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RESEARCH ARTICLE

SPATIO-TEMPORAL ANALYSIS OF LAND USE TYPES FROM 1993 TO 2023 IN THE SOUDANO-SAHELIAN ZONE OF CAMEROON

Haiwa Gilbert[1], Djibrilla Mana[2], Ondoua Joseph Marie[2], Tchobsala[3] and Ngakou Albert[4]

1. University of Maroua, National Advanced School of Enginering of Maroua, Department of Environmental Sciences. Cameroon P.O BOX 46, Maroua.
2. University of Buea, Faculty of sciences, Department of Plant Science, P.O box: 63 Buea, Cameroon.
3. University of Maroua, Faculty of Sciences, Department of Biological Sciences, BP: 814 Maroua, Cameroun.
4. University of Ngaoundere, Faculty of Sciences, Department of Biological Sciences, BP: 454Ngaoundere, Cameroun.

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Abstract

This work raises the problem of the evolution of deforestation in the Sudano-Sahelian zone of Cameroon. This land cover study was mainly based on diachronic analyzes of satellite images (Landsat). Diachronic analysis, used for a long time to understand the transformations of space, is an approach which carries out a comparative study, by superposition, or even juxtaposition of the different documents processed. Diachronic analysis in this study is developed over a three-decade period. Understanding vegetation dynamics in this study region requires careful analysis of how vegetation has evolved over the past three decades. It evolves according to management methods imposed by humans and climate variability. Satellite imaging (also called space imaging) refers to the taking of images from space, by sensors placed on satellites. The physiognomy of vegetation refers to the overall appearance of the vegetation, structure, and more particularly aerial system. This allows an overview on a very large scale, which depends on the species in an environment.In addition, topographic maps were acquired and digitized, as well as photographs. This study was undertaken with the aim of showing from satellite images the transformations undergone by plant formations in four Divisions of the Far North region of Cameroon and make a forecast of the vegetation of the study sites in thirty (30) years.From the analogical interpretation and mapping of land data, seven major land cover classes have been identified. These are: Steppe, Grassy Savannah/Fields, Shrubby Savannah, Wooded Savannah, Forest Gallery/Clear Forest, Surface Water and Buildings/Bare Soil and Sand Strip. The evolution of deforestation does not affect all vegetation, but there is an increase in other types of plant formations to the detriment of others. In addition, the vegetation of the study area is undergoing a regressive evolution due to the phenomenon of deforestation. Satellite images clearly show a number of negative changes in plant physiognomy. The 1993 image shows homogeneity of spots. Thirty (30) years later (2023), it indicates heterogeneous spots. Overall, the simulation of percentage changes in

Corresponding Author:-Haiwa Gilbert
Address**:-**University of Maroua, National Advanced School of Enginering of Maroua, Department of Environmental Sciences. Cameroon P.O BOX 46, Maroua.

deforestation is very accentuated in the study area. The results of this study show that vegetation is in full decline in the Sudano-Sahelian zone of Cameroon. This regression is due to deforestation and the deforestation is a function of ethnicities, cultures and traditions.Deforestation, which is mainly caused by human activities, has the major consequences of flooding and loss of biodiversity. These results could serve as a reference for the search for strategies for the exploitation of natural resources and sustainable conservation of plant diversity in the Sudano-Sahelian zone of Cameroon.

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Introduction:-

Spatial analysis constitutes an important tool and is integrated into almost all fields and particularly that of ecosystem management [8]. In this precise context, land use mapping stands out a little more today. Tool allowing the visualization and analysis of the composition and distribution of objects on the surface of a territory, and which can be updated using geographic information systems. The land use map offers excellent possibilities for planning and land use. This reality has been well understood by Western municipalities, which are demonstrating their desire to optimize the management of their spaces, through the multiplication of mapping and land use analysis projects. The advantage of this instrument could also benefit municipalities in Africa in general, and Cameroon in particular.

Savannahs are fragile ecosystems based on the co-existence of grassy and woody strata [5,31]. They are dynamic systems whose evolution depends on the intensity of environmental factors [8]. In the context of global climate change and strong growth of the world population, pressure on dryland ecosystems is increasing at breakneck speed [11]. In Cameroon, the Sahelian zone is essentially silvopastoral whose economy in this region is based on the exploitation of natural resources, vegetation in particular. This provides natural pasture for livestock feed and allows rural populations to meet their needs through the exploitation of various wood and non-wood products [1]. The Sudano-Sahelian zone is often considered as the result of the degradation of forest plant formations under the effect of natural and anthropogenic processes [18,20]. This will provide the information necessary for the reconstitution and sustainable and rational management of the natural plant resources of this region. This study was undertaken with the aim of: (i) showing from satellite images the transformations undergone by plant formations in four Divisions of the Far North region of Cameroon; (ii) make a forecast of the vegetation of the study sites in thirty (30) years.

