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(Research Article)

Space-time dynamics of the Minawao plant cover and surrounding area (Far North, Cameroon)

Paul Kodji [1,*], Tchobsala [1] and Adamou Ibrahima [2]

[1] *Department of Biological Sciences, Faculty of Sciences, University of Maroua, P. O. Box 644, Cameroon.*
[2] *Department of Biological Sciences, Faculty of Sciences, University of Ngaoundere, P. O. Box 454, Cameroon.*

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Abstract

The study, which covered "study the dynamics of the Minawao vegetation cover and its surroundings (Far North, Cameroon), took place in five villages: Minawao, Gawar, Sabongari, Windé and Zamay. The main objective was to help manage the impacts of populations on the Minawao vegetation cover and its surroundings in order to improve the living conditions of refugees and local populations. In each village, floristic surveys were carried out in 5 plants formations (shrub savannah, forest gallery, tree savannah, field and dwellings). For satellite images, the 14-year interval (2006 to 2020) was retained. Analysis of the data identified 23 species, 21 gender and 14 families over the 120 hectares of study area. The annual rate of regression indicates that the village of Minawao and the river side villages are experiencing more degradation after the settlement of refugees than before, with their respective regression rates of -10.81 ha/year and -8.93 ha/year. The maximum carbon is stored by *Acacia albida* (11.77 tC/ha) and *Tamarindus indica* (8.11 t/ha). The total amount of carbon in this area is 32.32 tC/ha.

Keywords: Dynamics; Vegetation Cover; Minawao; Sustainable Management; Far North Cameroon

1. Introduction

The dynamics of the vegetation cover occur in any plant space in a natural way [1]. However, this dynamic phenomenon can become problematic when masses of people settle in a space and enhance the natural resources there [2]. It is along the same line as Rabiou *et al.* [3] point out that refugee's camps, where large numbers of people settle, and experience considerable environmental degradation. According to the United Nations High Commissioner for Refugees (UNHCR), the density of refugees associated with that of indigenous people leads to a significant transformation of the vegetation in the areas of their settlement [4].

The dry zones of Cameroon in general and the semi-arid region in particular have undergone significant socioeconomic and cultural changes over the past decades, accompanied by rapid transformations of rural landscapes. Despite these different changes, populations, for the most part poor, depend on natural resources for their well-being [5]. Research on the assessment of floristic diversity to date has often been more focused on natural ecosystems such as protected areas [6], grazing areas and very little in anthropized systems [7]. Other studies have been carried out on the impact of refugees on the dynamics of the vegetation cover, such as those of Black [1] on the environment and refugees in sub-Saharan Africa, of Florence [8] on the migratory effects in the East of Chad, of Bodel [2] on land use by refugees in the eastern region of Cameroon and those of Rabiou *et al.* [3] on the impact of refugees on the exploitation of wood resources in the Diffa region of Niger, hence the following problem: problems such as the lack of firewood, the decline in production, climate change and conflicts between the refugees and the natives of the neighboring villages (Zamay, Sabongari, Gawar, Windé) also arise in this locality for the acquisition of wood and soil [9]. The main objective of this

* Corresponding author: Kodji Paul
Department of Biological Sciences, Faculty of Sciences, University of Maroua, P. O. Box 644, Cameroon.

study is to contribute to the management of the impacts of the populations on the plant cover of Minawao and its surroundings in order to improve the living conditions of the refugees and local populations and to restore degraded lands. specifically, to: i) show the influence of the effects of human activities on the vegetation cover of Minawao and the neighboring villages, ii) study the effects of anthropization on vegetation regeneration, iii) study the dynamics spatio-temporal vegetation cover and iv) assess the effects of human activities on carbon sequestration of the vegetation cover.

2. Material and methods

2.1. Study zone

The study was carried out in 5 villages (Gawar, Minawao, Sabongari, Windé and Zamay) south of Mokolo Minawao, which are located in the Far North region of Cameroon, precisely in the Department of Mayo Tsanaga between 10 ° 33'38 '', North latitude and 13 ° 51'25 '', East longitude and altitude 595 m [10]. The climate in the area is Sudano-Sahelian. The soils are mainly represented by weakly evolved arenas and soils with a hydromorphic tendency in alluvial lowlands, due to a hydrographic network that is sometimes poorly hierarchical [11]. The plant formation is predominantly shrubby and woody, mostly thorny. In general, it consists of species such as *Acacia albida, Acacia seyal, Acacia nilotica, Ficus* spp., *Tamarindus indica, Azadirachta indica*, *Anogeiossus leiocarpus*, *Ziziphus mauritiana*. These species serve mainly as shade trees in fields, as a source of fuelwood and timber [12].

2.2. Methodology

Concerning the identification of the different factors of the dynamics of the vegetation cover around Minawao and the four riparian villages, four transects of 15,000 mx 20 m following the directions of four villages (Gawar, Sabongari, Winde and Zamay) were delimited using wire from Minawao. This method was applied successfully by Doulkom [13] in a refugee camp in Burkina Faso. Systematic sampling was carried out along each transect from Minawao to assess the spatial dynamics of the vegetation as one moves away from the Refugees Camp. Three repetitions are performed from right to left of each transect. In each 15,000 m x 20 m plot, all the species are inventoried. Concentric circular plots of 4 m, 14 m and 20 m radius were used for the vegetation surveys. In fact, circular-shaped plots are used for forest inventories in Burkina Faso [14,15] and to characterize the vegetation in the savannahs in Senegal [16] and in the Miombo in the DRC [17].

