Original Research Article

Mapping of the geospatial dynamics of plant formations in the upper Ouémé sub-catchment by remote sensing and GIS approach (Benin)

Abstract

This work aims to map the geospatial dynamics of plant formations in the upper Ouémé sub-watershed from 1995 to 2020, i.e. 25 years. To achieve this objective, the combination of different methodological approaches were used. These are the remote sensing and GIS approach, Benaz plant formation inventory techniques, direct field observations and the calculation of the normalized vegetation index. Processing of satellite images from Landsat TM 5 (1995), Landsat 7 ETM+ sensors from 04-23-2002 and 05-14-2005, Landsat 8 OLI/TIRS from 03-04-2015 and 03-06-2015 and finally that of Sentinel-2B of 04-23-2020 enabled the results to be achieved.

Thus, different classes of forest entities were discriminated (dense forests, gallery forests, open forests and wooded savannas, wooded and shrubby savannas and grassy savannas). Between 1995 and 2020, the rate of plant formations increased from 95.98 to 66.32%, i.e. a plant cover of 611,971 ha in 1995, 591,672 ha in 2005, 561,595 ha in 2015 and 422,528 ha in 2020 with a NDVI which oscillates between -0.076 and 0.315 during this last year. Benaz's method has made it possible to carry out ecological and phytosociological surveys and to measure the diameters and heights of trees in the identified formations.

Despite the efforts to conserve and protect the natural resources available to the study area, wood resources are in decline, as they are subject to anthropogenic pressure amplified by population growth and uncontrolled activities.

Key words: Cartography, geospatial dynamics, plant formations, watershed, BENIN.

Introduction

Inbotanical land inbiogeography, a plant formation designates aplant species community, characterized by a certain physiognomy, and which determines acountrysidefeature (wikipedia.org).

Being a plant formation, forests play a big role in our daily life. It performs multiple functions which confirm its usefulness: soil and water conservation, limitation of the effects of climatic irregularities, braking of erosion, restoration of soil fertility (FAO, 1992, pp. 43-45).

Today, serious threats weigh on the natural resources subjected, on the one hand, to the effect of the climatic changes and, on the other hand, to the impacts of the actions of the man..

Like other African countries, these threats are increasingly felt in Benin, a West African country where the primary sector is booming. Handicapped by these meager forest resources and because of its location in the dry corridor called Dahomey-Gap, Benin is not immune to this squandering of natural resources (AC Adomou et al., 2007, p. 221 – 233).

According to the FAO, tropical forests and woodlands are essential to the economic and social well-being of developing countries (FAO, 1994,www.fao.org).

Despite the multiple functions of the forest, we see that the primary objective of the populations is to transform these resources to meet their daily needs through several income-generating activities. However, the pressure on theplant formationsof the SBV of the OS disappears at a very accelerated rate.

Thus, several factors such as demographic, economic, institutional, socio-political and cultural pressure contribute to the degradation of these formations. The latter therefore results from complex processes and in most cases, it is impossible to isolate a single cause (D. Kaimowitz and A. Angels in, 1998, pp. 73-98; A. Contreras-Hermosilla, 2000, p. 18).

Agricultural production, grazing, bush fires, logging, etc., are major causes of land degradation and deforestation indeed contributes to the degradation of production systems, the deterioration of the environment, the loss of biodiversity, the increase in greenhouse gases, the drop in agricultural yields and the exacerbation of poverty.

But, it is clear that atBenin, plant formations unfortunately not available to many communities are threatened by a number of environmental problems. The issue of the environment is marked by anarchic and uncontrolled deforestation resulting in part from the practice of itinerant slash-and-burn agriculture and extensive livestock farming which end up transforming due to the demographic explosion and the reduction in time vast area fallows formerly covered with forests and where trees and shrubs proliferated, in completely denuded, even desert regions with the key to the almost total disappearance of biodiversity (I. Bamba, 2010, p. 52).

It is following these multiple alarming observations and the relevance of this theme, it is necessary for this research work to use geomatics. The latter brings together all the tools and methods used to represent, analyze and integrate geographic data. It uses new technologies for image processing, photo-interpretation and mapping, all in a computer tool for data acquisition, storage, processing and dissemination.

To then contributeto the sustainable management of plant formations, cartography is essential through the remote sensing and GIS approach.

2. MATERIALS AND METHOD

2.1 Study environment

The present study took place in a sub-catchment of the upper Ouémé in the center-west of Benin. The study area is composed of three (3) sub-watersheds of Terou, Adola and Adjiro whose areas are respectively approximately 3363.70 km², 1061.98 km² and 1950.18 km², i.e. the proportions 52.76 %; 16.66% and 30.59% of the total area (6375.87 km²).

The SBV delimits the study area being on six (6) commune either to the north by the commune of Djougou, to the east by that of Tchaourou, to the southeast by Ouèssè, to the south by Bantè and Glazoué. Most of this sub-watershed is occupied by the commune of Bassila, i.e. 76.25% of the total area of the Upper Ouémé sub-watershed. The whole forms any geometric figure.

Starting from north to south of the SBV, we note in the upper part in a horizontal way a distance of about 40 km measured between 1°31'51" E; 9°25'30"N and 1°53'32"E; 9°25'30"N, in the center 79 km between 1°37'16"E; 8°44'30"N and 2°4'22"E; 8°44'30"N. The height of this sub-catchment gives a distance of about 152 km from northwest to southeast. The Upper Ouémé S-BV represents only 20.27% of the total area of the Ouémé watershed and 5.56% of the national territory. The upper Ouémé S-BV which is the subject of this study is located between the meridians 1°28'52" and 2°19'21" with the parallels 8°25'21" and 9°42'37". Figure 1 presents the geographical situation and its location in the upper Ouémé watershed.

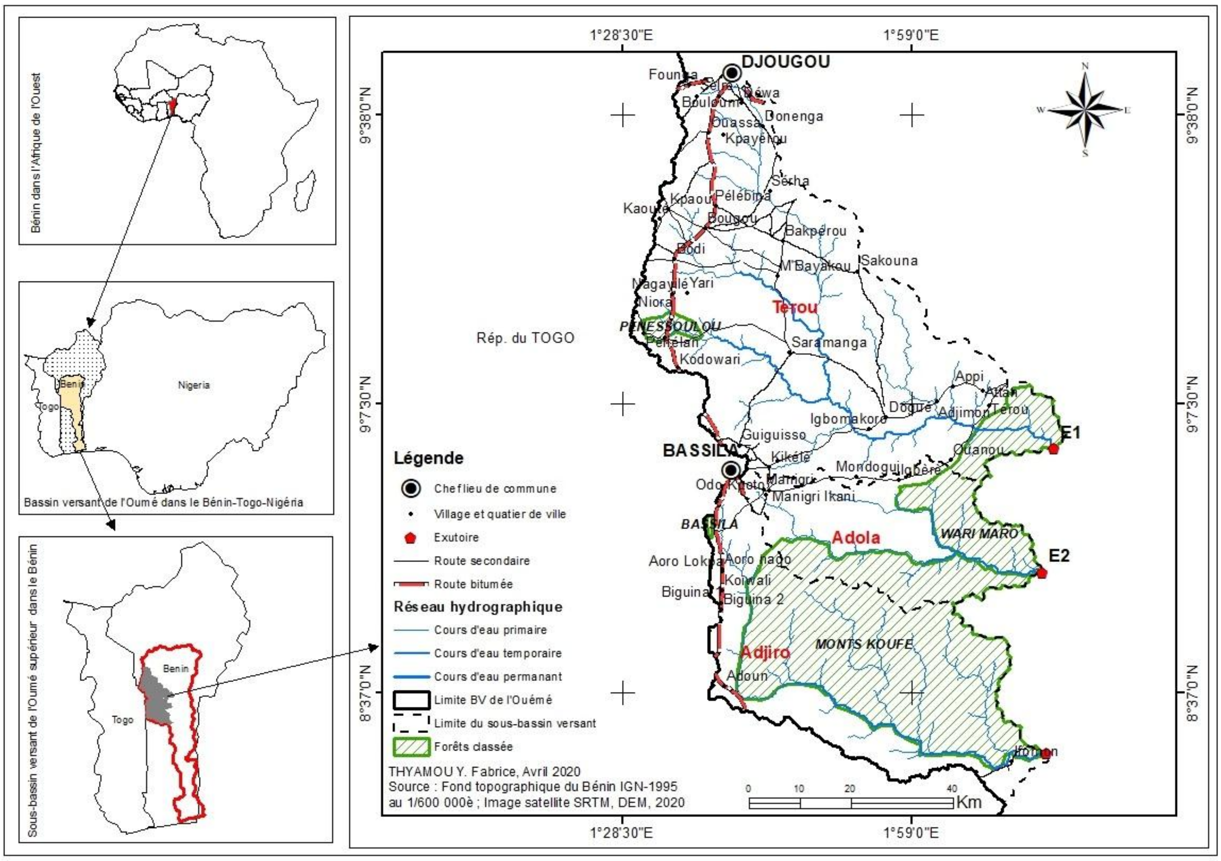

Figure 1: Geographic location of the study area

2.2-Method

2.2.1. Land covers study of 1995, 2005, 2015 and 2020

Satellite data supported by field datawere collected for mapping plant formation units. Satellite data made it possible to make a mosaic of the area using cartographic software such as: Arc GIS 10.8 and ENVI.