Materials and Methods:-

Presentation of the study area

The investigations took place in Mayo-Danay, Mayo-Kani, Mayo-Sava and Logone and Chari Divisions and were based on four types of plant formation (shrub savannahs, tree savannahs, sacred forests and protected areas). This study area was chosen because of its exposure to desert settling and it is also considered the gateway to the desert in Cameroon. These Divisions belong to the Far North region of Cameroon occupying the eastern part of the latter. The study area belongsto the Sudano-Sahelian zone, from the climatic point of view, characterized by an alternation of a long dry season from October to June and a short rainy season between July and September. The months of August and September, which record the maximum rainfall, are considered the heart of the rainy season. Rainfall is monomodal with duration and intensity varying on average between 800 and 1000 mm/year (Gerhard, 2003). The average annual temperature is 28º C (Mainam, 1999). The soil is sandy-clayey and sandy. Plant formations is of the Sudano-Sahelian type characterized by steppes dominated by thorny shrubs and by its extreme fragmentation due to natural conditions and anthropogenic action.

This region is occupied by a large plain which extends from the Mandara Mountains to the limits of Lake Chad [19]. It covers an area of approximately 34.263 km² [10.23] and extends between latitudes 10 and 13 degrees North and Longitudes 13 and 15 degrees East [10]. And it is limited to the east by two permanent rivers:Logone and Chari, to the west and north by the Federal Republic of Nigeria and to the south by the northern region.

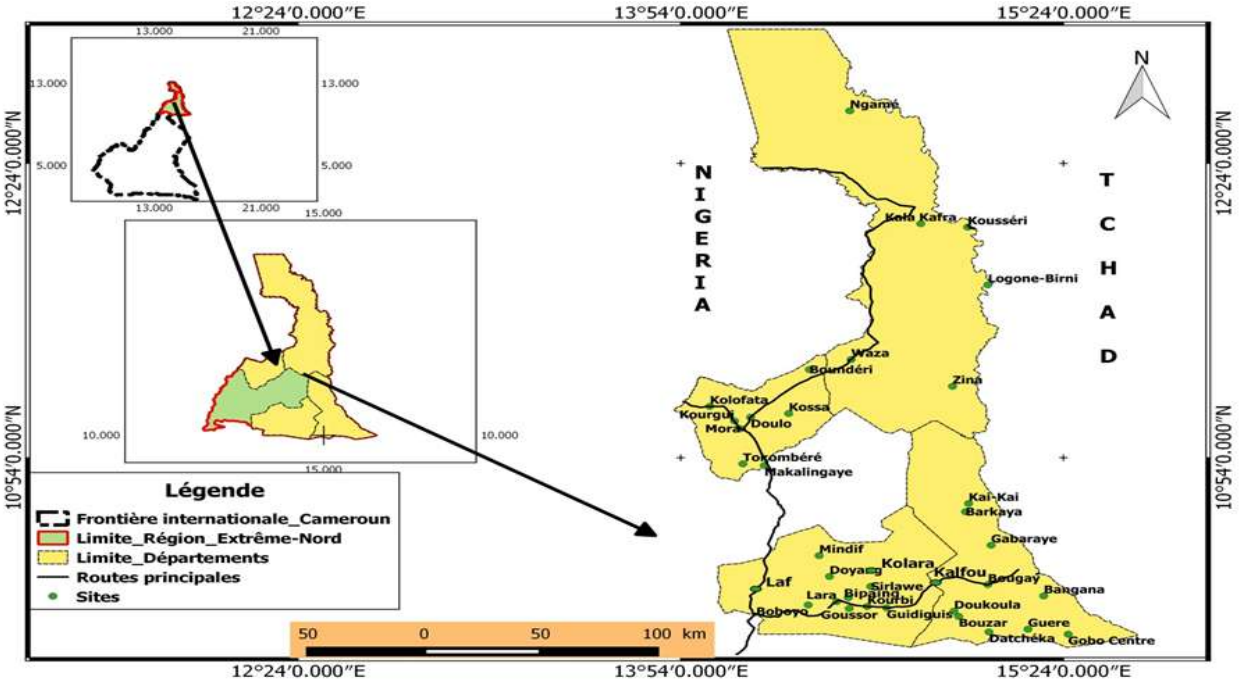

Figure 1:- Location of study sites.