The satellite data were obtained from ETM+(Enhanced Thematic Mapper Plus) sensors, because they offer a resolution indicated for the detection of land cover elements at the local scale [18]. The annual average spatial expansion rate (T) is evaluated by: T = ((lnSj-lnSi)) / ((t x lne)) x100. Where t is the number of years of evaluation; Si and Sj respectively the areas of the class for an old year i and for a more recent year j; ln, the natural logarithm; lne, the natural logarithm of e (its base) = 1; (e = 2.71828). The calculation of theoretical values of projection of the different surfaces (Sp) in time and given by the following formula: Sp= ((Txtx lne))/((100+lnSi)). Where Sp is the projection area, t the number of years of projection; T the average annual rate of spatial expansion; If the area calculated in a more recent year; lne, the natural logarithm of e (its base) = 1; (e = 2.71828). In order to know the rate of variation of the identified land use categories, the following formula was used: Δs= ((SP2-SP1))/ ((t2-t1)). Where: Δs=Speed of variation (extension or regression in ha/year); SP1=Area occupied by the occupation category considered in year 1 (ha); SP2=Area occupied by the occupation category considered in year 2 (ha); t1=year 1; t2=year 2.

2.3. Carbon estimation methods

The aerial carbon stock is given by: QCv = B x Cv with: QCv or QCaerial=vegetation carbon (tC/ha), B=Biomass (t/ha) and Cv=vegetation carbon concentration (0.5). To determine the amount of carbon in the root phytomass, we used the formula used by Ibrahima *et al.* [19]. QCr = Br x Cv. With: QCr=root carbon (tC/ha); Br=Root biomass (t/ha); Cv=vegetation carbon concentration (0.5). The total carbon value was quite simply obtained by summing the quantities of carbon of all the components of each type of plant formation by: QCtotal=QCaerien+QCracinaire

3. Results and discussion

3.1. Factors impacting the vegetation cover of Minawao and neighboring villages

The manifestation of factors in the villages is variable from 56.37±28.02% (Windé) to 73.49±18.89% (Minawao). The analysis of variance shows a significant difference between the different villages ($p<0.001$) as well as between the impact factors (p<0.0001). Based on the above, the factors of degradation of the vegetation cover are more present in the village of Minawao (73.49±18.89%) and Gawar (65.14±23.56%). Their proximity to the Minawao refugee camp could be the reason for these higher degradation factors compared to other study sites.

Among the factors influencing the dynamics of the vegetation cover, logging (99.62±0.60%) is the main cause of the degradation of the vegetation cover in Minawao and the other surrounding villages. This is followed by the high density (82.06±10.18%) of refugees at the Camp. According to the populations surveyed, the vegetation cover of Minawao and the surrounding villages has experienced an aggravated loss of species since the arrival of the refugees. The duration of the Camp could also be a factor which increases the impact of the refugees on the vegetation cover (78.40±7.91%). This result is in agreement with that of Florence [8] in eastern Chad, who found that the displaced use resources in their host country abusively more than in their own country.

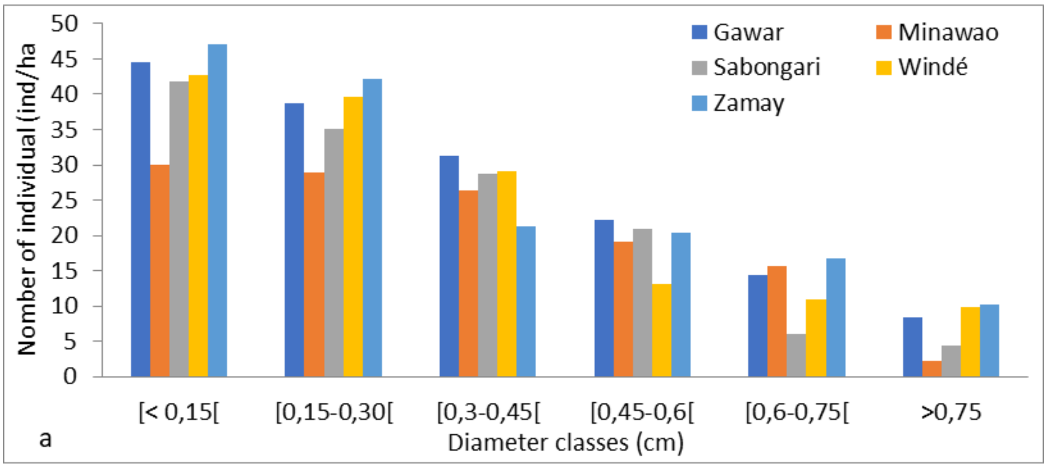
Table 1 Factors impacting the environment

Impacting factors	Gawar	Minawao	Sabongari	Winde	Zamay	Average
Density of refugees	100	89,59	80	69,4	71,32	82,06±10,18b
Camp life	70	81,1	69,33	76,1	96,5	78,40±7,91c
Agriculture	52,1	75,33	61,45	45,98	72,1	61,39±7,09d
Craftsmanship	15,07	11,32	13	14,08	25,34	15,76±3,83e
Breeding	45,77	69,55	30	10,98	21,34	35,52±17,70d
Wood cutting	100	98,1	100	100	100	99,62±0,60a
Average	65,14±23,56d	73,49±18,89c	63,22±24,35d	56,37±28,02bc	64,8±23,69d	64,60±23,18d

Means followed by the same letter are statistically identical (p <0.05).

3.2. Diameter distribution of species in plant formations in villages

The stand shows a high density between the diameter classes] 0.15] and] 0.15-0.30] meters. The village of Zamay as demonstrated previously shows the best distribution of individuals whose density varies between 10.23 stems/ha and 47.04 stems/ha. While the village of Minawao indicates a low density of individuals relatively low on all distribution classes whose values of individuals evolve from 2.18 stems/ha to 30.07 stems/ha. In the sense that Rabiou *et al.* [3] asserted that the analysis of different forms of pressure shows that for all indicators, the frequencies are higher at the level of the refugee camps than at the level of the indigenous villages. The "L" structure of the graphic reflects the presence of numerous stems of the future or that have been subjected to anthropogenic activities [20]. In the shrub savannah, the number of individuals at all intervals varies between 1.65 stems/ha and 71.81 stems/ha). In the forest gallery, this density varies from 1.90 stems / ha to 76.20 stems/ha. At the level of cultivated land and habitat, the distribution of individual diameters is relatively small. The analysis of variance shows a highly significant difference between the densities of inventoried individuals in each village (0.0001<0.05).



