use between 1986, 2000 and 2020

2.3.1. Image preprocessing (pre-treatment)

The image pre-processing in this work consisted of applying radiometric correction, and atmospheric correction (QUAC module and FLAASH module), to get good readings of these spectral images. Several authors have already carried out these pre-treatments (Girard et al., 1999; Caloz and Pointet, 2002; Diallo et al., 2011; Tra Bi, 2013; Jofack-Sokeng, 2016; Chaima Grimene et al., 2019). The geometric correction was applied during the download, edited with the software ArcGIS 10.4.1, and projected into the projection coordinate system: WGS_1984_UTM_Zone_30N. Then, the assembly is applied to the strips to obtain a single multi-spectral image. Mosaicking of the scenes was done to form a larger image covering the study area. Finally, the extraction of the study area was done from the mosaic scenes using ENVI software to carry out the color composition of the bands. The combination of bands is as follows: bands (2, 3, and 5) for the 1986 image, bands (6, 5 and 4 or 4, 3 and 2) for the 2000 image, and bands (5, 6, and 7) for the 2020 image. These operations facilitated the interpretation and discrimination of regions of interest.

2.3.3. Image treatment

The processing of the images started with the calculation of spectral indices. The indices are chosen to describe and interpret the state of evolution of land use in the N'ZI watershed. This approach offers a way to analyze the bio-Geo-physical processes of landscape occupation and the degradation of the surface condition of the area. These indices describe the state of a phenomenon and are based on an empirical approach using experimental data (Caloz and Pointet, 2002; Hady Diallo et al., 2011; Grimene et al., 2019; Tra Bi, 2013). There are many, but this work has used indices such as the NDVI (Normalized Difference Vegetation Index), the IB (Gloss Index), the IR (Soil Redness Index), the IC (Coloration Index), the IBI (Built Sector Based Index). The visual interpretation of the colored compositions as well as the visualization of the maps of the calculated indices allowed a good reading of the information sought (degradation or change of the surface state). The land use classes discriminated in this study are validated by reconnaissance trips carried out in the study area to check the control points for the 2020 images (17; 18; 26 and 27/12/2020; 31/03/2021; 01; 02 and 08/04/2021). This justified the choice of the supervised classification method. For the 1986 and 2000 images, their visualization on Google Earth served as a photo interpretation to attest to the information. Finally, based on all this information, the areas of interest have made it possible to distinguish the different land use classes to opt for supervised classification. Therefore, the Maximum Likelihood algorithm has been chosen to visualize the land use maps.

2.3.3. Quantification of changes in land use in the N'ZI watershed

Quantification of changes in land use classes over the study period from 1986 to 2020 was used to detect changes in the study area using multi-date satellite images as follows:

- **Change (Δ) in the area of the unit concerned between 1986, 2000 and 2020**

Δ1, the difference in the area of the units concerned between 1986 and 2000;

Δ2, the difference in the area of the units concerned between 2000 and 2020;

Δ3, the difference in the area of the units concerned between 1986 and 2020.

If Δ1 or Δ2 or Δ3 = 0, the area of the unit is stable in time and space;

If Δ1 or Δ2 or Δ3 > 0, the area of the unit concerned is increasing;

Si Δ1 ou Δ2 ou Δ3 < 0, la superficie de l'unité concernée est dite en régression.

- **Change in the overall rate of change (Tg) in the area between 1986, 2000 and 2020**

The overall rate of change in the area of land use classes between years is estimated from the following equation, proposed by FAO (1996), which is commonly used to measure the growth of macroeconomic aggregates between two given periods (Alexis et al., 2018; Kpedenou et al., 2016b, and 2017; Salomon et al., 2021 Soro et al., 2014).

$$T_g = \frac{\Delta 2 - \Delta 1}{\Delta 1} \times 100$$

Finally, the change in the land cover of the N'ZI basin between the selected periods is certified by the difference in validation by analyzing the confusion matrix through the global precision and the Kappa coefficient (Congalton, 1991; Skupinski et al., 2009). To assess the degree of degradation of soil conditions in the basin, the methods already developed upstream and previously were used.

3. Results and discussions

3.1. Image corrections

Figure 3 shows the results of the radiometric and atmospheric corrections applied to 1986, 2000, and 2020 image scenes respectively.