Methodology:-

To assess the state of vegetation under the influence of deforestation from the diachronic analysis of satellite images from 1993 to 2023, work on remote sensing was used.

This remote sensing initially consisted of:

• Download satellite images (landsats) from different sites. For the mapping and monitoring of vegetation cover dynamics, images from two dates were chosen because of the time needed to monitor savannah dynamics and the availability of images. This is a so-called initial image from 1993, and a so-called final image from 2023. For each of these periods, two Landsat Enhanced Thematic Mapper (ETM) scenes and two landsat8 Operational Land Imager (OLI) (183/55 and 184/55) were downloaded due to the fact that our entire study area can only be obtained by merging two scenes.

• digitally processing of these different scenes using the ENVI 4.5 software. This step can be summarized in several phases which are:

1. The operations of preprocessing images and assembling the tapes of the different scenes. To better carry out the processing operations, the selected bands have been grouped together in the same multi-spectral image file. All the strips of the file from the mosaic of scenes 183/55 and 184/55 have been combined in a single file under ENVI using the layer stacking tool for these images;
2. Mosaicking, which consists of linking several landsat scenes that make up a given area in a single block. ENVI 4.5 allowed us to perform this operation for the GNP area and its periphery;
3. A colored composition which consists of combining the bands in order to bring out the different types of surfaces on a multi-spectral image. Compositions 4-3-2 (Landsat TM and ETM+) and 5-4-3 (Landsat OLI) known as "false colors" were used for studies of vegetation in which it appears in shades of dark to light red depending on the type. Water points in shades of dark blue to blue-green, buildings in shades of very light blue and bare soil in pinkish red [21];
4. Cutting of the study area consisted of extracting the part of the image corresponding to the study area from the polygon representing the boundaries of the Divisions. It should also be noted that at first, we downloaded all the images of the six Divisions that make up the Far North region of Cameroon before moving on to cutting and extracting the images from the concernedDivisions;
5. Supervised classification consists in extracting the classes of information on the images in colored composition. For our study, the land cover classes used for the classification are: gallery forests, open forests, wooded savannahs, wooded savannahs, shrubby savannahs, grassy savannahs, bare soils, water and burned [9];

6. Vectorization allows to go from a layer inside which the information is represented by pixels to a vector layer where the information is represented by objects (points, lines, polygons) [26]. The different land cover classes obtained by classification were transformed into polygons for the rest of the work;
7. Production of maps: for the production of vegetation cover maps, several manipulations under QGis 2.10 were necessary. These include queries, spatial analyses, adding other layers of information, and layout.

Results:-

State of deforestation in the Sudano-Sahelian zone from satellite images

Evolution of deforestation in Mayo-Danay from 1993 to 2023

Understanding the dynamics of the vegetation cover in this study region requires a careful analysis of how the vegetation has evolved over the past decades. It evolves according to management methods imposed by man and climatic variability. Figure 2 shows the state of evolution of deforestation in the Mayo-DanayDivision in terms of landscape variation between 1993 and 2023. The evolution of land use in this area is not an evolution in totality in general. This evolution of deforestation does not affect all vegetation, but there is an increase in other types of plant formations to the detriment of others. In addition, the vegetation of the study area is undergoing a regressive evolution due to the phenomenon of deforestation. However, these two images clearly show changes. The 1993 image shows homogeneity of the spots, however, 30 years later (2023), the spots have become heterogeneous. The water level, the bare/built soil and the steppe have increased and are very visible in 2023 figure 2b, all this sufficiently shows the extent of anthropogenic activities.