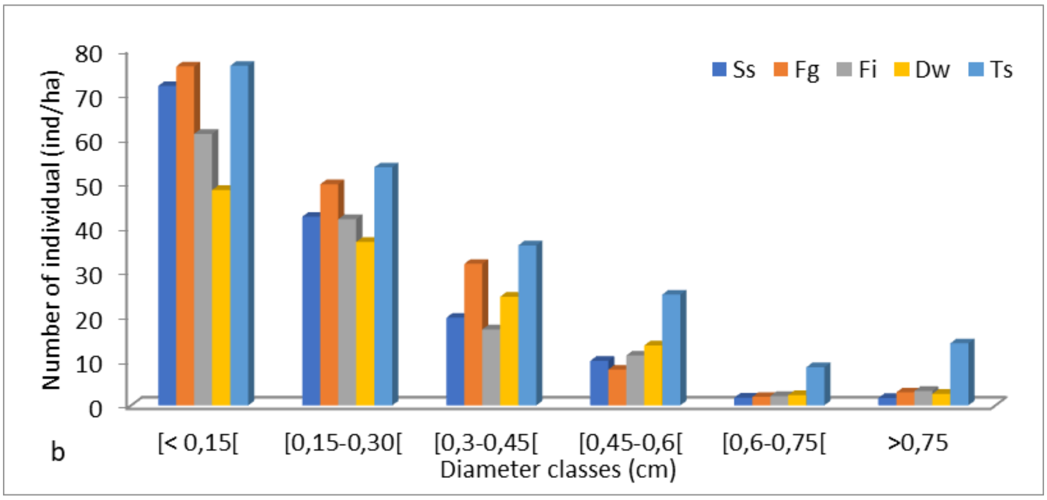


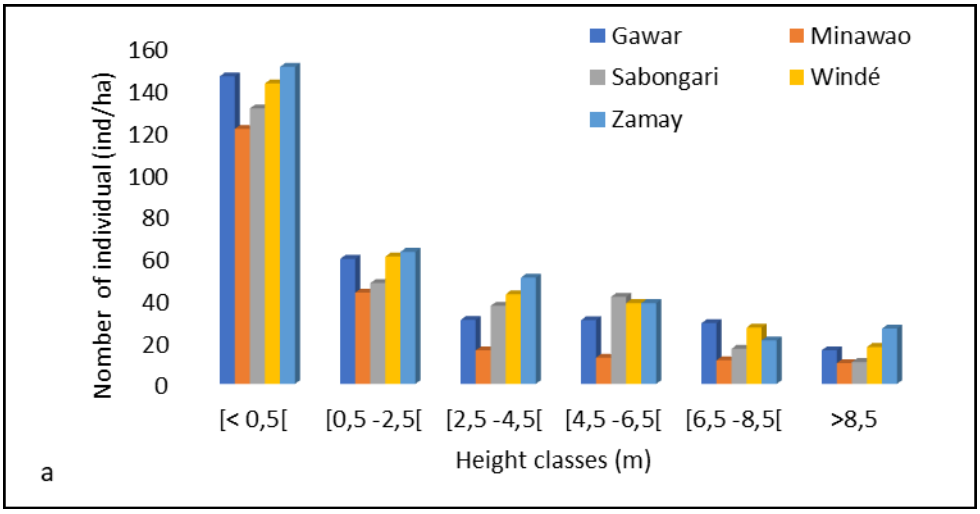
Figure 1 Diametric classes of species according to villages (a) and plant formations (b)
Ss: Shrub savannah, Fg: Forest gallery, Fi: Field, Dw: Dwellings, Ts: Tree savannah

3.3. Vertical structure of plant species in villages

The woody flora of the study sites, 23 species were identified and grouped into 21 genera and 14 families on the 120 hectares of study area. The Zamay wooded savannah is more diverse with 21 species, 20 genera and 13 families.

Individuals belonging to the class [<0.5[are the most represented on the graph. These individuals whose height is less than 0.5 represent 690.57 stems / ha, or 49.16% of all individuals. The very low percentage of individuals above 0.5 m could be linked to the cutting of fuel wood in the area. The analysis of variance shows a significant difference between the different villages (p<0.0097).

In the shrub savannah, the density of individuals varies between 6.89 stems/ha and 130.08 stems/ha. The analysis of variance shows a highly significant difference between the different villages (P<0.00001). In terms of cultivated land, this density varies from 2.13 stems/ha to 131.72 stems/ha. In the forest gallery and in the wooded savannah, the maximum values are respectively 134.01 stems/ha and 146.41 stems/ha. This result revealed less ecological diversity in all the villages compared to that of Kemeuze [5] in the same ecological zone in the Mandara Mountains.