To achieve the objectives of this study, several steps were defined.

Thus, the methodological approach adopted is multivariate. It includes several phases such as the pre-study, the actual study as well as the interpretation of the data and the analysis of the results.

- **Type and sources of data**

They concern satellite, socio-economic and demographic data:

- remote sensing: satellite data, theirprocessing allows the production of land use and vegetation maps as well as NDVI. The DEM images were used for the delimitation of the sub-watersheds. It was question of the use of various satellite images in order to achieve the fixed objectives.In this work, only the 10, 20 and 30 m bands were used.

Table I: Characteristics of the satellite images of the study.

Picture ID	Sensor	Acquisition date	Resolution	Number of bands	Image size (km)
-	Therendsat 5 TM+	1995	30m	07	192*054
ELP192R054_7T20020423	Therendsat 7 ETM+	23-04-2002	30m	08	192*054
ELP192R054_7T20060514	Therendsat 7 ETM+	14-05-2005	30m	08	192*054
LC81920542015349LGN00	Therendsat 8 OLI/TIRS	04-03-2015	30m	11	192*054
LC81920542015365LGN00	Therendsat 8 OLI/TIRS	06-03-2015	30m	11	192*054
LC08_L1TP_192054_20200416_20200423_01	Sentinel-2B	23-04-2020	10m	13	192*054
DEM	SRTM	16-02-2020	10 – 30m	-	-

Source: Landsat 5, 7, 8 and Sentinel 2B satellite image from 1995, 2005-2015-2020

Failing to obtain images such as SPOT, JERS and IRS and Radar images (crosses the clouds), etc. which have a high spectral precision, images from other sensors such as Landsat and Sentinel-2B were used. The spatial resolutions of these images used are 30 m and 10 m. Indeed these resolutions are considered acceptable for the methodology adopted in this study.

- **Processing and interpretation of satellite images.**

This processing is the set of adaptation processes that allowed to transform the image to extract information. It comprises three (3) essential steps: the preparation of the image, its interpretation and the organization of the results of the interpretation. Interpretation is the identification of the different information contained in the image. There are two interpretation keys: analog and classification. Table II presents the interpretation key for the satellite images used for the study.

Table II: Interpretation key for satellite images

Coded	Tone	Identification
1	Bright red	clearforest
2	Bright red	Forest Gallery
3	Moderatered	woodedsavanna
4	Pale red	Treesavanna
5	Green streaked with fine reds	shrubbysavanna
6	Blue	watercourse

Source: CENATEL, 2007

2.2.2. Data processingmethods

They concern the processing of survey forms and interview guides and the processing of data. The analysis consists of entering the answers collected from the questionnaires and interview guides according to a table framework designed in Excel software and which can be used to make the necessary graphs or analyses. Processing the data means harmonizing the responses and developing tables and graphs for analyzes and interpretations.

2.2.3. Remote sensing and GIS method

Satellite remote sensing systems all provide digital data. To carry out this study, digital processing methods made it possible to make the best use of data from sensors with many channels. Three major steps should be remembered. This is the stage of satellite data acquisition, pre-processing and the development of thematic maps from GIS tools.

2.2.4. Plant formation inventory method

The inventory of plant formations in the upper Ouémé sub-watershed was made by combining remote sensing and field surveys. The latter consists of first collecting satellite data and thento do their construction on the screen what our eye cannot even from classic images by assigning colored filters corresponds to the "true" color of each of these bands. The method used is called "*the principle of additive synthesis*": all the colors of the visible spectrum added together, or the 3 primary colors added together give white light). This technique was done through GIS software (ArcGIS). To recreate what the eye would see with the Landsat 8 bands, the combinations of bands 6, 5 and 4 then 5, 4 and 3 respectively give the colored composition in true color with a green tint for vegetation and in false color giving a red tint to plants.With the method of Benaz (2013,benaz1.e-monsite.com), three (3) plant formation inventory techniques were used. It's about:

1) Ecological survey
2) Phytosociological survey
3) Measurements of diameters and heights of trees

1.2.4. Study of plant formations

The study of plant formations was made from observation points generated in the ArcGIS software.On the ground, 61 observation points were placed and spaced 10 km apart on a regular basis.This technique consists of taking vegetation readings in the field on a reference surface of size (or dimension) adapted to the plant formation studied and in a homogeneous whole.

The analysis of all these data allowed the establishment of digital maps of synthesis and materialized.This step also allowedto establish a typology and draw up a minute on plant formations. The plant formations encountered vary from one place to another and there are dense formations with grassy savannas.Figure 2 shows the distribution of the observation points covered.

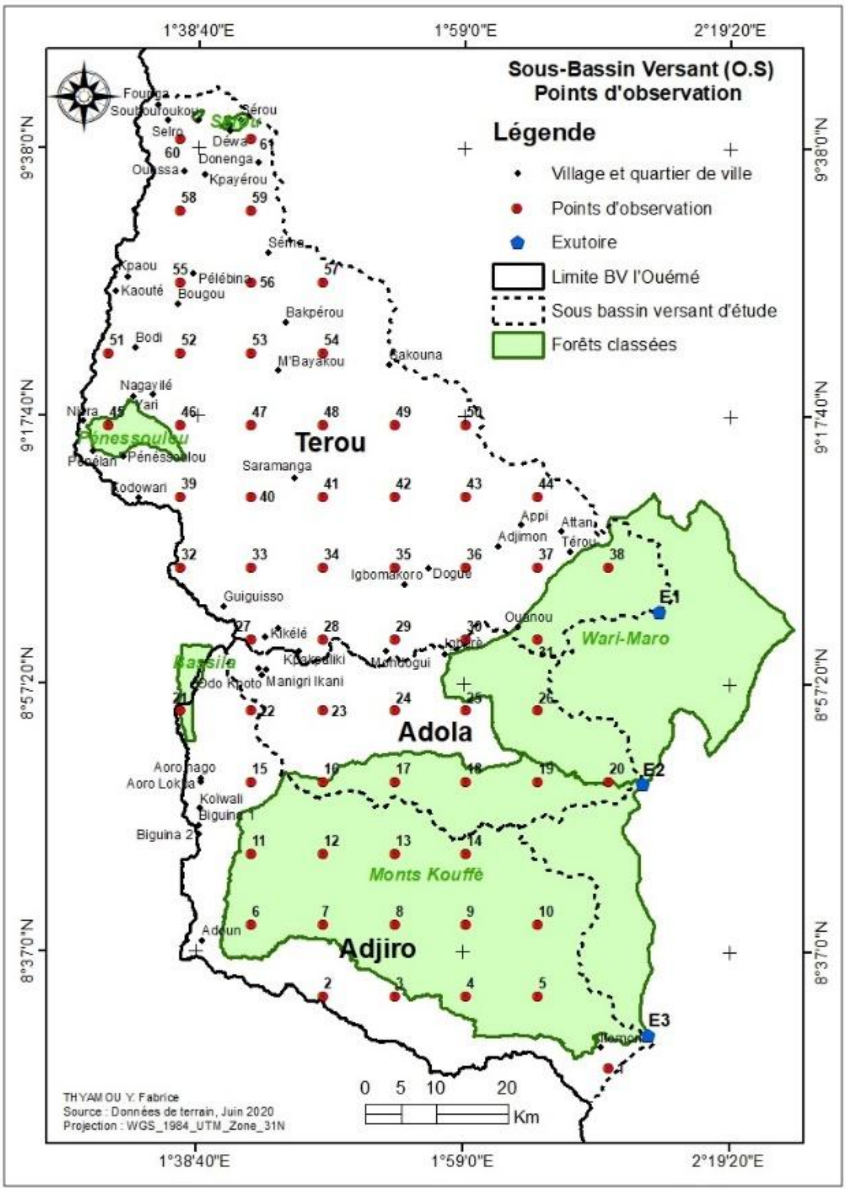

Figure 2: Observation points covered

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2.2.5. Vegetation index: NDVI

The NDVI is a standard vegetation index in the study of vegetation. Thus, it calculates from the formula of JW Rouse et al, (1974, p. 51).

It has made it possible to describe the plant cover and is based on the fact that plants absorb light energy in the red wavelengths for photosynthesis and, on the other hand, reflect energy in the near infrared. This index was calculated with the electromagnetic bands of red (R) and near infrared (IR). The result is normalized between -1 (other than vegetation such as water, bare ground, etc.) and 1 (dynamic vegetation).

$NDVI = \frac{(IR - R)}{(IR + R)}$;With**R=**red and IR: Infrared

2.3. Data processing and analysis

Acquisition and interpretation of satellite images

THEtime series of satellite imageswere obtained through different channels from different time periods. This technique made it possible to recompose the landscape of the sub-watershed.

Interpretations were performed using conventional manual methods for interpretation.

The direct interpretation of these images on the screen and their classificationsupervised by maximum likelihoodwith the ArcGIS 10.8 software made it possible to put the different land use units and the calculation of their respective areas then thevalidation of these classifications during ground truth operations.