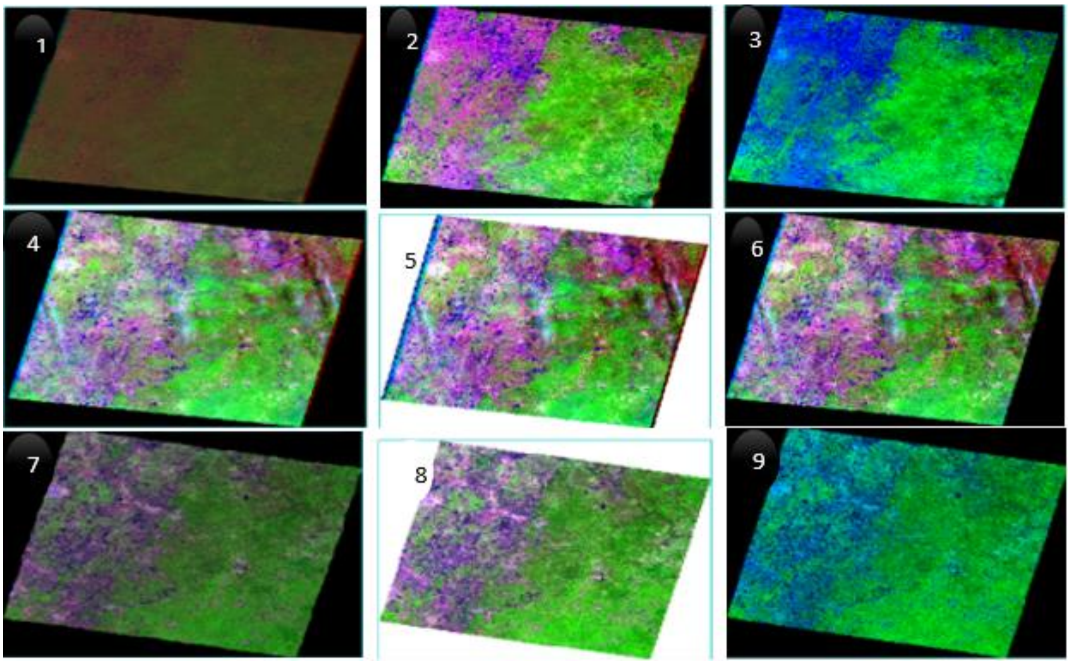


Figure 3: Raw image (1, 4 and 7), atmospheric (2, 5 and 8) and Radiometric (3, 6, and 9) corrections of Landsat images 1986 (1, 2, and 3), 2000 (4, 5, and 6), and 2020 (7, 8, and 9) respectively.

3.2. Image Mosaicking

It should be noted that the fusion of the bands follows the mosaics of the images. Fusion consisted of putting all the bands to produce a new image that retains the information contained in each of the original images.

The results of the different treatments have led to the mosaic stage presented by the maps (1986, 2000, and 2020) in Figure 4. The different scene mosaics are intended to create a new satellite image by combining several image scenes that cover the N'ZI watershed. This section concluded with the extraction of the study area shown on the maps in Figure 4.

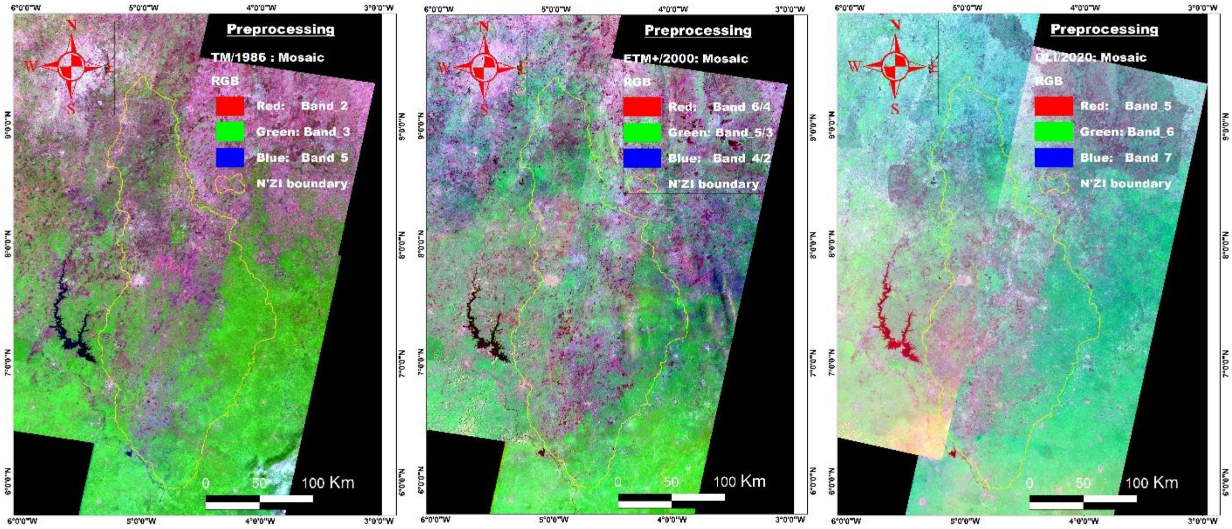


Figure 4: Mosaic of scenes and colored composition of bands.

3.3. Land use changes classes and maps

The pre-treatment and treatment methods contributed to 1986, 2000, and 2020 land use maps of the N'ZI watershed (Figure 5). The validation of the classification by the confusion matrix evolves significantly with Kappa values increasing slightly between 1986, 2000, and 2020 by 0.86; 0.90, and 0.92 respectively, and overall accuracy of 94.07%, 95.81%, and 94.39%. These values mean that more than 90% of the pixels in the three images were correctly classified according to the ground-truth data. The analysis of these images made it possible to define six (6) land use classes. These were the forest class; savannah class; low cover soil class; agroforestry and fallow plantation class; bare dwelling class; and water body class.