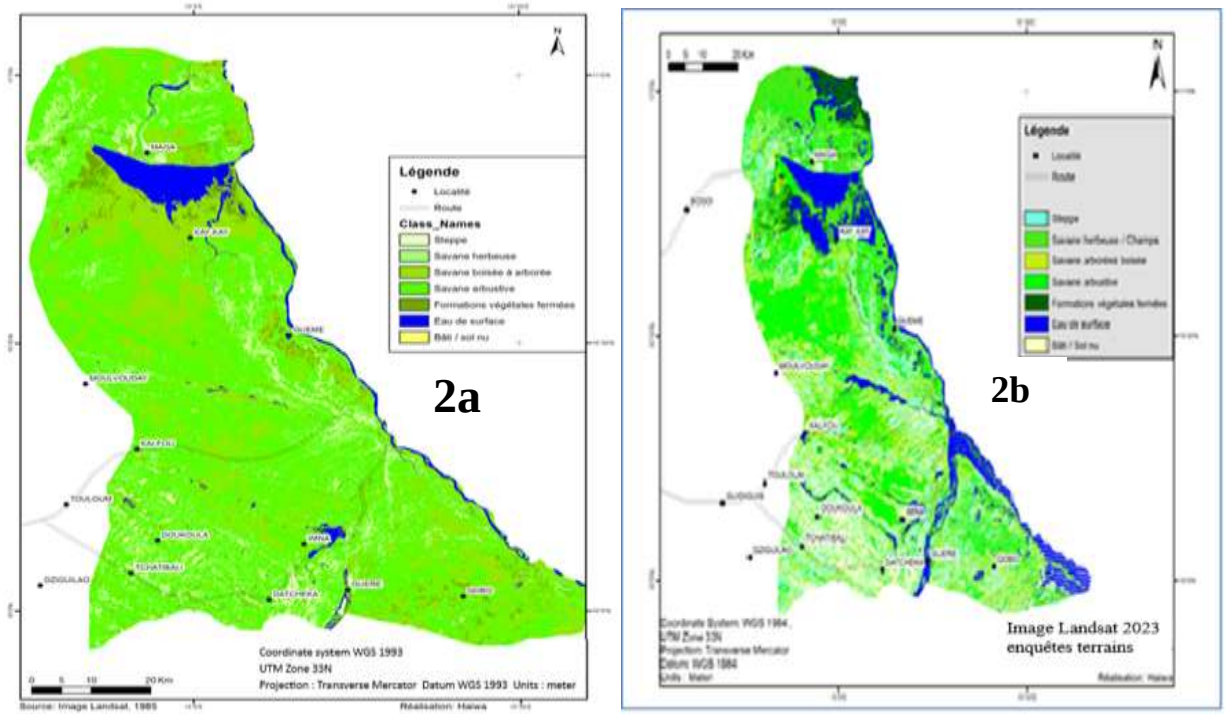

Figure 2:-Mayo-Danay land cover maps in 1993 (a) and 2023 (b).

Evolution of vegetation in the Mayo-DanayDivision from 1993 to 2023

Table 1 presents a large influence of the types of plant formations in the study area. The total area of the Mayo-DanayDivisions is 579,328.46 ha. Thus, in 1993, the steppe occupied an area of 47028.1 ha in the entire image, i.e. 8.12% of the vegetation. On the other hand, in 2023 the steppe occupies 49.399.2 ha, which represents 8.53% overall, i.e. an increase of 2.371.1 ha and a simulation in thirty years of 0.41%, with a rate of increase of 0.79 ha/year and a simulation within 30 years of 23.711 ha. Tree/wooded savannahs and open forests, when degraded, are mainly converted into more marginal and less wooded formations such as shrub savannahs or into crop and fallow areas.

Most of the areas lost by the land cover classes affected by the regressive dynamics have been colonized by grassy savannahs and fields. It is noted that plant formations of this region are degrading at a significant rate. Thus, out of a

total of 579,328.46 ha in 1993, grassy savannah and fields occupied 51,808.5 ha in the entire image, or 8.94% of all vegetation. However, in 2023 grassland and fields occupy 78,886.6 ha. This represents 13.62% overall, i.e. a total difference of 27078.1 ha and a percentage in 30 years of 4.67. With an evolution rate in one (01) year of 9,026 ha/year and a simulation within 30 years of 270,781 ha. For this purpose, to maintain or reduce and even reverse the trend; a solution must be considered because the net change in area is very worrying.

The shrub savannah in 1993 represented 346,779 ha in the whole image, or 59.86% of the whole vegetation. However, in 2023 it occupies 279,412.16 ha. This represents 48.23%, i.e. a regression of -67,366.84 ha in 30 years and a decrease in 30 years of -11.63%, with a regression rate of -22.45 ha/year and a simulation of 30 years of -673,668 ha. The extension of the shrubby savannah is explained by two antagonistic phenomena. It results on the one hand from the degradation of wooded formations and on the other hand from the aging of fallow land characterized by an increasingly significant woody cover. These are the remains of the reconstitution of the wooded vegetation cover following more or less recent human exploitation.