3- RESULTS

3.1. Visual interpretation of Landsat images, classification and validation of the classification of these images into class groups

3.1.1. Visual interpretation

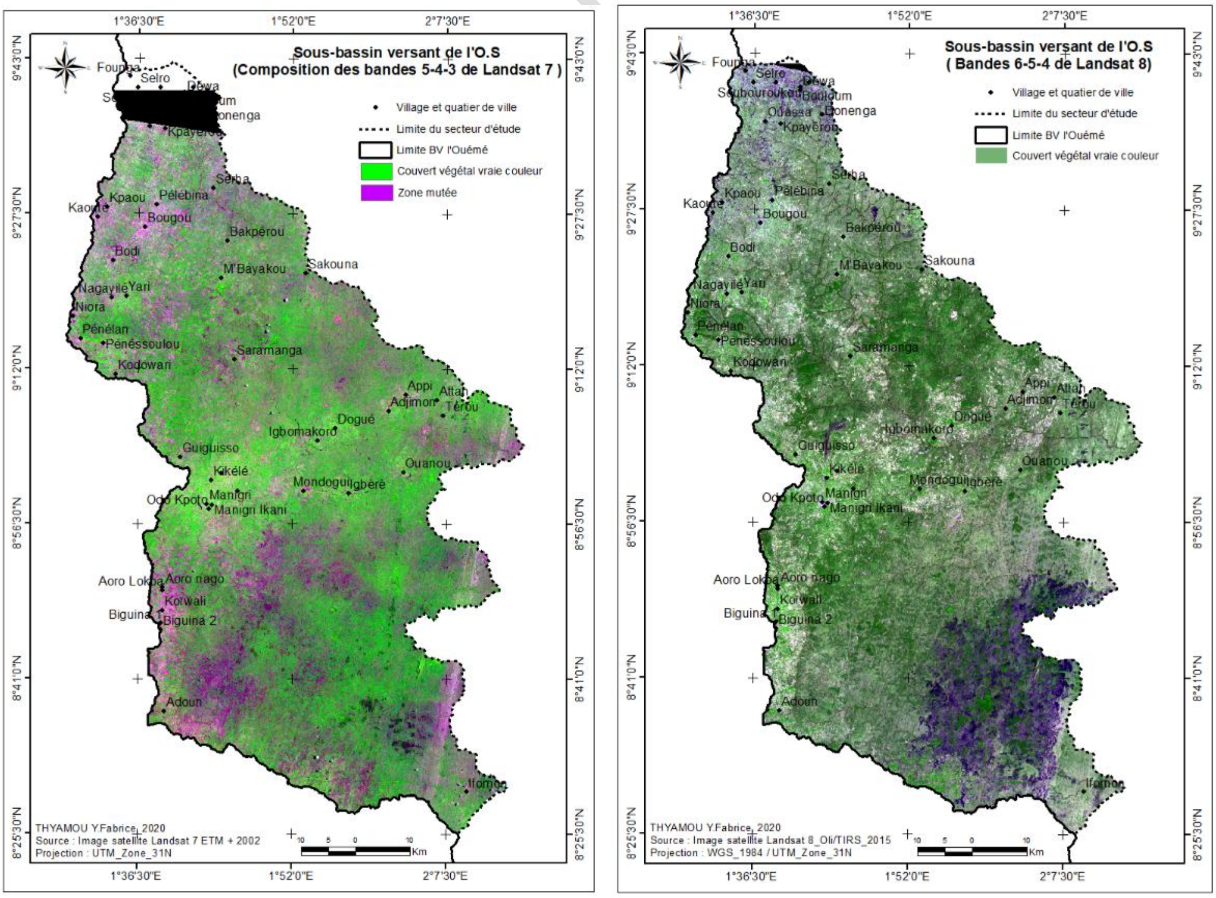
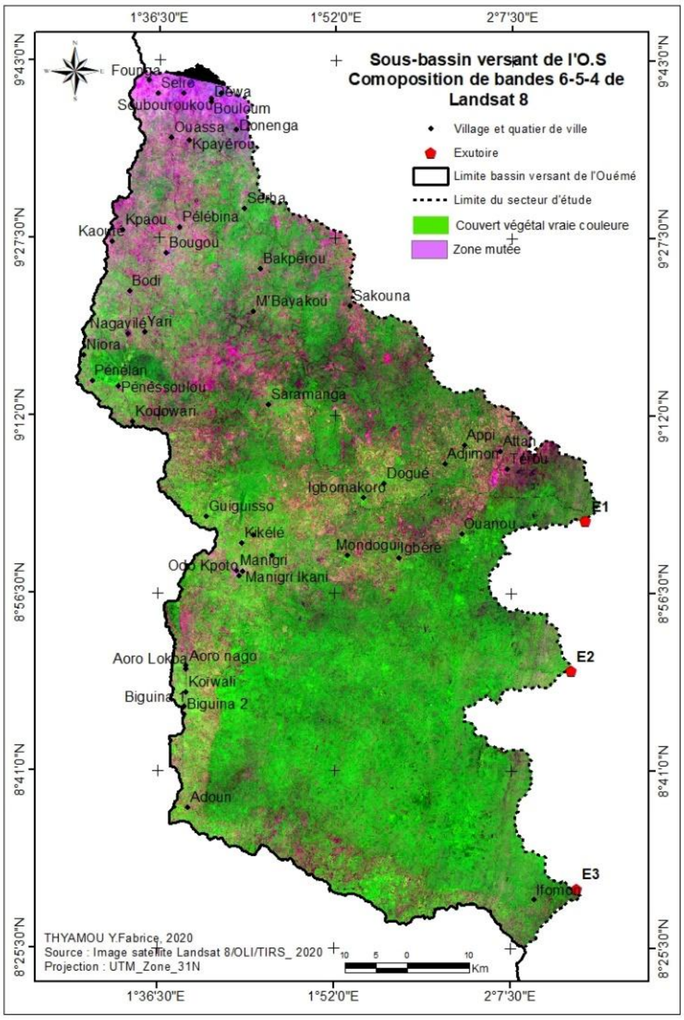


Figure 3 and 4: Colored composition of satellite images 2002, 2015

From these combinations, the green color is the frame that identifies the areas covered with vegetation from the degraded areas.

3.2. Inventory of plant formations

From the exploitation of satellite data from April 2020, it appears initially that the Upper Ouémé SBV contains forest massifs rich in wood made of plant formations with characteristics of shrubby and tree savannas (2 to 10 m height of dominant strata), open forests and wooded savannas (15 to 20 m of dominant strata), dense forests (15 to 25 m of height of dominant strata), gallery formations (20 to 30 m), plantations and fallows.Each plant formation has its own characteristics both in terms of coverage and height of strata. In a second step, the combination of the raw data bands (B6, B5 and B4) in true color gives figure 5 and that of the false color data bands (B5, B4 and B3) gives figure 6.