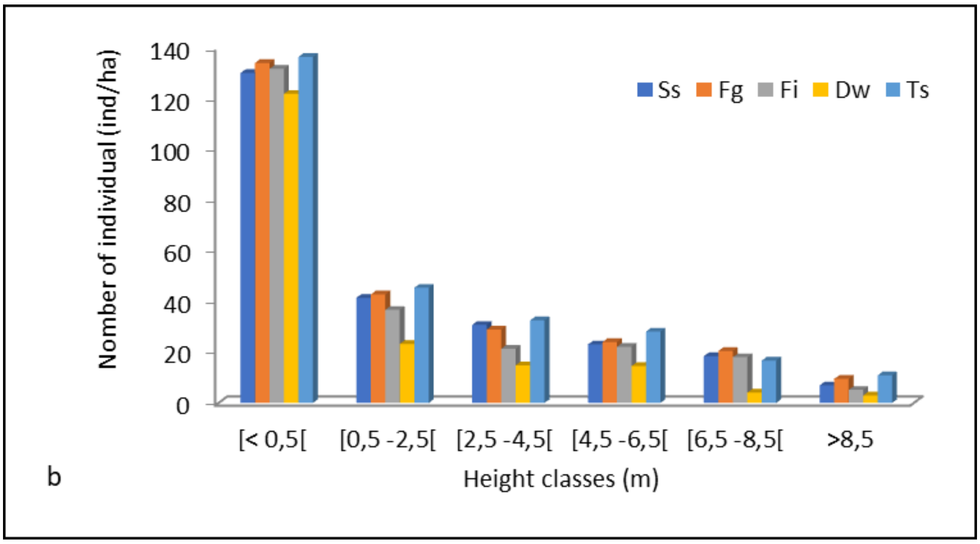


Figure 2 Height of the plant population as a function of villages (a) and plant formations (b)
Ss: Shrub savannah, Fg: Forest gallery, Fi: Field, Dw: Dwellings, Ts: Tree savannah

3.4. Dynamics of species regeneration in the vegetation cover

Concerning the different villages, the number of suckers varies from 90.6±48.72 ind/ha in the Minawao formations to 206.2±94.24 ind/ha in those of Gawar. In plant formations, the number of rejections varies between 65.2±23.76 ind/ha in dwellings and 262.8±61.76 ind/ha in wooded savannahs. The analysis of variance shows a significant difference between the different plant formations of the villages ($p<0.00001$). Apart from the cutting of fuelwood and barking, precipitation and fires are also factoring in the significant forest dynamics of the restoration of savannahs [21]. These results also corroborate with those of Tchobsala *et al.* [22] where *Daniellia oliveri* and *Hymenocardia acida* for example regenerated very quickly and in abundance after logging and especially with the passage of fire in the peri-urban savannahs of Ngaoundere.

Table 2 Regeneration of species according to villages and plant formations

Plant formation	Gawar	Minawao	Sabongari	Winde	Zamay	Average
Ss	289	121	134	201	207	190,4±50,32a
Fg	105	57	92	67	74	79±15,6d
Fi	359	182	231	221	321	262,8±61,76a
Dw	197	61	156	113	125	130,4±36,88b
Ts	81	32	91	83	39	65,2±23,76cd
Average	206,2±94,24a	90,6±48,72c	140,8±42,16b	137±59,2b	153,2±88,64b	727,8±27,31

Ss: Shrub savannah, Fg: Forest gallery, Fi: Field, Dw: Dwellings, Ts: Tree savannah; Means followed by the same letter are statistically identical ($p<0.05$).

3.5. Dynamics of land use in Minawao and its surroundings between 2006 and 2013

Figure 3 shows the evolution of the impacts of local populations before the arrival of the refugees. This evolution leads to a progression of other types of plant formations such as grassy savannah from 26,308 ha (2006) to 28,568.24 ha (2013) and the steppe from 4,138.8 ha (2006) to 6,351.17 ha (2013) to the detriment of other classes. This reflects the dynamic experienced by this environment between these two dates. However, these two images clearly show changes. The 2006 image shows homogeneity of spots, 7 years later (2013), the spots have become heterogeneous.