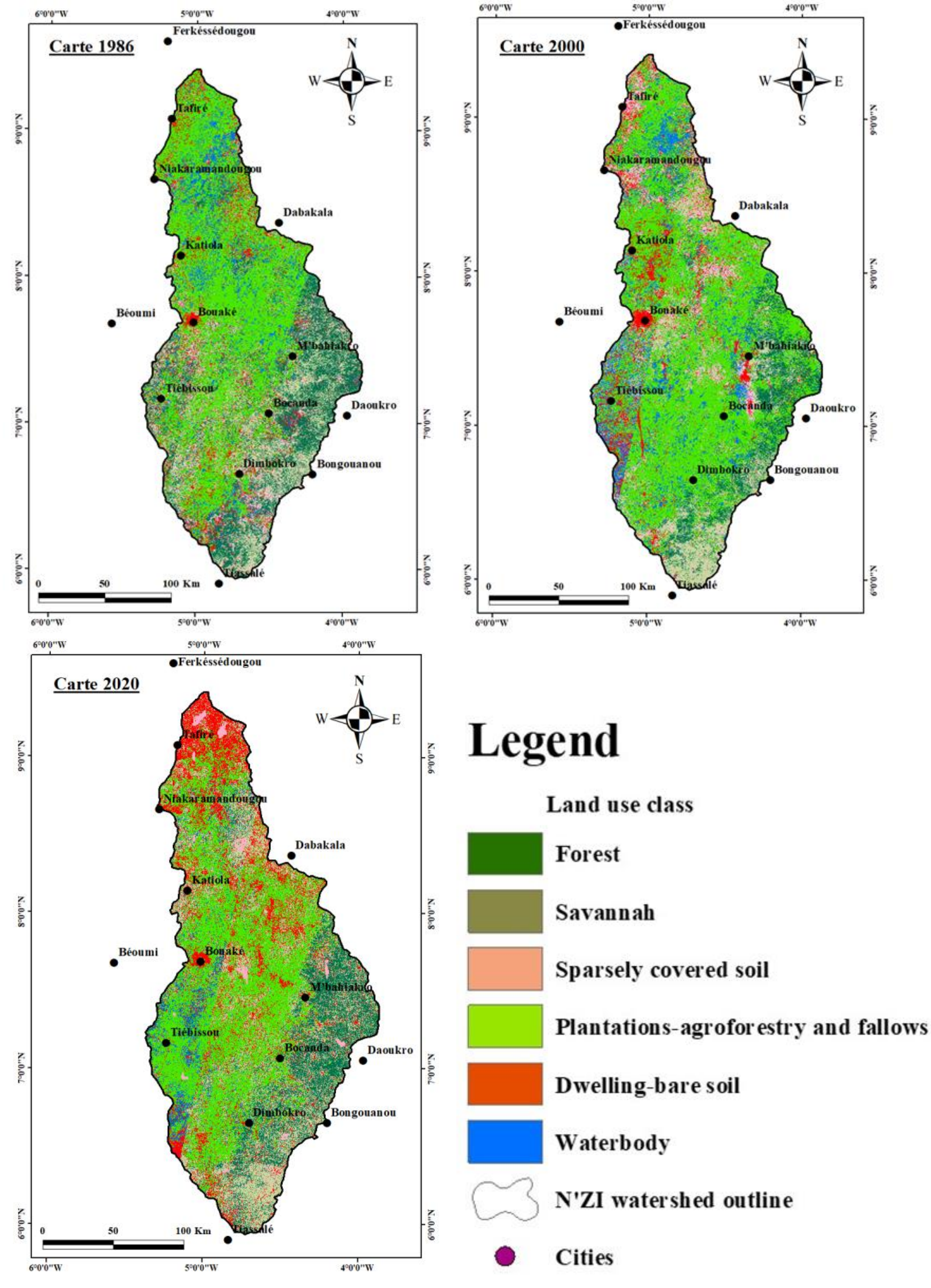
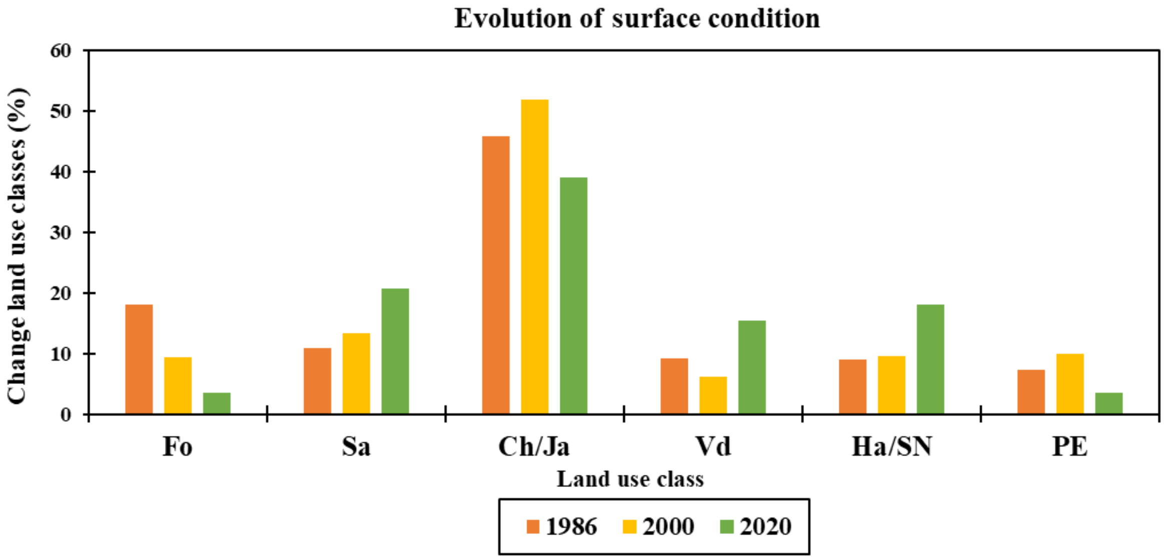


Figure 5: Land use maps of the N'ZI watershed from 1986; 2000 and 2020

- **Variation of the different classes**

The analysis of the evolution of land use classes in a GIS environment is illustrated by the histograms in figure 6. It shows a strong regression of the Forest class (18.01%; 9.42%; 3.52%) to the advantages of the Bare-Floor Housing class which rose from 8.89% in 1986 to 9.45% in 2000 and then to 18.08% in 2020. Forest decline also benefited the savannah class, which rose from 10.85% in 1986 to 13.30% in 2000 and 20.62% in 2020. While the Low Covered Soil class shows a particular increase of 15.35%

over the period 2000-2020. There is an average increase of about 6% in the Plantations-agroforestry and fallow land class from 1986 to 2000 and a sharp decrease of about 14% from 2000 to 2020. In addition, the Water Bodies class increased between 1986 and 2000 and decreased between 2000 and 2020 (Figure 6).