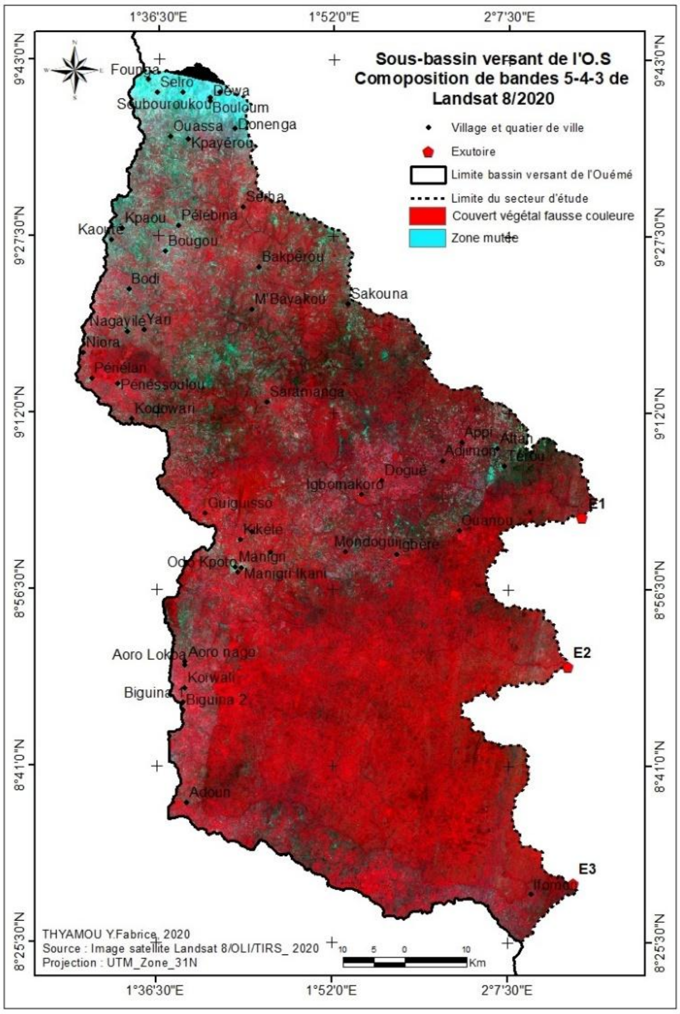
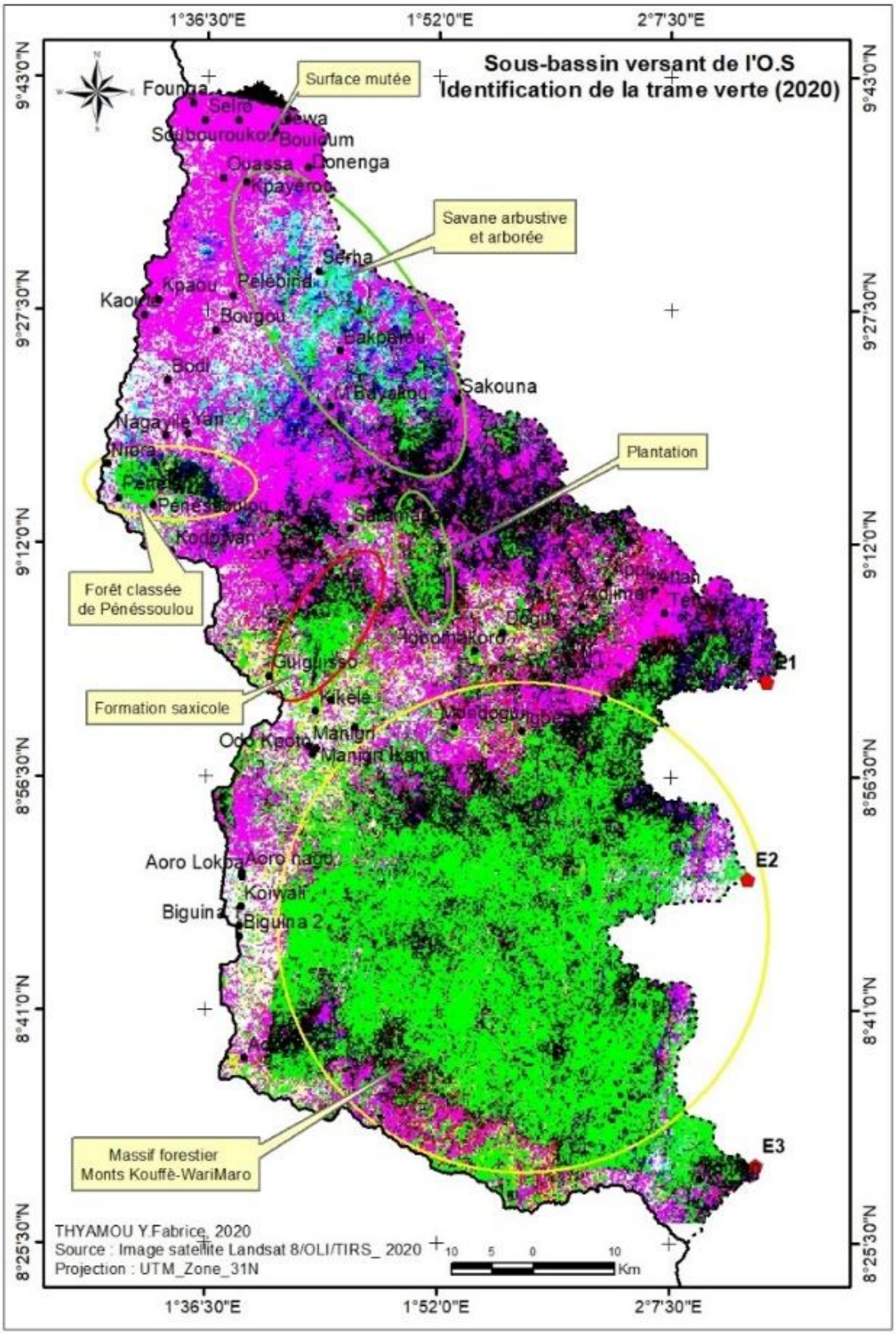


Figure 5 and 6: Colored composition in true and false color of the plant cover of the SBV

The analysis of these two figures (5 and 6) indicate that whatever the type of combinations used, the plant formations appear in an identical or similar way (green in real color and red in false) with gradations of tones of these colors to express the density of said formations.

Applying to any of these figures,Using the "Custom Stretch" function of the ENVI.5.1 software, areas covered with plants (woody) and those not covered (fields, bare soil, rocky surfaces and small plants) were isolated (figure 7).



Figures 7: Frames of areas covered by plants and those not covered

From the analysis of Figure 7, dense plant formations cover 66.32% of the territory of the SBV. For example, we can see that the largest covered area corresponds to the MontsKouffè – Wari-Maro forest complex in the south of the figure and some enclaves such as those corresponding to the classified forest of Pénéssoulou; the saxicultural formations in Guiguissou.

3.2.1. Assessment of land cover in 1995, 2005, 2015 and 2020

Data from satellite images during the periods of 1995, 2005, 2015 and 2020 made it possible to trace the spatio-temporal evolution of each plant formation identified at the level of the sub-watershed. These formations have evolved from dense forests to wooded and shrubby savannas with bare soils.

However, the floristic heritage of these different periods is presented in figure 8 which shows the spatio-temporal evolution of the plant formations resulting from the heritage inventory floristicsof the upper Ouémé SBV.

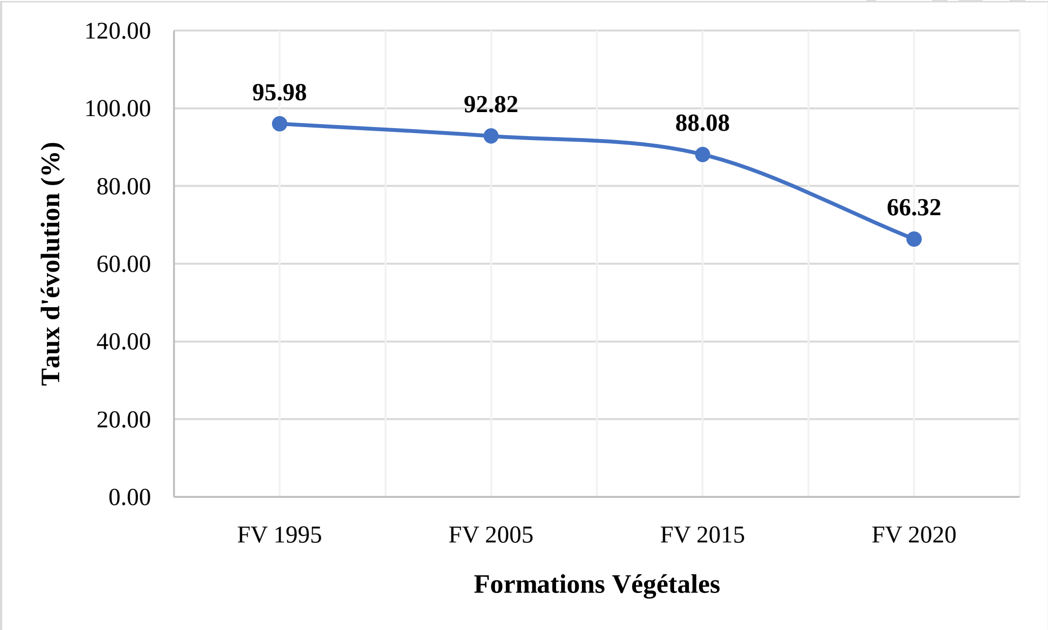
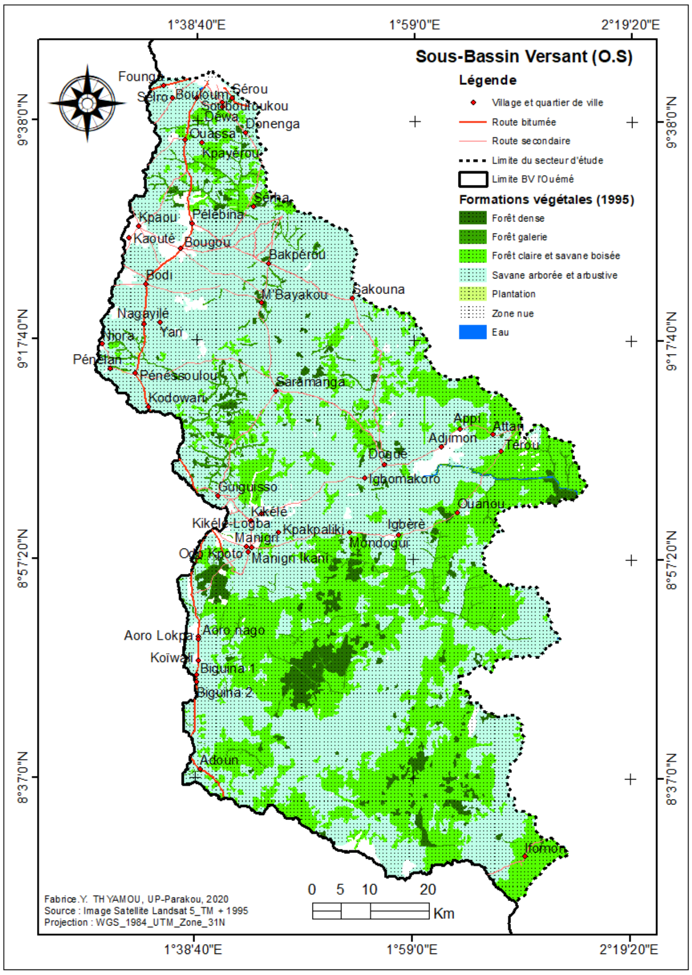