The wooded savannah occupied in 1993 an area of 90041.59 ha and a percentage of 15.54%. However, in 2023, it goes from 110,004 ha, a percentage of 18.99% and a difference of 19,962.41 ha in 30 years, a percentage of 3.45% in 30 years, a rate of change in one (01) year of 6.654 ha/year and a simulation within 30 years of 199.624 ha.

The gallery forests/clear forests had an area of 18900.7 ha and a percentage of 3.26% in 1993, thirty (30) years later (2023), it was increased by 20410.4 ha and a percentage of 3.52% or a difference in 30 years of 1509.7 ha, with a 30-year evolution of 0.26%, a rate of evolution of 0.503 ha and a simulation within 30 years of 15.097 ha. This clear progression can be explained by the fact that in this zone, protected areas and reforested areas are felt and the presence of dangerous animals (lions, elephants and snakes) constitutes a blockage.

Deforestation is one of the primary causes of flooding. It has been accentuated during these decades in the Mayo-Danay because of galloping demography which exerts pressure to harvest wood resources leaving the bare soil easily flooded. The surface water area is increasing with 22682.6 ha and a percentage of 3.92% in 1993. Thirty years later (2023), it has increased from 31399.2 ha and with a percentage of 5.42 % i.e. a difference in evolution in 30 years of 8716.6 ha, a percentage of evolution in 30 years of 1.5%, a rate of progression in one (01) year of 2.905 ha/year and a simulation of here 30 years of 87.166 ha.

The demographic explosion of the Cameroonian population calls for more needs in the field of nutrition (agriculture and firewood), clothing and housing (construction of houses). These are the culminating factors baring the ground. In 1993, the building/bare soil/sand strip had an area of 2087.97 ha and with a percentage of 0.36%. Thirty years later (2023), it has increased exponentially from 2087.97 ha to 9816.9 ha, with a percentage increase of 0.69%, i.e. a difference in thirty years of 7728.93 ha/year, with a rate of annual evolution of 2.576 ha/year and a simulation within 30 years of 77.289 ha.

Table 1:-Evolution of vegetation in the Mayo-DanayDivision from 1993 to 2023.

Land use	1993 area (ha)	in (%)	2023 area (ha)	in (%)	evolution in 30 years in (ha)	evolution in 30 years in (%)	Rate of evolution in 1 year	Simulation in 30 years
Steppe	47028.1	8.12	49399.2	8.53	2371.1	0.41	0.790	23.711
Grassland/Fields	51808.5	8.94	78886.6	13.62	27078.1	4.67	9.026	270.781
shrubby savannah	346779	59.86	279412.16	48.23	-67366.84	-11.63	-22.455	-673.668
Tree savannah	90041.59	15.54	110004	18.99	19962.41	3.45	6.654	199.624
Forest Gallery / Open Forest	18900.7	3.26	20410.4	3.52	1509.7	0.26	0.503	15.097
Surface water	22682.6	3.92	31399.2	5.42	8716.6	1.50	2.905	87.166
Buildings / Bare	2087.	0.3	9816.	1.6	7728.93	1.33	2.576	77.2893

soil and strip of sand	97	6	9	9				
General area	5793 28.46		5793 28.46					

Land cover in the Mayo-KaniDivision from 1993 to 2023

Figure 3a shows that the vegetation in 1993 was homogeneous in the Mayo-KaniDivision. On the other hand, thirty years later (2023), we observe a fragmentation of this plant formation into several patches. This division is characterized by an increase in the number of colours, the reduction in the size of the spots by the break in continuity and the increase in the isolation of these spots and in the end, the appearance of burning is very visible in figure 3b. These burns did not exist in 1993. However, the image of 2023 differs from that of 1993 by the appearance of an additional class: burnt areas. This phenomenon has been recognized as a major ecological risk. The evolution of deforestation does not affect all vegetation, but there is an increase in other types of plant formation to the detriment of others.