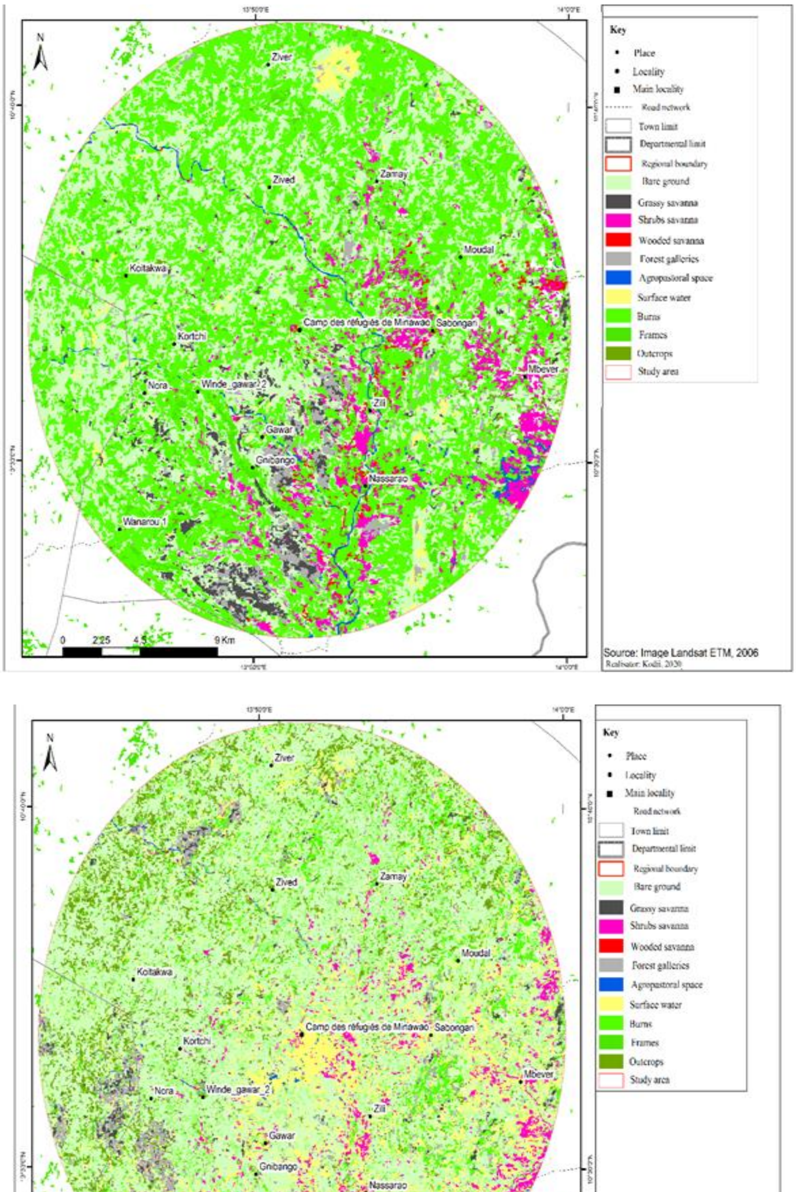


Figure 3 Dynamic of land use in Minawao and surrounding from 2006 to 2013

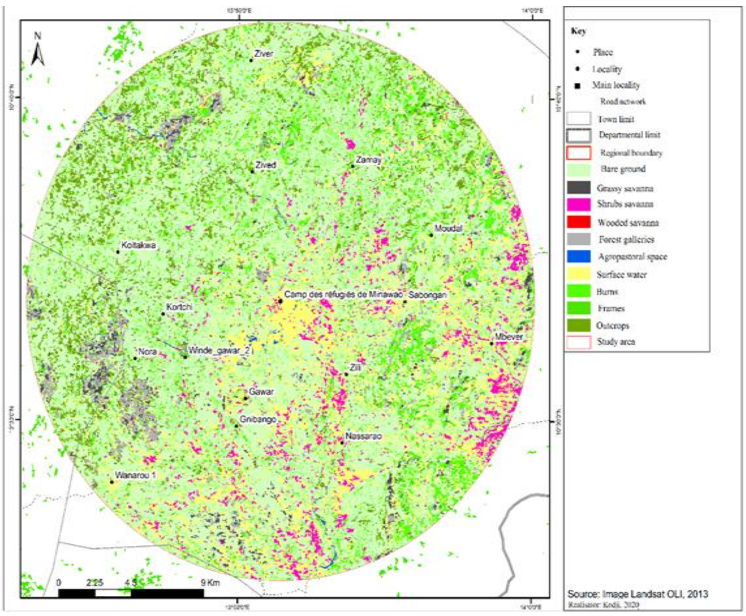
Reading Table 3 shows that the area of grassy savannah, steppe and built-up areas experienced a substantial increase between these two dates with respectively an evolution rate of 2.08%, 2.61% and 1.10%. While shrub savannahs, tree savannahs and forest galleries have seen their areas regressed with a respective evolution rate of -4.44%, -1.63% and -1.09%. Our results are similar to those of Bidossessi *et al.* [23], obtained between 2000 and 2016, of which natural plant formations such as wooded and shrub savannahs, dense forests, open forests and wooded savannahs have lost areas in favor of highly anthropized environments in Benin. The steppe and the built-up areas experienced the greatest growth between 2006 and 2013 with respectively 4.89% (4,138.85 ha) and 1.86% (1,574.05 ha) in 2006. They rose to 7.50% (6351.17 ha) and 2.96% (2505.06 ha) in 2013. While shrub savannahs, wooded savannahs and forest galleries show a regression with a respective evolution rate of -4.44%, - 1.63% and -1.09% in 7 years. This marked decline can be explained by the increasing increase in the local population, agricultural practices and the cutting of firewood. The annual rate of decline observed in woody formations is approximately -7.16% during the period 2006-2013. This result is much lower than those obtained in the forest formations of Benin, this rate was evaluated at -1.2% for the period from 1990 to 1995 [24] and at -1.8% for the period 19862005 [25].

Table 3 Evolution of the vegetation cover of Minawao and its surroundings from 2006 to 2013

Classes	Area (ha) in 2006	%	Area (ha) in 2013	%	Evolution rate in 7 years	Evolution rate in 1 year	Simulation in 14 years
Bare ground	4708,3	5,56	5404,3	6,38	0,82	11,74	164,4
Grassy savannah	26308	31,08	28068	33,15	2,08	29,7	415,8
Shrub savannah	27781	32,81	24021	28,37	-4,44	-63,4	-888
Tree savannah	12930	15,27	11546	13,64	-1,63	-23,3	-327
forest galleries	5759,8	6,8	4839,1	5,72	-1,09	-15,5	-218
Steppe	4138,9	4,89	6351,2	7,5	2,61	37,33	522,6
Surface water	440,55	0,52	467,01	0,55	0,03	0,45	6,25
Burn	1020,1	1,2	1458,2	1,72	0,52	7,39	103,5
Frame	1574,1	1,86	2505,1	2,96	1,1	15,71	219,9
Total	84660	100	84660	100			

3.6. Dynamics of land use in Minawao and its surroundings between 2013 and 2020

The changes observed mainly affect the density of tree cover. The degradation process presents a very significant spatial differentiation depending on the management mode implemented. The regression of plant cover mainly concerned shrub savannahs. The 2020 map also shows an increase in the number of colors by decreasing the size of the spots. These results highlight the spatial influence of agricultural production activities, agro-pastoral activities and the frequency of bush fires in 2020. The phenomenon of environmental fragmentation affects most regions and its importance has increased due to development. This phenomenon has been recognized as a major ecological risk [26]. The evolution of deforestation affects almost all vegetation cover. However, some classes (bare soil, shrub savannah, etc.) have increased.