Fo: Forest; Sa: Savannah; SFC: Sparsely Covered Soil; Pl-Agro-Ja: Plantations-agroforestry and fallow land; Ha-SN: Dwellings-bare soil; PE: Waterbody

Figure 6: Spatial evolution of land use classes 1986, 2000 and 2020

3.4. Quantification of changes in land use

The histograms in Figures 7 show two trends in land cover classes, the periods 1986-2000; 2000-2020 and 1986-2020 has revealed the changes which have occurred. Those pointing down indicate a loss in the land use class. This means a rate of change from these classes to others. While the upwardly oriented histograms highlight a gain. This means a rate of change from these classes to others. While the upwardly oriented histograms highlight a gain (Figure 7). This is a change of landscape from the study area to other landscapes and vice versa. The results show a regression of forests (Fo), water bodies (PE), and plantations-agroforestry and fallow (Pl-Agro-Ja). Except for the period 1986-2000, there is a progression of Water Bodies, and Plantations-agroforestry and fallow. There was a large increase in Savannah, low-cover soils, and bare dwellings over the periods 1986-2000, 2000-2020, and 1986-2020 (Figure 7).

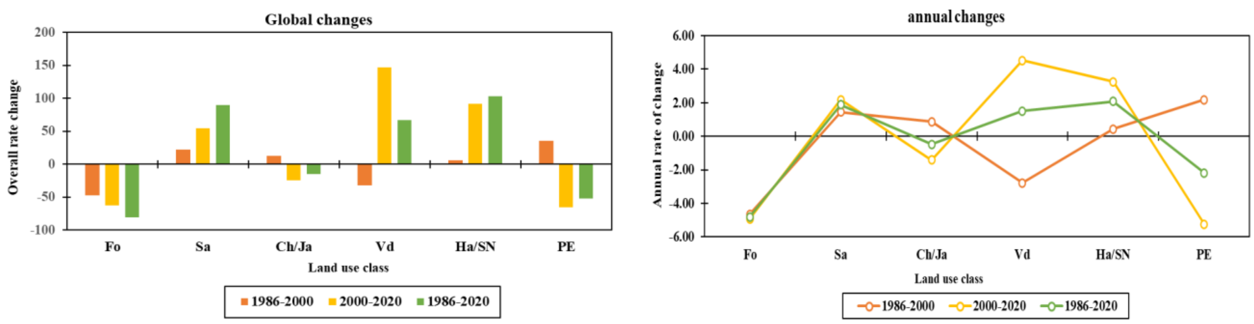


Figure 7: variation in land use classes in the N'ZI watershed

3.5. Structuring changes

Figures 8, 9, and 10 show the different statistical variations in the temporal change of land use classes in the N'ZI watershed. After analyzing the evolution of the different classes, there is a strong transformation of land use classes over the periods 1986-2000, 1986-2020, and 2000-2020.

- **General change in land use**

Figure 8 provides information on the different variations in the overall change of forest, savannah, low cover, plantation-agroforestry and fallow, dwelling-bare land; and water body classes over the periods 1986-2000, 2000-2020, and 1986-2020 that did not change.

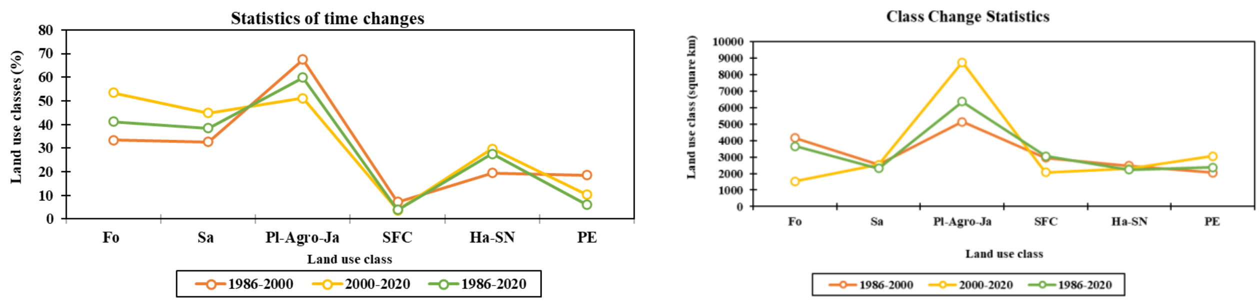


Figure 8: Statistical evolution of changes in land use units between 1986, 2000 and 2020

- **changes in the different land use classes**

Figure 9 shows the changes in the different land use classes considered during the different calibration periods 1986-2000, 2000-2020, and 1986-2020.

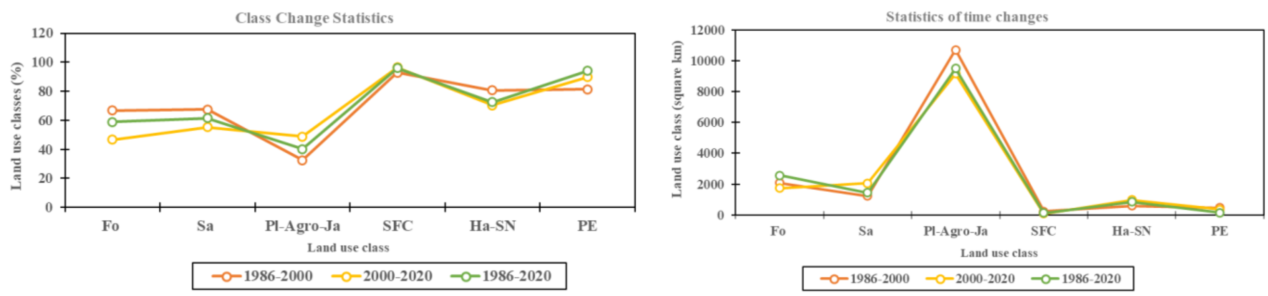


Figure 9: Statistical summary of changes in land use units between 1986, 2000 and 2020

- **variability of individual class changes**

Figure 10 clearly illustrates the different changes in percentage and area of the classes considered during the periods studied: 1986-2000, 2000-2020, and 1986-2020. The forest, low soil cover, and water classes have decreased significantly over the three periods, except for an increase in water over the period 1986-2000. On the other hand, there was a strong increase in the savannah, bare dwelling and agroforestry, and fallow classes over the periods 1986-2000 and 1986-2020. Except between 2000 and 2020 that there has been a decline in plantations-agroforestry and fallow land.