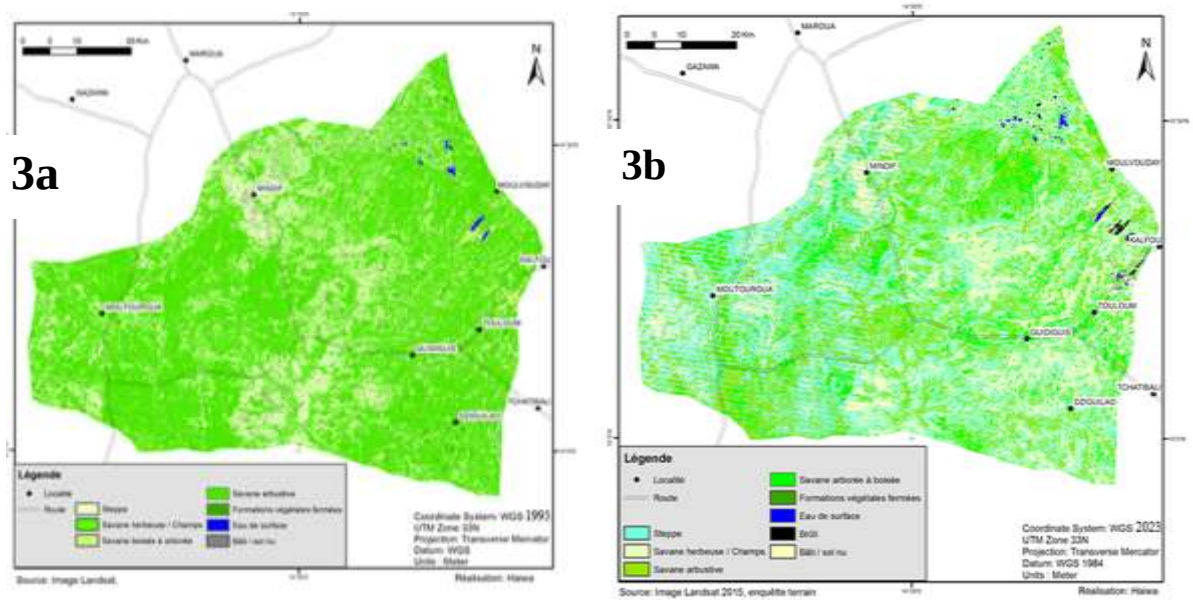

Figure 3:-Mayo-Kani land cover maps in 1993 (a) and 2023 (b)

Evolution of vegetation in the Mayo-KaniDivision from 1993 to 2023

Table 2 shows an overview of the types of vegetation formations in the study area. This table reveals that the total area of Mayo-KaniDivision is 464638.3 ha. Thus, out of a total of 464.638.3 ha, in 1993 the steppe occupied 106.766 ha in the entire image, i.e. 22.98% of the total vegetation. In addition, in 2023 the steppe increased from 112,680.45 ha, which represents 24.25% overall, i.e. an evolution in 30 years of 5,914.45 ha. The steppe, which is also characterized by a semi-arid climate and sometimes forms the transition with the desert areas, settles quickly over time compared to other types of plant formations.

Most of the areas lost by the land cover classes have been colonized by grassy savannah formations and fields. Careful observation shows that the plant formations of this study area are deteriorating at a significant rate because the demographic explosion is galloping. To feed this growing population, cultivated agricultural land is increasing throughout the Sahel. Thus, out of a total of 464,638.3 ha, in 1993 grassy savannah and fields occupied 4,036.15 ha, or 0.87% of all vegetation. However, in 2023 the grassy savannah and fields increased by 18,327.001 ha which represents 3.333% overall, i.e. a total difference of 11,508.8 ha and with an increase of 5.94%. For this, we record an evolution in thirty years of 14290.851 ha; with an evolution in one (01) year of 3.08 ha/year and a simulation within thirty years of 142.908 ha.

The shrubby savannah results on the one hand from the degradation of wooded formations and on the other hand from the aging of fallow land characterized by an increasingly important ligneous covering. However, in 1993, shrub savannah represented 322,422 ha in the entire image. That is 69.39% of all vegetation. On the other hand, in

2023, it fell by 235,118.7 ha. Which represents 50.60% overall. That is a regression in thirty years of -87303.3 ha, a decrease in thirty years of -18.79%, a rate of regression in one (01) year of -29.101 ha/year and a simulation within thirty years of -873.033 ha.

In 1993, the wooded savannah occupied an area of 19128.1 ha. In 2023, it increased to 22205.49 ha, a difference of 3077.39 ha. Thus, out of a total of 464,638.3 ha in 1993, wooded savannah represented 4.12%, against 4.78% in 2023 as a whole, i.e. an evolution in thirty years of 0.66%, a rate of evolution in one (01) year of 1.025 ha/year and a simulation within thirty years of 30.773 ha. This slight increase may be due to the various reforestation campaigns in this study area.