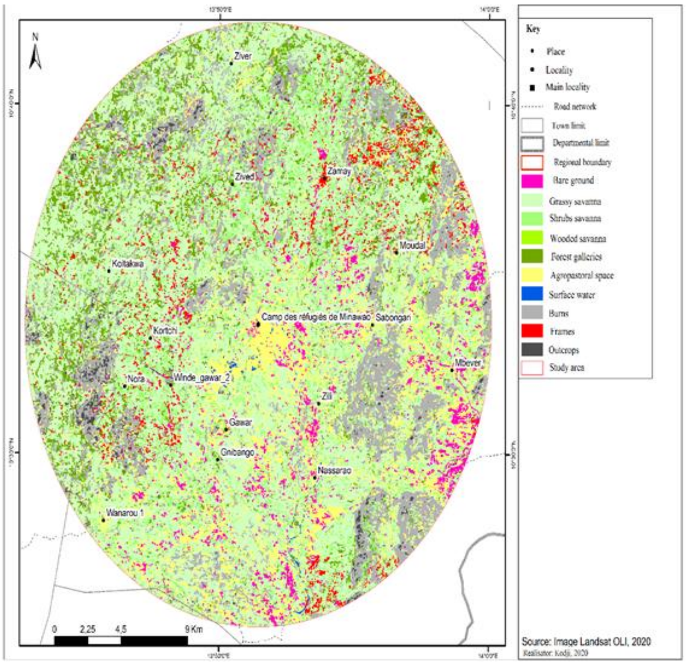


Figure 4 Dynamic of land use in Minawao and surrounding from 2013 to 2020

Reading Table 4 shows that the area of bare soil, grassy savannahs, steppes, burns and built-up areas has increased between 2013 and 2020 with respectively an evolution rate of 4.19%, 3.36%, 2.59%, 1.65 and 3.34%, and an annual expansion rate of 59.91%, 47.97%, 36.96%, 27.52% and 47.74% respectively. While shrub savannah, tree savannah, forest galleries and surface waters have seen their surface areas regressed with a respective evolution rate of -7.26%, -4%, -3.69% and -0.18% and an annual expansion rate of -103.66%, -57.19%, -52.65% and -2.59% respectively.

There are areas of both progression and regression. The most degraded areas are those closest to Minawao, which is in line with the classic area model of deforestation. The annual rate of decline observed in plant formations is -15.13% during the period 2013-2020. For a study covering all the forest formations of Benin, this rate was evaluated at -1.2% for the period from 1990 to 1995 [24] and at -1.8 for the period 1986-2005 [25]. This result further illustrates the danger of pressures from refugees combined with those from indigenous peoples. It is along the same lines as Rabiou *et al.* [3], report highlights of the changes that have taken place in the four (4) year interval around the refugee camps at Lake Chad and the degradation of natural vegetation.

Table 4 Evolution of the vegetation cover of Minawao and its surroundings from 2013 to 2020

Classes	**Area (ha) in 2013**	**%**	**Area (ha) in 2020**	**%**	**Evolution rate in 7 year**	**Evolution rate in 1 year**	**Simulation in 14 years**
Bare ground	5404,3	6,38	8954,6	10,58	4,19	59,91	838,7
Grassy savannah	28068	33,15	30911	36,51	3,36	47,97	671,6
Shrub savannah	24021	28,37	17878	21,12	-7,26	-104	-1451,26
Tree savannah	11546	13,64	8157	9,63	-4	-57,2	-801
forest galleries	4839,1	5,72	1718,8	2,03	-3,69	-52,7	-737
Steppe	6351,2	7,5	8541,4	10,09	2,59	36,96	517,4
Surface water	467,01	0,55	313,62	0,37	-0,18	-2,59	-36,2
Burn	1458,2	1,72	2851,8	3,37	1,65	23,52	329,2
Frame	2505,1	2,96	5334,3	6,3	3,34	47,74	668,4
	84660	100	84660	100			

3.7. Rates of land cover change in Minawao and surrounding areas before and after the arrival of refugees

Before (2006 to 2013) the arrival of the refugees, the steppes and the built-up areas experienced a relatively higher gradual speed than after the establishment of a refugee camp in this locality. One of the highlights of the changes that have taken place in the 14-year interval in the locality of Minawao and surrounding villages is the degradation of natural vegetation. This 14-year wide transformation is the result of human actions such as deforestation activities, a meteoric increase in the population which has recorded a massive flow of people.

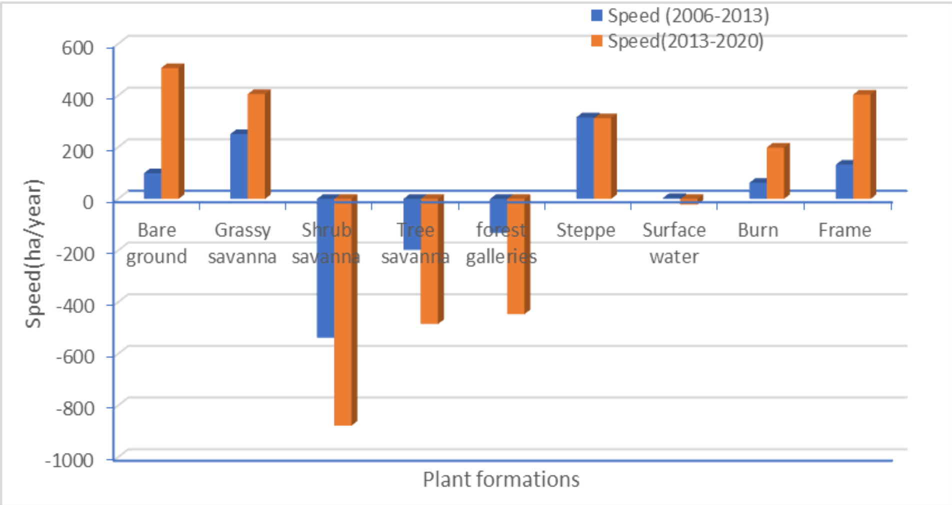


Figure 5 Rates of change in land cover in Minawao and its surroundings before and after the refugee camp

Figure 5 shows that only bare soils, grassy savannahs, steppes and built-up areas have a fast speed in terms of gain. Concerning losses, shrub savannahs, wooded savannahs and forest galleries have a rapid speed. However, the shrub savannahs (-877.60 ha/year) experienced a very rapid rate of decline after the settlement of the refugees. The annual rate of decline observed in plant formations is -7.16% before the arrival of refugees (2006 to 2013). However, this rate is - 15.15% during the period 20132020 (after the settlement of refugees). This increase in the area of anthropized units is linked on the one hand to the increase in the population and an increasingly growing demand for agricultural land on the other hand, as indicated by Amoussou *et al.* [27].