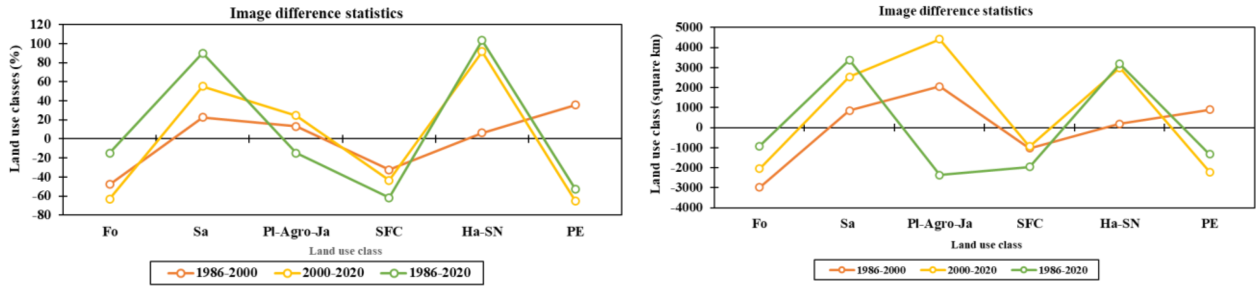


Figure 10: Statistical summary of changes in land use units between 1986, 2000 and 2020

3.6. Calculation of omission and commission errors

Errors of commission and errors of omission are summarized in Table 3.

Omission errors, the highest rates are recorded in the low cover class on the 2000 and 2020 images and the 1986 image in the Bare dwellings class.

Commission errors, the highest rates are also observed in the low coverage soil class for 1986, 2000, and 2020 images (Table 1). Error rates are very low, below 15% in general, except at the level of soil classes poorly covered in 2020.

Table 1: Variation of class discrimination errors on images (1986, 2000, and 2020)

1986	Commission errors (%)	Omission errors (%)
Forests	11,54	2,58
Savannah	1,49	3,84
Plantations-agroforestry and fallow	6,07	6,16
Low cover soils	27,22	1,52
Bare dwellings	10,98	8,71
Water body	3,67	6,44
2000	**Commission errors (%)**	**Omission errors (%)**
Forests	12,76	4,41
Savannah	4,73	5,53
Plantations-agroforestry and fallow	3,92	2,44
Low cover soils	14,94	13,53
Bare dwellings	5,42	7,44
Water body	0,46	3,01
2020	**Commission errors (%)**	**Omission errors (%)**
Forests	21,85	1,69
Savannah	12,75	5,72
Plantations-agroforestry and fallow	1,94	2,49
Low cover soils	43,86	70,09
Bare dwellings	3,9	5,78
Water body	2,42	6,56