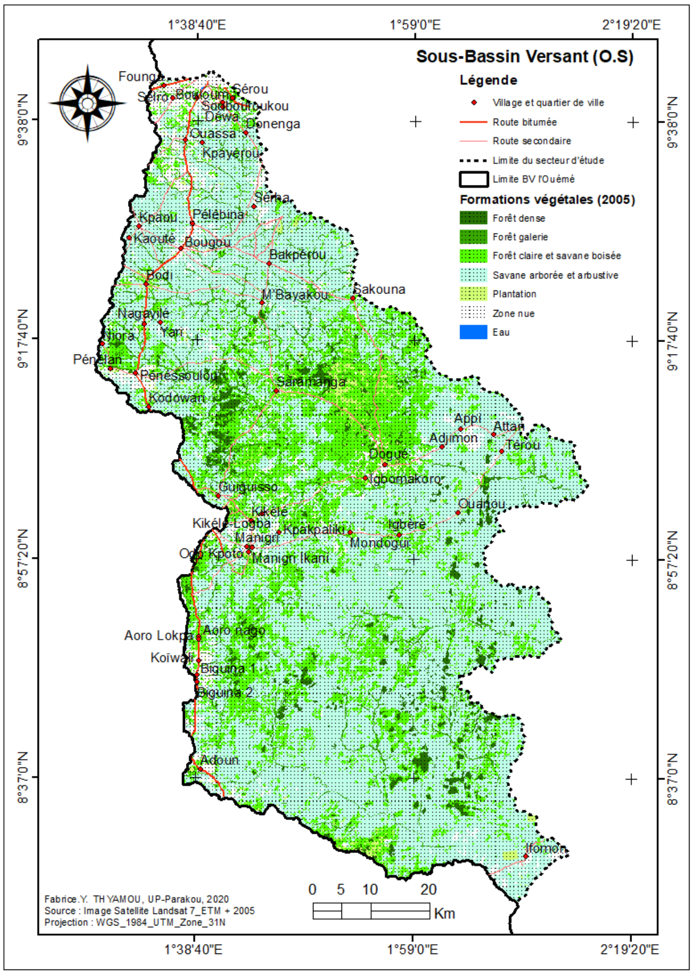
Figure 8: Evolution of the floristic heritage of 1995, 2005, 2015 and 2020

Source: Processing of Landsat satellite data from 1995 to 2020

Figure 8 shows that the forest heritage of the SBV has experienced a decreasing evolution over the last 25 years (1995-2020).

From 1995 to 2020, the rate of evolution of these plant formations indicates a gradual decrease in the area of the plant formations. Between 1995 and 2020, the rate of vegetation cover goes from 95.98 to 66.32%. The processing of satellite images enabled the production of the maps shown in Figures 9 and 10.





Figures 9 and 10: Plant formations of the SBV in 1995 and 2005

Between 2005 and 2015, the rate of vegetation cover increased from 92.82 to 88.08%, i.e. a loss of 4.74% of vegetation formations (figures 9 and 10).

From 2015 to 2020, the rate of evolution of these plant formations indicates a much more accelerated decrease in the area of the plant formations, thus leading to the loss of the plant cover, which goes from 4.74% in 2015 to 21.77% in 2020. plant formations (figures 11 and 12).

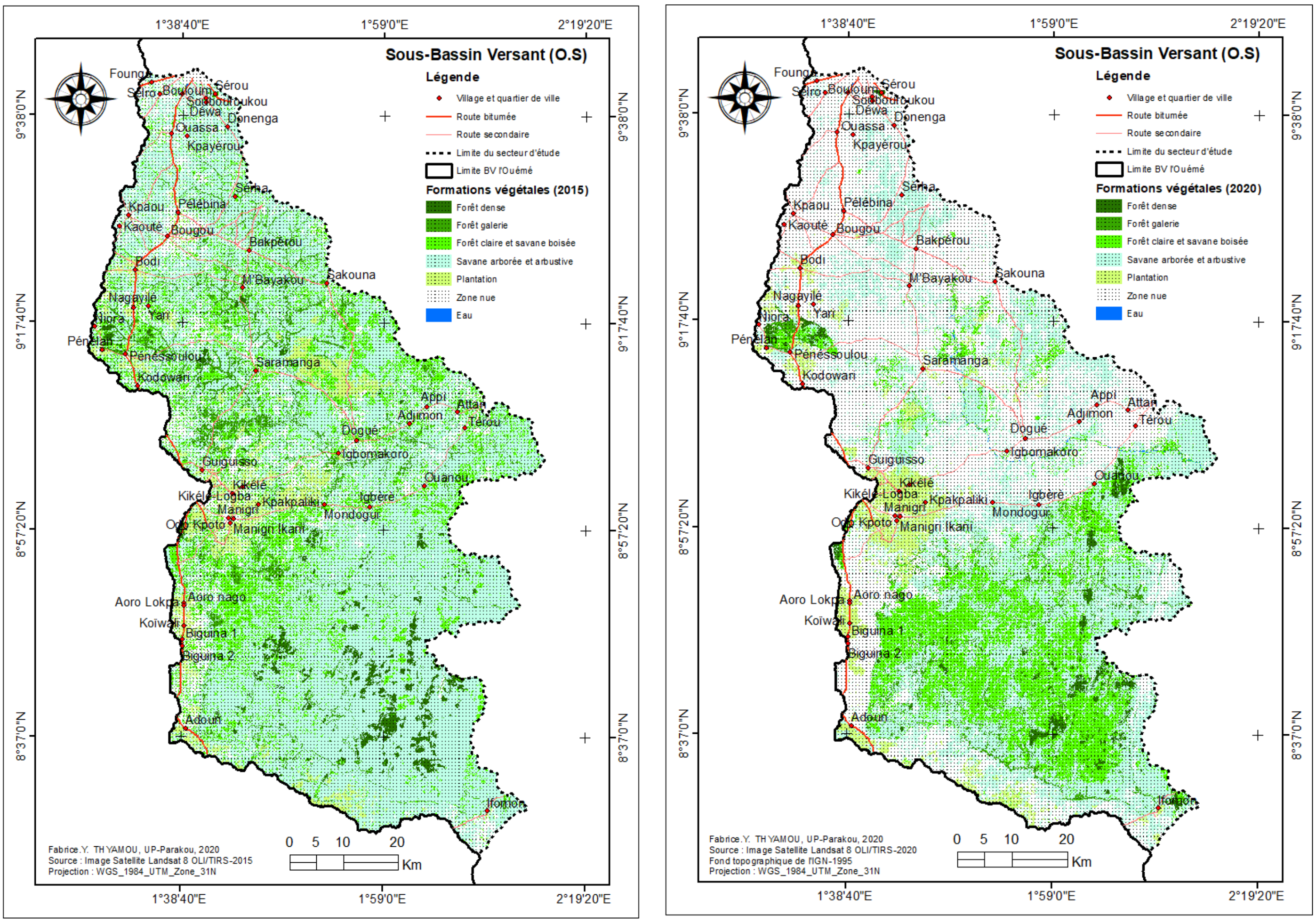
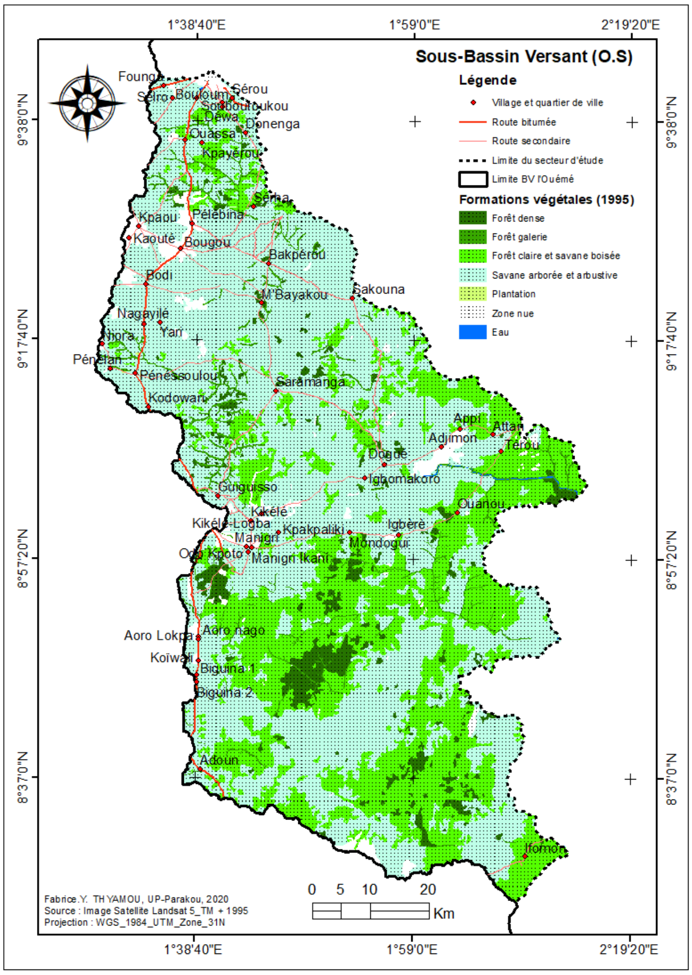


Figure 11 and 12: Plant formations of the SBV in 2015 and 2020

From these figures 11 and 12 we can see a significant pressure on the floristic resources which causes their reductions considerably.