3.8. Total carbon stock of species according to villages

The total value of carbon stock varies from village to village. These are, in descending order, 22.29 tC/ha in Zamay, 17.61 tC/ha in Windé, 13.74 tC/ha in Gawar, 12.98 tC/ha in Sabongari and 10.31 tC/ha in Minawao. There is a significant difference between the different values of the amount of carbon sequestered by the species ($p < 0.0001$). The maximum carbon is stored by *Acacia albida* (11.77 tC/ha) followed by *Tamarindus indica* (8.14 tC/ha) and *Anogeissus leiocarpus* (7.96 tC/ha). Our results are similar to those reported by Kemeuze [5] in the shrub savannahs of the Far North, where species such as *Anogeissus leiocarpus* and *Tamarindus indica* are the species that sequester the greatest amount of carbon. Carbon sequestration by a tree is a function of its diameter at breast height (dbh). The more dbh a tree has, the better it sequesters carbon. It is for this reason that these species of high carbon value show higher dbh in our various study sites.

The diversity of species could be an important factor in the valorization of carbon in a given vegetation. This last hypothesis is illustrated by *Balanites aegyptiaca* (5.06 tC/ha). *B. aegyptiaca* does not have large dbh but because of its high density, shows a fairly large carbon stock. The total carbon obtained in this zone is 76.92 tC/ha. This result is in agreement with those of Tiessen *et al.,* [28] who showed that the carbon storage potential of natural ecosystems in semi-arid regions is in the range 20-150 tC/ha.

Table 5 Carbon stock in the villages

Species	**Gawar**	**Minawao**	**Sabongari**	**Winde**	**Zamay**	**Total**
Acacia albida	2,44	0,69	1,42	3,32	3,91	11,77
Acacia ataxacantha	0,16	0,03	0,37	0,17	0,31	1,04
Acacia nilotica	0,20	0,21	0,69	0,05	0,57	1,73
Acacia seyal	0,06	0,06	0,50	0,06	0,22	0,90
Adansonia digitate	0,08	0,09	0,11	0,10	0,01	0,38
Annona senegalensis	0,58	0,44	0,22	0,44	0,33	2,00
Anogeissus leiocarpus	1,39	1,17	1,87	1,22	2,31	7,96
Azadirachta indica	1,51	0,42	0,61	0,89	1,48	4,91
Balanites aegyptiaca	0,78	0,84	0,75	0,86	1,84	5,06
Boswellia papyrifera	0,30	1,72	0,40	0,54	0,32	3,26
Combretum glutinosum	0,09	0,04	0,55	0,42	0,69	1,80
Commiphora africana	0,05	0,69	0,05	0,77	1,23	2,79
Diospyros mespiliformis	0,44	0,25	0,38	0,54	0,91	2,51
Ficus sur	0,42	0,41	0,34	0,49	0,85	2,51
Ficus sycomorus	0,59	0,34	0,54	0,73	0,81	3,00
Hymnocardia acida	0,42	0,25	0,01	0,91	0,55	2,14
Khaya senegalensis	0,57	0,40	0,57	0,61	1,10	3,25
Parkia biglobosa	0,70	0,63	1,14	0,75	0,76	3,97
Piliostigma thoningii	0,24	0,15	0,36	0,29	0,45	1,49
Sclerocarya birrea	0,37	0,32	0,43	0,48	0,11	1,70
Tamarindus indica	1,76	0,74	0,77	2,47	2,39	8,14
Terminalia macroptera	0,43	0,37	0,49	0,68	0,49	2,46
Ziziphus mauritiana	0,16	0,07	0,41	0,86	0,66	2,15
Total	13,74	10,31	12,98	17,61	22,29	76,92

3.9. Total carbon stock of species according to plant formations

At the shrub savannah level, *Acacia albida* (3.29 tC/ha), *Anogeissus leiocarpus* (2.09 tC/ha), *Tamarindus indica* (1.84 tC/ha), *Boswellia papyrifera* (1.12 tC/ha) and *Parkia biglobosa* (1.02 tC/ha) sequester more carbon. In the forest galleries, *Acacia albida* (1.82 tC / ha), *Tamarindus indica* (1.76 tC/ha), *Anogeissus leiocarpus* (1.39 tC/ha) and *Balanites aegyptiaca* (1.20 tC/ha) are those which show significant carbon stock value. Regarding the fields, *Acacia albida* (2.03 tC/ha) and *Anogeissus leiocarpus* are the two species whose carbon stock value is greater than 1 tC/ha. For dwellings, the greatest carbon stock value was observed in *Azadirachta indica* (2.91 tC/ha), *Ficus sycomorus* (1.10 tC/ha) and *Khaya senegalensis* (1.29 tC/ha). *Azadirachta indica* is an exotic species, which would explain its dominance in homes. In tree savannahs, Acacia albida (3.94 tC/ha), *Anogeissus leiocarpus* (2.66 tC / ha), *Balanites aegyptiaca* (2.09 tC/ha), *Tamarindus indica* (2.96 tC/ha) and *Parkia biglobosa* (1.65 tC/ha) indicate the best amount of carbon stock. The amount of carbon in trees in plant formations varies significantly ($p <0.001$).

The difference in the capacity for carbon sequestration would be due not only to the difference in their structure, such as the type and density of vegetation, the distribution of diameter classes, but also to the intensity of the anthropogenic pressure that s exercises on the types of savannah [29]. Another hypothesis is that the plots located in the wooded savannah belong to private property which is partially protected from zooanthropic pressures. While in the wooded savannah most of the amount of carbon is stored, the dwellings register the small amount. To do this, Ibrahima and Abib [29] have shown that the sustainable management strategy in maintaining the carbon balance must vary according to the type of plant formation.