3.7. Discussion

The classification models and the different remote sensing images of 30 m spatial resolution were used to generate the land use classes as well as the detection of changes in general in the basin. About these means of studying land use by satellite data, several researchers have made use of them in recent work by showing the contribution of Landsat images in the discrimination of the main categories of land use (Alexis et al., 2018; Diallo and Bao, 2010; Agoualé et al., 2017; Kouassi, 2010; Lienou, 2009; Mellor et al., 2013; Pal and Antil, 2017; Pelletier, 2017; Salomon et al., 2021; Useni et al., 2020; Noho et al., 2018). The land use classification resulting from the analysis of the 1986 TM images, the 2000 ETM+ images, and the 2020 OLI images gave overall accuracies (94.07%, 95.81%, and 94.39%) and Kappa coefficients of 0.86; 0.90 and 0.92 respectively for the years 1986, 2000 and 2020. According to (Landis and Koch, 1977; Pontius Jr, 2000) classifications are statistically good qualities and can be used wisely for the remainder of the study. Indeed, for an image analysis whose Kappa value is higher than 0.50, the results are good and exploitable. But, if the results are acceptable, they must not lose sight of the constraints encountered when analyzing the images used. Indeed, errors were recorded during the analysis of the images from several sources when discriminating against the classes mentioned. These errors can be explained by the confusion between classes with generally similar spectral signatures. In addition, the difficulties of visual observation make the distinction of the elements of land use delicate by the structure of the landscape offering homogeneous characters. This can be explained by the fact that Savannah, forest, and low-covered soils are very heterogeneous in terms of temporal evolution. They are developed, with rubber and cocoa plantations in the south and towards the center-north with cashew plantations; Also included are agricultural clearings and areas used for food crops in the previous year after the harvest (fallow). Also, cocoa plantations are mainly grown under forests. This can make it difficult to discriminate between the different formations. The same observation was made by (Kouassi, 2019; N'Guessan, 2020). Bare-ground dwellings blend with the savannah to the agricultural grip and the savannah. Analysis of the results of the evolution of the natural environment in the N'ZI watershed is regressive between the three dates. Looking at land use maps, it appears that this degradation appears to be general and affects almost the entire basin. The overall rates of change over the 1986-2000, 2000-2020, and 1986-2020 series show regressions for the forest, savannah, plantation-agroforestry, and fallow and dwelling-bare land classes. Natural formations (forests, savannas) are increasingly replaced by anthropogenic occupation classes (fields and fallows, plantations and agroforestry, dwellings-bare ground). The same finding is made by (Mama et al., 2013) on the territory of Benin and Togo (Koumoi et al., 2013; Kpedenou et al., 2017, 2016a; Takou et al., 2021). This situation of degradation of the natural landscape in the N'ZI watershed is also noted by Noho et al., (2018**)** and in the department of Katiola by Agoualé et al., (2017) in other parts of Côte d'Ivoire by studies by (Aké et al., 2012; Alexis et al., 2018). Environmental degradation, reflected in the regression of natural formations, is essentially linked to the development of socio-economic activities (e.g., slash-and-burn, timber and fuelwood, mining); as observed during the field missions (Figure 11). More significantly, there is a regression of vegetation formations and an increase in the area of anthropized landscapes in the basin. The main factors in the degradation of the vegetation cover are agriculture, the remarkable increase in the population of the N'ZI region between 2010 and 2014 (INS, 2014), and late wildfires that destroy everything in their path (granaries, plantations, and various natural plant formations). Results of the work by **Kouassi, (2019)** on the impact of bushfires in the N'ZI watershed confirm our results. These same observations were made in the studies of several authors on peri-urban occupations in the world (Salomon *et al.*, 2020, Useni *et al.*, 2020, Aguejdad and Hubert-Moy., 2016, André *et al.*, 2014). Charcoal production and crushing also contribute to soil and vegetation degradation. Savannas burned and left in the same state remain in the same places while increasing their surface area following the degradation of certain fallow areas. In addition to wildfires, livestock farming appears to be an activity that increases land degradation in the region (Figure 11). The study area is characterized by overgrazing aggravated by internal transhumance. Indeed, overgrazing leads to a reduction in the natural regeneration of woody plants, a decrease in herbaceous cover, and the stripping of the soil and its hardening according to Agoualé et al., (2017); Soungalo and Dessouassi, (2015).

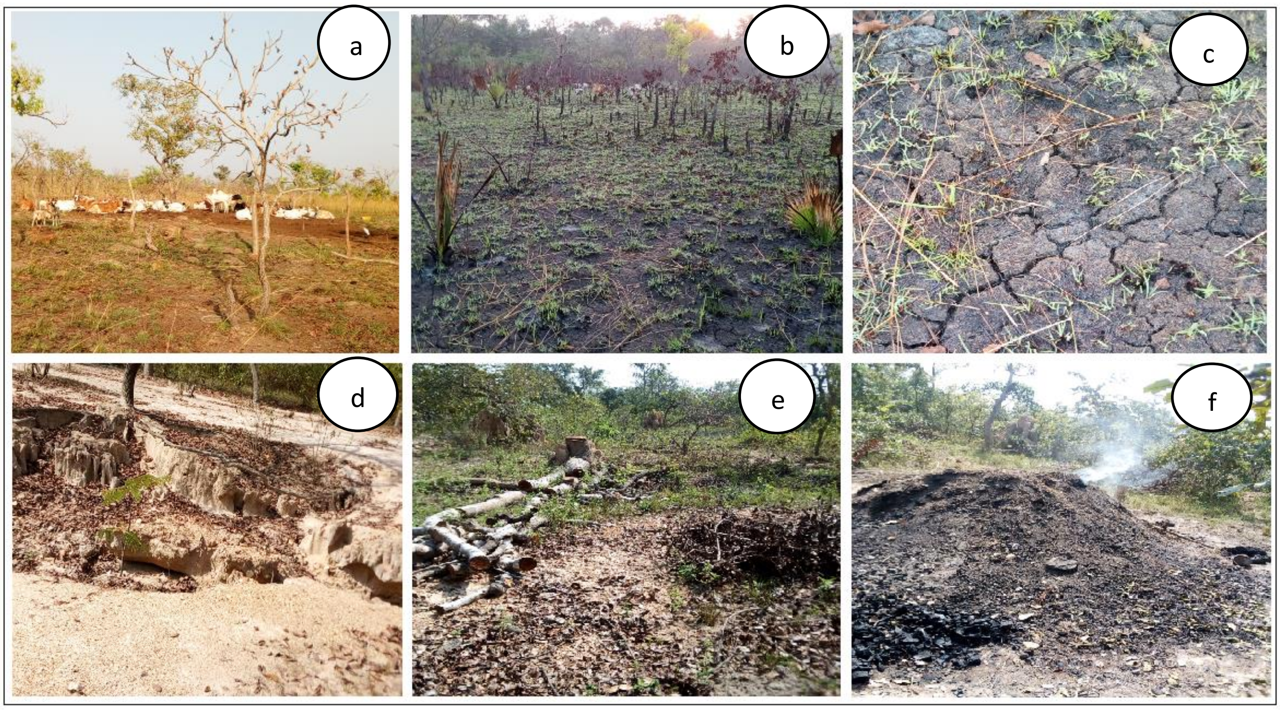


Figure 11 Illustrative photos attesting to the anthropized of the N'ZI watershed (field mission: 18; 26 and 27 /12/2020: a) Bouaké; b) M'bahiakro c) Fétékro; d) Bocanda; e) Katiola, and f) Dabakala)