It then follows from the analysis of its data that between 1995 and 2020, the plant formation experienced a considerable decrease in its area in the SBV corresponding to a rate of 29.67%. This rate of degradation can be explained, first of all, by a rapid demographic increase manifesting itself by a relentless pressure on resources. Then come the socio-economic activities (agriculture, forestry, charcoal production) and urbanization (density of roads and the expansion of agglomerations) which contribute to this physical degradation of floristic resources. This is illustrated by thefigures 13 and 14.

From the outskirts of the MKWM complex to urban areas such as Bassila, Bougou, Djougou etc. there is a loss of resources compared to the initial state in 1995.



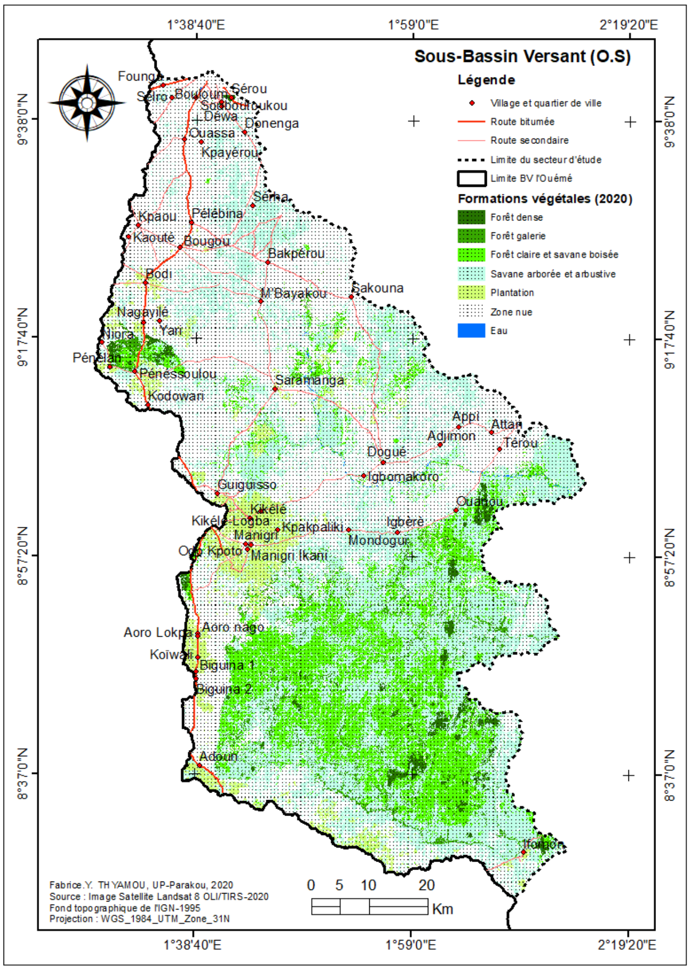


Figure 13 and 14: Vegetation formations of the SBV from 1995 and 2020

However, to confirm the inventory of plant formations obtained from the additive synthesis method, the NDVI calculation method follows the formula of JW Rouse et al. (1974, p. 51).This calculation of the NDVI made it possible to obtain figures 14 and 15.

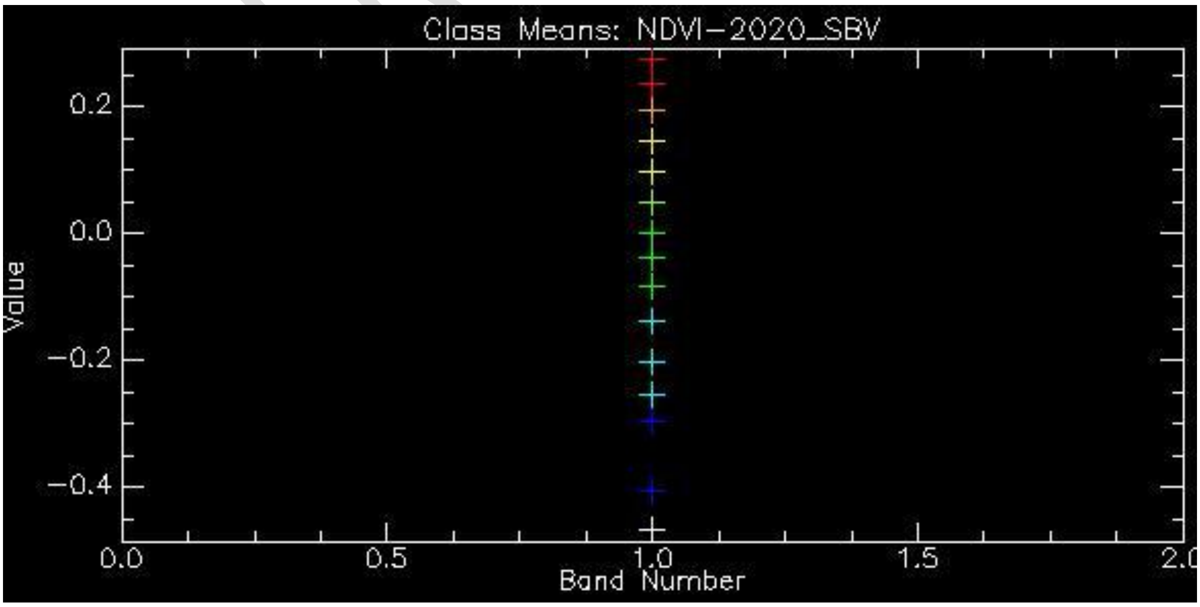


Figure 15: Gradual evolution of SBV NDVI

Source: 2020 Landsat 8 satellite image processing

Knowing that the threshold of the NDVI index is between -1 and 1, the values between 0 and

-1 correspond to the absence of plants while those from 0 to 1 reflect the presence of plants. However, the NDVI of the study area oscillates between -0.076 and 0.315. These results confirm that the SBV contains spaces not covered with plants, all of which are divided into 14 classes (figure 15).

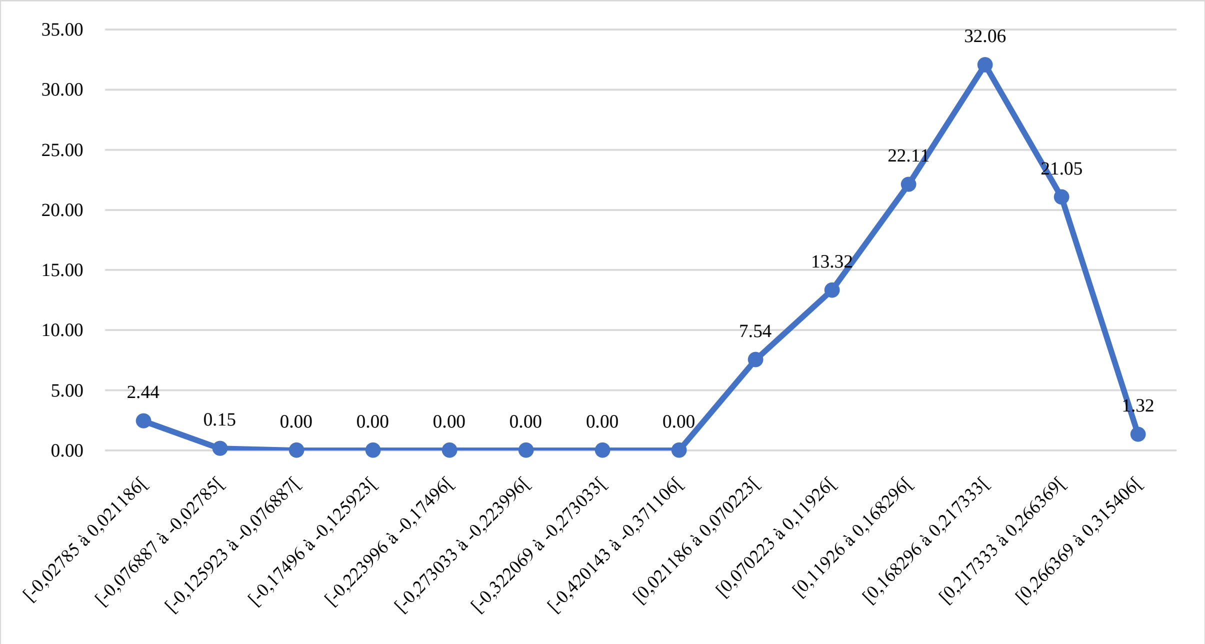


Figure 16: Evolution of the proportions of NDVI classes in 2020

From the analysis of the 14 classes in figure 13, only the 6 classes of positive values between [0.021 to 0.070 [and [0.266 to 0.315 [indicate the presence of plants. Figure 16 also shows the current state of plant formations through the Normalized Vegetation Index (NDVI) and confirms the results from the inventory of these plant formations obtained in 2020.