The gallery forests/clear forests covered an area of 5074.04 ha, or 1.09% of the total area of this Division in 1993. Thirty years later (2023), it has fallen from 2134.551 ha and with a percentage of 0.46% or a reduction of -2939.489 ha, with a percentage regression of 0.63%. These formations are degraded to the benefit of grassy savannahs, buildings, burns and steppes.

Deforestation caused mainly by human activities is the cause of the flooding. The latter, during these three decades has increased because of the demographic boom which exerts pressure to harvest wood resources leaving the bare soil, easily flooded. Surface water surface area is significant. Indeed, in 30 years there appears an evolution of 0.19% (872.032 ha in 1993 to 1755.22 ha in 2023) i.e. an annual evolution rate of 0.294 ha/year and a simulation within thirty years of 8.831 Ha. This clear progression could be explained by the fact that the gallery forests which could retain water in the rivers are destroyed and consequently, these surface waters and the strips of sand find faults and invade the soil.

In 1993, the building/bare ground had an area of 6340.02 ha with a percentage of 1.36%, thirty years later (2023), it rose from 71299.71 ha with a percentage of 15.35%, i.e. a difference of 64959.69 ha. All this with a percentage of evolution in thirty years of 13.98% with an annual rate of progression of 0.240 ha/year and a simulation within thirty years of 649.596 ha is possible. This increase in the surface area of agglomerations has been made mainly to the detriment of the areas of fields and fallow land, open forest, shrubby savannah, wooded savannah and formerly more or less bare soils. The main cause of this increase is the increased population growth in recent decades. The boom in agricultural development in the area, with the installation of new agricultural settlers, explains the creation of new agglomerations and hamlets. In addition, some agglomerations have emerged with the development and improvement of rural service roads along which they have settled.

Burns that did not exist in 1993 appear thirty years later (2023), with an area of 1117.22 ha and a percentage of 0.24%. That is, a percentage change in 30 years of 0.24%, an annual rate of change of 0.372 ha/year and a simulation within thirty years of 11.172 ha. This marked increase could be explained by the intensification of bush fires in the study area. Thus, in the study area, the practice of fire is also combined with the cutting of wood and the making of charcoal. To this end, we sometimes observe fires caused by shepherds in search of green pastures, farmers light fires to develop the fields and the practice of hunting to lead game to traps. Failure to control these fires generates significant damage to the survival of biodiversity each year.

Table 2:-Evolution of vegetation in the Mayo-KaniDivisionfrom 1993 to 2023.

Land use	**1993 area (ha)**	**in (%)**	**2023 area (ha)**	**in (%)**	**evolution over 30 years in (ha)**	**evolution over 30 years in (%)**	**rate of evolution in 1 year**	**Simulation in 30 years**
Steppe	106766	22.98	112680.45	24.25	5914.45	1.27	1.971	59.144
Grassland/Fields	4036.15	0.87	18327.001	3.94	14290.851	3.08	4.763	142.908
shrub savannah	322422	69.39	235118.7	50.60	-87303.3	-18.79	-29.101	-873.033
Tree savannah	19128.1	4.12	22205.49	4.78	3077.39	0.66	1.025	30.773
Forest galleries / Open forests	5074.04	1.09	2134.551	0.46	-2939.489	-0.63	-0.979	-29.394
Surface water	872.032	0.19	1755.22	0.38	883.188	0.19	0.294	8.831
Building / bare ground /	6340.02	1.36	71299.71	15.35	64959.69	13.98	21.653	649.596

strip of sand								
Burning			1117.22	0.24	1117.22	0.24	0.372	11.172
Total area	4646383		464638.3					

Land cover in the Mayo-Sava Division between 1993 and 2023

An observation of figure 4 reveals that the vegetation in 1993 was almost homogeneous in the Mayo-SavaDivision. But thirty years later (2023), there is a fragmentation of these plant formations into several patches. There is also an increase in the number of colours, with the reduction in the size of the spots, the break in the continuity of the lines of the vegetation and the increase in the isolation of these spots and finally the appearance of burns. However, this burning did not exist in 1993. This situation suggests in particular that the vegetation fires used by the populations as a tool for managing farms and as a hunting technique are gaining more and more spatial extent.