Conclusion

This study shows that the N'ZI watershed has dynamic and rapidly changing environments. The discrimination of the regions of interest allowed to define of six (6) groups of land use (Forests; Savannas, Soils-low-cover; Plantations- agroforestry and fallow; Dwellings-bare soils; Water body) by the treatment of satellite images multi-dates (1986, 2000 and 2020). The confusion matrix of different dates with Kappa values which increase slightly between 1986, 2000, and 2020 respectively by 0.86; 0.90, and 0.92 testify to the classification of images was well done, when discriminating regions of interest. The detection of change using the area calculation, the overall rates of change, and the evolution statistics of the different class units indicate a degradation of the forest, plantation, and fallow classes, of the water areas in general. On the other hand, there are an increase in bare land (67.02%) and agglomerations (103.35%) to the detriment of forests (-80.45%) and water bodies (-52.47%). A regression of approximately (-14.87%) between 2000 and 2020 of plantations-agroforestry and fallow land to the advantage of savannas (89.98%). In the end, the basin is undergoing a significant change in all categories of its landscape. The most affected classes are groups of forests and water bodies that are renewed according to the rainfall fluctuations of the area.

References

Achbun, A., Mansour, M., Layelmam, M., Smiej, M., 2011. Comparative study of the object-oriented classification of a spot5 image for land cover mapping via Cognition 9. GEO OBSERVER N°19/2011, Royal Centre for Remote Sensing Morocco.

Agouale Y.J,Vei K.N, Afro M.J., 2017, Anthropogenic pressures and plant cover dynamics in the Sub-prefecture of Katiola, PhD student Alassane Ouattara University (Bouaké, Côte d'Ivoire), in Revue Ivoirienne de Géographie des Savanes, Issue 1, pp 78-86

Aguejdad, R., Hubert-Moy, L., 2016. Monitoring of the artificialization of the territory in urban areas by remote sensing and using landscape metrics. Application to a medium-sized town, Rennes Metropole, Cybergeo: European Journal of Geography. https://doi.org/10.4000/cybergeo.27465

Aké, G.É., Kouadio, B.H., Adja, M.G., Ettien, J.-B., Effebi, K.R., Biémi, J., 2012. Mapping of the multifactorial vulnerability to water erosion of soils in the Bonoua region (southeast of Côte d'Ivoire). Physio-Geo. Physical geography and environment 1–42.

Alexis, N., Kouadi, A., Deguy, J., Hien, A., Goula, A., Savané, I., 2018. Influence of land use dynamics on the amount of land loss south of the Sassandra watershed (Cote d'Ivoire).

International Journal of Advanced Research 6, 830–838. https://doi.org/10.21474/IJAR01/6918

André, M., Mahy, G., Lejeune, P., Bogaert, J., 2014. Towards a synthesis of the design and definition of areas in the urban-rural gradient. Biotechnology, Agronomy, Society and Environment 18, 61–74.

Assoma, V.T., Yao, N.A., Dio, J.S., Jourda, J.-P., 2021. Contribution of remote sensing and GIS to the mapping of land use changes in the Lobo watershed in Côte d'Ivoire. Physio-Geo. Physical geography and environment. 107–126. https://doi.org/10.4000/physio-geo.12654

BNETD, E., Tera, R., 2016. Qualitative analysis of the factors of deforestation and forest degradation in Côte d'Ivoire. UN-REDD Programme, Abidjan.

Brou, T., Y., O., Bigot, S., Servat, E., 2005. Deforestation risks in the permanent domain of the State in Côte d'Ivoire: what future for its last forests? Remote sensing 5, 105–121.

Caloz, R., Pointet, A., 2002. Contextual classification of very high-resolution images: Application to aerial photography.

Congalton, R.G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment 37, 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

INS, A.D., 2014. Mapping non-financial poverty in Abidjan District from the 2014 General Population and Housing Census of Abidjan Côte d'Ivoire 40.

Diallo, B.A., Bao, Z., 2010. Land cover change assessment using remote sensing: a case study of Bamako, Mali. Researcher 2, 7–14.

Diallo, Hady, Bamba, I., Barima, Y.S.S., Visser, M., Ballo, A., Mama, A., Vranken, I., Maiga, M., Bogaert, J., 2011. Combined effects of climate and anthropogenic pressures on the evolutionary dynamics of vegetation in a protected area of Mali (Fina Reserve, Baoulé Loop). Science and Global Change/ Drought 22, 97–107. https://doi.org/10.1684/sec.2011.0306

Dietzel, C., Oguz, H., Hemphill, J.J., Clarke, K.C., Gazulis, N., 2005. Diffusion and coalescence of the Houston metropolitan area: evidence supporting a new urban theory. Environ Plann B Plann Des 32, 231–246. https://doi.org/10.1068/b31148

Grimene, Chaima, Mghirbi, O., Le Grusse, P., Louvet, S., 2019. Spatial characterization of natural resource vulnerability and management of diffuse pollution risks related to agricultural phytosanitary practice. https://doi.org/10.13140/RG.2.2.16696.80640

Grimene, C., Mghirbi, O., Louvet, S., Le Grusse, P., 2019. Spatial characterization of natural resource vulnerability and management of diffuse pollution risks related to agricultural phytosanitary practices, in GFP (, F. (Ed.), 49. French Pesticide Group Congress: Pesticides and

Agroecological Transition: Challenges and Advances. GFP Editions, Montpellier, France, pp. 103–105.

Hoang, K., Bernier, M., Villeneuve, J.-P., 2009. Changes in land use in the Câu River watershed (Vietnam). Remote sensing.

Koné, K.H., Konan, K.E., Bi, Z.K., 2021. Characterization of the vegetation of the Comoé National Park (north-east of Cote d'Ivoire) 14.