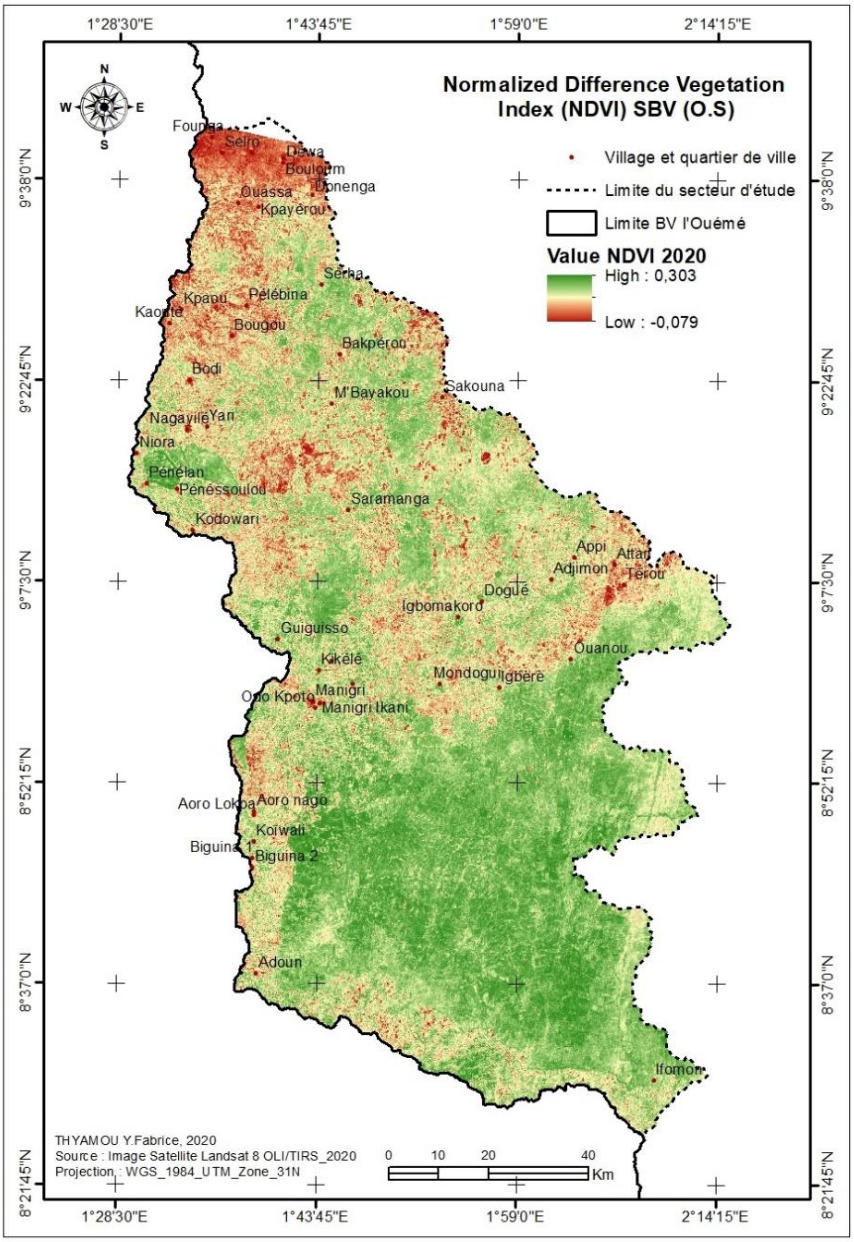


Figure 17: Mapping of plant formations from the NDVI

In addition, the 2020 NDVI displays frames ranging from green to red through yellow characterizing the state of plant formations in this sub-watershed. However, remote sensing in conjunction with other data sources provides remarkable and unique information for determining land cover degradation.

The results of the various processing of satellite data made it possible to draw up the thematic map of plant formations (figure 18).

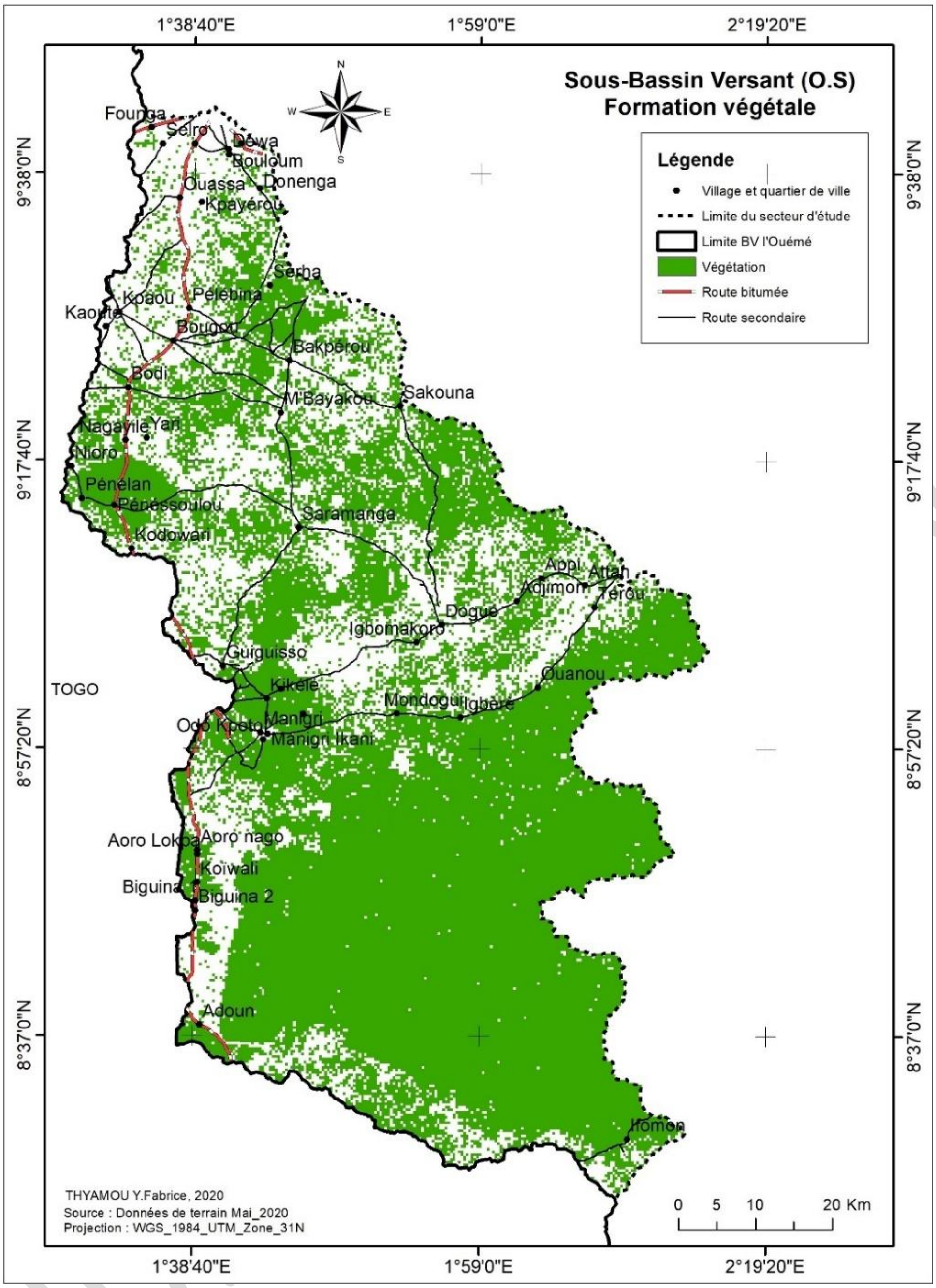
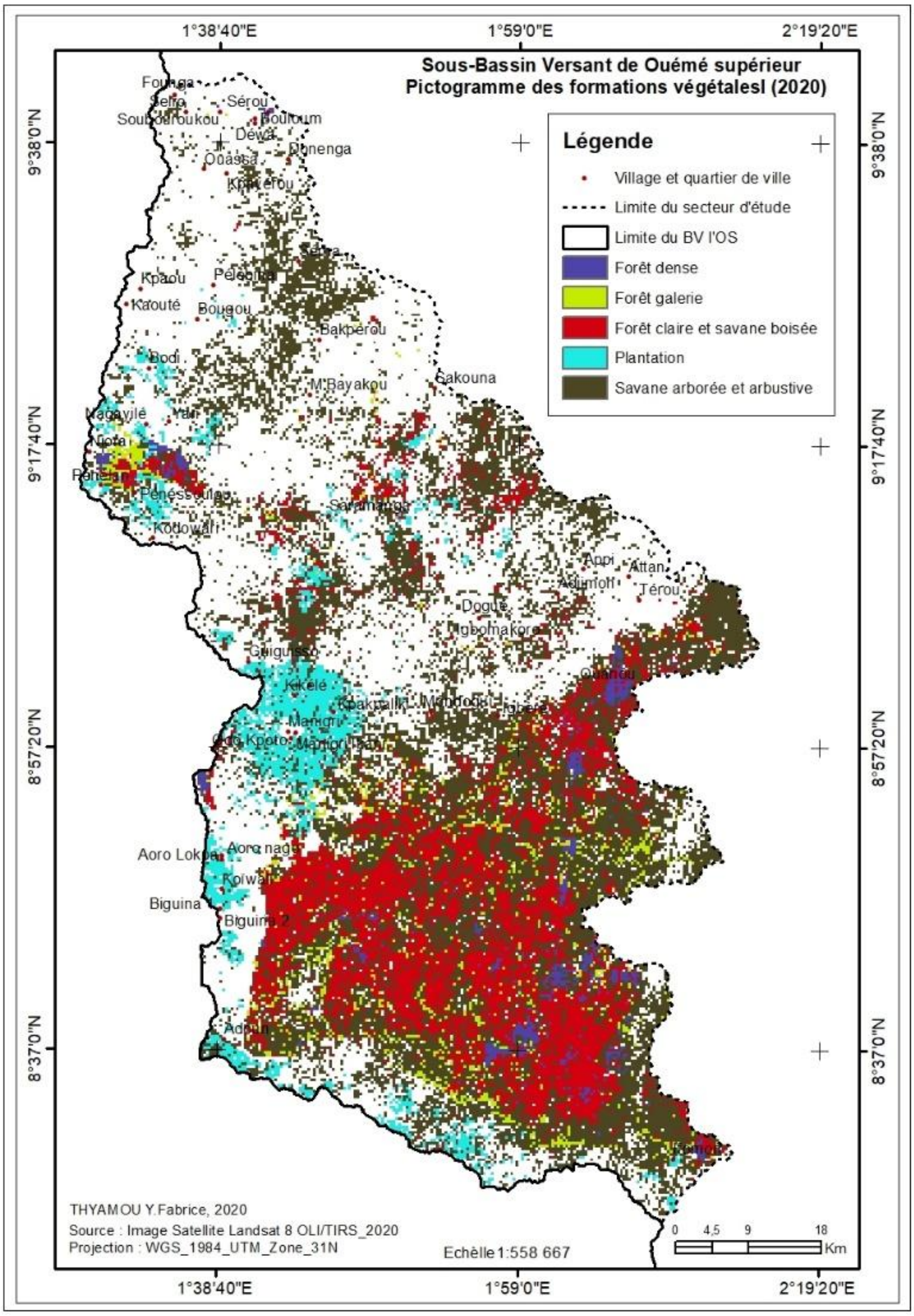