Table 6 Total carbon of species ecologically according to plant formation

Species	Shrub savannah	Forest galleries	Fields	Dwellings	Trees savannah	Total
Acacia albida	1,82	3,29	2,03	0,69	3,94	11,78
Acacia ataxacantha	0,16	0,19	0,37	0,01	0,31	1,04
Acacia nilotica	0,20	0,41	0,30	0,24	0,58	1,74
Acacia seyal	0,15	0,40	0,09	0,02	0,24	0,90
Adansonia digitata	0,02	0,00	0,01	0,32	0,01	0,37
Annona senegalensis	0,58	0,32	0,44	0,22	0,45	2,00
Anogeissus leiocarpus	1,39	2,09	1,21	0,58	2,66	7,94
Azadirachta indica	0,63	0,58	0,23	2,91	0,52	4,87
Balanites aegyptiaca	0,83	1,20	0,79	0,13	2,09	5,04
Boswellia papyrifera	1,12	0,75	0,61	0,33	0,47	3,28
Combretum glutinosum	0,41	0,44	0,16	0,01	0,78	1,80
Commiphora africana	0,79	0,97	0,19	0,00	0,84	2,79
Diospyros mespiliformis	0,97	0,87	0,03	0,12	0,50	2,49
Ficus sur	0,38	0,93	0,29	0,03	0,86	2,49
Ficus sycomorus	0,29	0,29	0,88	1,10	0,42	2,99
Hymnocardia acida	0,44	0,52	0,38	0,30	0,53	2,16
Khaya senegalensis	0,45	0,43	0,12	1,29	0,94	3,23
Parkia biglobosa	1,02	0,68	0,50	0,10	1,65	3,95
Piliostigma thoningii	0,35	0,22	0,30	0,02	0,60	1,48
Sclerocarya birrea	0,77	0,24	0,06	0,02	0,58	1,68
Tamarindus indica	1,76	1,84	0,68	0,89	2,96	8,13
Terminalia macroptera	0,56	0,50	0,40	0,40	0,60	2,46
Ziziphus mauritiana	0,24	0,79	0,41	0,06	0,66	2,16
Total	15,32	17,94	10,47	9,81	23,22	76,76

3.10. Total carbon stock in the vegetation cover of Minawao and its surroundings

The total carbon stock in the plant formations of the study site evolves in the order of increasing 20.82 tC/ha in dwellings, 21.4 tC/ha in fields, 27.7 tC/ha shrub savannahs, 43.45 tC/ha in the forest galleries and 61.38 tC/ha in the wooded savannahs. The variance test showed a significant difference between trees, grasses and litter ($p<0.0001$). Regarding the villages, the best value was recorded in Zamay (53.74 tC/ha). From the above, regardless of the vegetation formation of the different villages, the trees sequester the greatest carbon values. However, the greatest production of the litter carbon stock was reported in the plant formations of Gawar (0.16 tC/ha). Our results in tree savannahs and shrub savannahs show a difference of around 38.18 tC/ha. Kemeuze [5] in the Mandara Mountains reports a large difference in carbon value between shrub savannah and tree savannah of the order of 49.35 tC/ha. This result further shows the impact of refugees on the vegetation cover. To do this, Ibrahima and Abib [28] have shown that the sustainable management strategy in maintaining the carbon balance must vary according to the type of plant formation.

Table 7 Total carbon stock of villages and plant formations

Villages	Reservoirs	Shrub savannah	Forest galleries	Fields	Dwellings	Trees savannah	Total
Gawar	Trees	4,36	7,73	3,74	2,16	10,72	28,71
	Litter	0,02	0,07	0,02	0	0,05	0,16
Minawao	Trees	2,53	5,1	1,58	1,45	5,22	15,88
	Litter	0	0,01	0,01	0	0,01	0,03
Sabongari	Trees	5,38	7,34	2,72	3,89	9,2	28,53
	Litter	0,01	0,01	0,02	0,01	0,01	0,06
Windé	Trees	7,32	10,12	6,94	6,4	16,86	47,64
	Litter	0,01	0,01	0,01	0,01	0,03	0,07
Zamay	Trees	8,08	13,04	6,39	6,89	19,27	53,67
	Litter	0,02	0,02	0,01	0,01	0,01	0,07
Total		27,7	43,45	21,4	20,82	61,38	174,8

4. Conclusion

From this study, it emerges that in the woody flora of the study sites, 23 species were identified and grouped into 21 genera and 14 families on the 120 hectares of study area. The Zamay wooded savannah is more diverse with 21 species, 20 genera and 13 families. Species with diameters in the interval] 0.15] meters show a high density. The graphical representation of diametral data symbolizes the "L" structure, which reflects the presence of many future stems or have been subjected to human activities. Concerning the specific density according to heights, it is higher at the management level (Minawao-Zamay) with 29.86±18.74% individuals. The plant cover of Minawao and the neighboring villages (Gawar, Sabongari, Windé and Zamay) has experienced a regressive dynamic of its plant formations. The shrub savannahs (-877.60 ha/year) experienced the greatest rate of very rapid decline. The annual rate of decline observed in plant formations is -7.16% before the arrival of refugees (2006 to 2013) and -15.13% during the period from 2013 to 2020 (after settling in refugees). The maximum carbon is stored by *Acacia albida* (11.77 tC/ha) and *Tamarindus indica* (8.11 t/ha). The total amount of carbon in this area is 97.81 tC/ha. The government must set up a mechanism to restore degraded areas to conserve our environment.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors do not disclose any conflict of interest.

Statement of informed consent

The studies are not involved the information about any individual

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