Kouassi, A.M., 2010. Characterization of a possible change in the rain-flow relationship in West Africa: the case of the N'zi (Bandama) watershed in Côte d'Ivoire, PhD thesis, Cocody-Abidjan University, Côte d'Ivoire, 210 p. Physio-Géo. Physical geography and environment 3–4.

Kouassi, J.-L., 2019. Climate variability, fire dynamics, and local perceptions in the N'Zi watershed (Central Ivory Coast) (Ph.D. thesis). National Polytechnic Institute Felix Houphoët Boigny - Yamoussoukro., 250p.

Koudou, A., N'dri, B.E., Niamke, K.H., Adjiri, O.A., Sombo, A.P., Niangoran, K.C., 2016. Analysis of productivity and estimation of vulnerability to pollution for the optimization of the implantation of drilling in the basement aquifers of the N'zi watershed (Côte d'Ivoire). Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre 149–164.

Koumoi, Z., Alassane, A., Djangbedja, M., Boukpessi, T., Kouya, A.-E., 2013. Spatial and temporal dynamics of land use in central Togo. Ahoho - Revue de Géographie du LARDYMES 7, 163–172.

Kpedenou, K.D., Ahe, P., Boukpessi, T., 2016a. Spatio-temporal dynamics of land use/occupation in southeast Togo: mapping test using spatial, Ahoho,131–143.

Kpedenou, K.D., Boukpessi, T., Tchamie, T.T.K., 2016b. Quantification of land use changes in the Yoto prefecture (southeast Togo) using Landsat satellite imagery. Journal of Environmental Sciences 137–156.

Kpedenou, K.D., Drabo, O., Ouoba, A.P., Da, D.C.E., Tchamie, T.T.K., 2017. Analysis of land use for monitoring the evolution of the landscape of the Ouatchi territory in south-east Togo between 1958 and 2015. cahiers du cerleshs XXXI, 203–228.

Landis, J.R., Koch, G.G., 1977. The Measurement of Observer Agreement for Categorical Data. Biometrics 33, 159–174. https://doi.org/10.2307/2529310

Lienou, M.L., 2009. Machine learning of land use classes and visual representation of satellite images (Ph.D. Thesis). Telecom ParisTech.191p. ⟨pastel-00005585⟩

Mama, A., Sinsin, B., De Cannière, C., Bogaert, J., 2013. Anthropization and landscape dynamics in the Sudanese zone in northern Benin. Tropicultura 31.

Mellor, A., Haywood, A., Stone, C., & Jones, S. (2013). The performance of random forests in an operational setting for large area sclerophyll forest classification. Remote Sensing, 5(6), 2838–2856.

Monnet, C., 1972. Contribution to the study of the dynamics and nature of the suspensions of an intertropical river, Bandama, Ivory Coast: evolution of the chemical elements of the waters of its estuary. State Ph.D. thesis ès Sc. Nat, University of Nice, n CNRS, AO 7826, 427p.

N'Guessan, F.K., 2020. spatial dynamics of land use in the bembela finage (northeast of the ivory coast) 13.

Noho Y.A.W., N'guessan K.F., Koli B.Z 2018, Characterization of the vegetation of the N'zi catchment area (ivory coast), Félix Houphouët-Boigny University of Cocody-Abidjan, (EDUCI)

Pal, M., Antil, K., 2017. Comparison of Landsat 8 and sentinel 2 data for accurate mapping of built-up area and bare soil.

Pelletier, C., 2017. Mapping land use from time series of high-resolution satellite images: identification and processing of mislabelled data (Ph.D. Thesis)., University of Toulouse III-Paul Sabatier.

Perraud, A., 1971. The soils of Côte d'Ivoire. Avenard JM (ed.) The natural environment of Côte d'Ivoire. Submission ORSTOM 268–391.

Pontius Jr, R.G., 2000. Comparison of categorical maps. Photogramm. Eng. Remote Sens 66, 1011–1016.

Salomon, W., Sikuzani, Y.U., Kouakou, A.T.M., Barima, Y.S.S., Theodat, J.M., Bogaert, J., 2021. Mapping and quantification of forest cover loss in the national parks of the Republic of Haiti from 1985 to 2018: role of local agricultural activities. International Journal of Biological and Chemical Sciences 15, 477–496.

Skupinski, G., Tran, D.-B., Weber, C., 2009. Satellite images Spot multi-dates and spatial metrics in the study of urban and suburban change – The case of the lower Bruche valley (Bas-Rhin, France). CyberGeo: European Journal of Geography. https://doi.org/10.4000/cybergeo.21995

Soungalo, K., Dessouassi, R., 2015. Strict and Efficient Management of Water Resources in River Basin-A Case of the Cross Border Basin of Niger, in 5th International Yellow River Forum on Ensuring Water Right of the River's Demand and Healthy River Basin Maintenance Conference Location Zhengzhou, peoples r china. Yellow river conservancy press location Zhengzhou, pp. 418–423.

Takou, P.W., Houet, T., Tchiame, T., 2021. Prospective modeling of the city of Lomé: scenario, simulation, and prospective monitoring. Donni International Journal.

Tra Bi, Z.A., 2013. Study of the impact of anthropogenic activities and climate variability on vegetation and land use, by using remote sensing and agricultural statistics, on the Bouregreg watershed (MAROC). (Ph.D. doctorate). Artois. 1992p., http://www.theses.fr/2013ARTO0008/documenthttps://www.sudoc.fr/**184252598**

Useni Sikuzani, Y., Boisson, S., Cabala Kaleba, S., Nkuku Khonde, C., Malaisse, F., Halleux, J.-M., Bogaert, J., Munyemba Kankumbi, F., 2020. Land use dynamics around mining sites along the urban-rural gradient of the city of Lubumbashi, DR Congo. Biotechnology, Agronomy, Society, and Environment.