Figure 18: Plant formation of the Upper Ouémé sub-catchment

Furthermore, by refining the level of classification of plant formations from figure 14, the characteristic and/or dominant plant formations in place and picted have been identified (figure 19).



Figures 19: Pictogram of plant formations inventoried in 2020

From the analysis of Figure 19, dense formations and gallery forests occupy 1.47% and 2.47% respectively; open forests and wooded savannas represent 13.90% while wooded and shrubby savannas give 31.90%. On the other hand, herbaceous savannas and plantations respectively occupy 11.86% and 4.69% of the total area of the SBV. These plant formations have been converted into pictograms to better understand their respective location.

3.2.2. Synthesis of plant formations on the Upper Ouémé SBV

The various formation inventory maps were produced using Landsat 8 and Sentinel-2B satellite images.

The plant formations listed constitute both an element of ecological heritage, a remarkable plant landscape and a real attraction for local residents.

The degradation of these plant formations are natural disasters, on the one hand, and caused, on the other hand, by the climate change situation and human activities causing environmental damage.However, the degradation of the flora is more and more recurrent.

Over the past 25 years, the SBV of Upper Ouémé has experienced an increase in anthropogenic spaces (see figure balance sheet of land use from 1995 to 2020) through increasing agricultural activities, in particular the expansion of cotton fields. And yams, the exploitation of firewood, lumber, the manufacture of charcoal, etc. thus causing unprecedented degradation of the vegetation cover.

However, the classified forests, in particular those of Killir and the MontsKouffé Wari-Maro forest complex, are suffering the adverse effects of human actions and the disappearance of several rare species, etc.

According to investigations on logging, forest products, charcoal and logs are sometimes transported in refrigerated trucks to thwart the vigilance of forest inspection agents heading to Togo. This state of affairs in no way encourages the conservation of the flora in the sub-watershed. The illegal exploitation of these resources has led to a spectacular decline in vegetation cover.

In summary, the causes of this degradation ofplant formationsare of several order know :

- Poverty ;
- Literacy;
- The socio-economic situation (population growth)
- Urbanization;
- Socio-political situation;
- Natural (climate, water, soils, etc.)

- Institutional (non-compliance with texts and laws in force), etc.

However, the demand for wood products and derivatives has become increasingly important. Figure 20 shows the purpose of forestproducts.

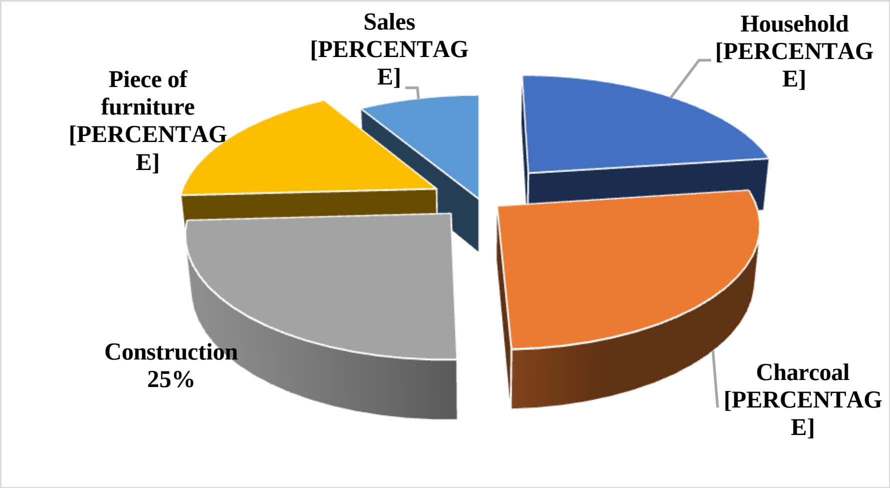


Figure 20: Destination of wood products.

Source: Field data, June 2020

For the operators, the harvested wood is used to meet financial and household needs, as shown in Figure 20. This growing demand for forest products associated with agricultural expansion is the frequent cause of degradation suffered by the SBV through these formations.

In the current state ofplant formations, it is a biodiversity crisis where the upper Ouémé sub-catchment is bogged down in a profound degradation of these natural resources. Indeed, theplant formationspreceded Man, but Man left behind a desert. Therefore, the areas where theseplant formationsthrive are therefore considered sensitive.

Discussion

The mapping of plant formations has made it possible to know the floristic diversity through the inventory of the said plant formations of the upper Ouémé sub-watershed. The study of the floristic diversity of a forest gives an idea of the floristic composition of a forest and all the species that constitute it (Ali et al., 2014).

The quality of the Landsat TM and ETM+ images used, the respect of the processing steps and especially the use in the ArcGIS 10.8 and ENVI 5.1 software contributed to a very good land cover classification for all the images. Between 1995 and 2020, the most extensive vegetation classes, such as dense and forest forests, have strongly regressed. These results agree with the decline in woody vegetation reported by various authors for the Sahel (Yongkang X. and

Jagadish S., 1996; L. Thiombano, 2000; HOUNTONDJI YC, 2008 and de Avakoudjo J. et al., 2014 Tankoano B. et al., 2016).

The extension of the classes of plant formations identified during this study for the period 1995 to 2020 is obviously negative. This is justified through the 2020 plant formation map. Field data has shown that several anthropogenic factors are responsible for the threat to these formations.

In these ecosystems, the damage is visible and must challenge the authorities. In addition, the inventory carried out in the upper Ouémé sub-watershed has made it possible to identify different dominant plant species through the five (5) mapped plant formations. From these results, theshrub and tree savannas include: (*GardemaRubens; Colinum; Dyalium; Vitelariaparadoxa; Anogeisus l. + Vitelariaparadoxa + Terminalia macroptera; Vitelariaparadoxa + Isoberliniadoca+garamine, Isoberliniadoca+undergrowth; Vitelariaparadoxa + Isoberliniadoca; Terminalia macroptera; Pseudocedrela k. ; Terminalia macroptera + Vitelariaparadoxa,*; Pseudocedrela k. + Vitelariaparadoxa), open forests and wooded savannas include: (*Vitellaria paradoxa*; Parkiabiglobosa; Isoberliniadoka; Isoberliniatomentosa; Danielliaoliveri; Anogeissusleiocarpus), dense forests include: (*Albizzia ferruginea; albizzazygia; Antiarisafricana; Bombax costatum; Ceiba pentandra; Cola cordifolia; Diospyros mespiliformis; Diospyros ferrea; Holopteleagrandis; Tetrapleuratetraptera;Afzeliaafricana.*), the gallery formations include: (*Anogeisus l. + Pseudocedrela k. ; Anogeisus l. + Isoberlinia; Anogeisus l. + Isoberlinia + Pseudocedrela k; Isoberlinia+ Pseudocedrela; Anogeisus l. +Isoberlinia; Vitelariaparadoxa + Isoberliniadoca+garamine; Isoberliniadoca+undergrowth; Acacia Pinata; Anogeisus l. + Rouneacocisnea + liana uvariachemea + Mitragina; inersus; Cordifolia+MitraginaInersus;Berlinia grandiflora; Cynometra; megalophylla; Hexalobuscrispiflorus; Parinaricongensis; Pterocarpussantalinoides; Napoleonaleonense; Polysphaeriaarbuscula*), and plantations and fallow land include: (Teck; Gmélina, Anacadium, etc.). These dominant species identified in the field are prey to and threatened by human actions and accentuated by climate change.

Conclusion

The regression of plant formations in the upper Ouémé sub-watershed is highly correlated with the rapid evolution of human activities over the past twenty-five (25) years. Conflicts, population growth, sedentarization, intensification of agriculture, logging, wood production, legislative power, wildfires, etc. weaken the plant cover and threaten the sustainability ofplant formationsand the human populations that depend on them in the long term.

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