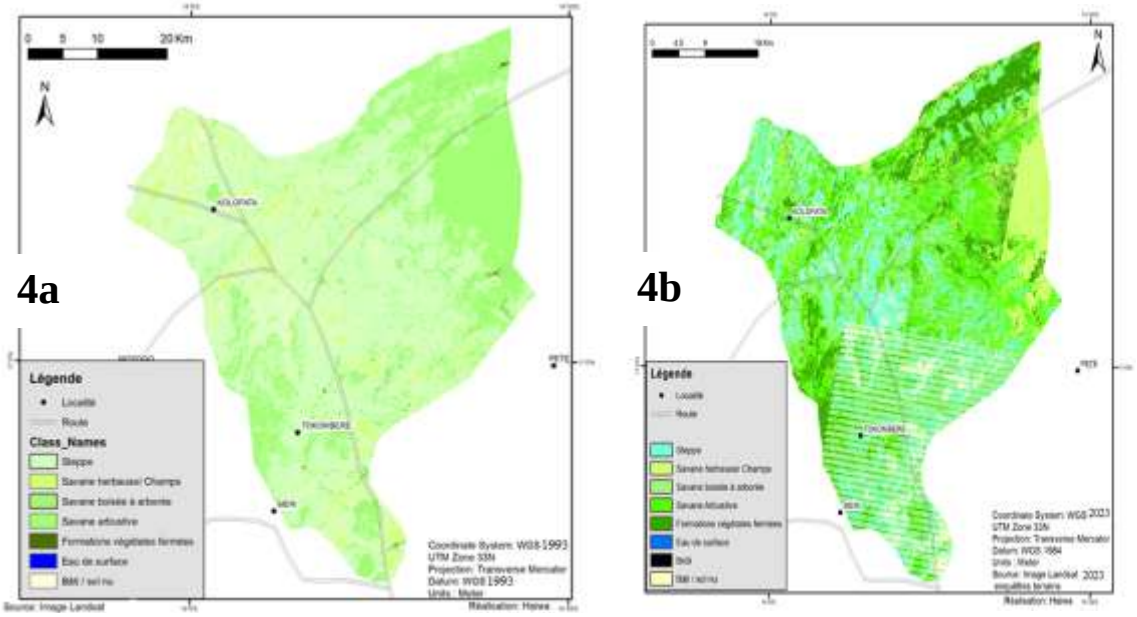

Figure 4:-Land cover map of Mayo-Sava Division in 1993 (a) and 2023 (b)

Evolution of the vegetation in Mayo-Sava Division between 1993 and 2023

Table 3 shows an overview of the types of land use by the different plant formations in the Mayo-Sava area. This table reveals that the area occupied by the steppe in this Division in 1993 was 126054.3 ha and in 2023 it fell to 88921.84 ha, this corresponds to a difference of -37132.49 ha, i.e. a regression of -16.22%, with a regression rate in one year of -82.51 ha/year and a simulation within thirty years of -2475.49 ha.

The evolution of grassy savannahs and fields in the Mayo-Sava Division is going at a significant pace. Thus, out of a total of 228933.81 ha in 1993, grassland and fields occupied 15813.24 ha in the whole image, or 6.91% of the whole vegetation. In 2023, on the other hand, the grassy savannah and fields occupy 26,471.7 ha, which represents 11.56% overall, i.e. a total difference of 10,658.45 ha, an evolution in thirty years of 4.66%, an evolution in one year of 23.68 ha/year and a simulation within 30 years of 710.56 ha.

Overall, the level of land cover by shrub savannah in Mayo-Sava in 1993 was 67,088 ha and in 2023 it drops by 60,875.1 ha, a difference of -6,212.9 ha. Thus, in 2023, there was a regression of -0.71% corresponding to -13.806 ha, therefore a simulation within thirty years of -414.19 ha. The wooded savannah occupied in 1993, 1820.012 ha (0.79%). In 2023, it increased to 29,534.7 ha, which represents a percentage of 12.9%, i.e. a difference of 27,714.68 ha, with an evolution in thirty years of 12.11%, an annual evolution rate of 61.58 ha/year and an evolution within thirty years of 1847.64 ha.

The gallery forests/clear forests had an area of 3412.26 ha (1.49%) in 1985. Thirty years later (2023), it has increased from 2697.6 ha and with a percentage of 1.18%, i.e. a regression of -714.66, with a regression percentage of -0.31%, a regression rate in one year of -1.58 ha/year and a simulation within thirty years of -47.64 ha.

The surface water area in the Mayo-SavaDivision is decreasing over the years. In 1993, it was 381.75 ha and with a percentage of 0.17%. Thirty years later (2023), it has been increased by 947.79 ha, i.e. a percentage of 0.41%, with a difference of 566.03 ha, an evolution in thirty years of 0.25%, an annual rate of 1.25 ha/year and a simulation over the next thirty years of 33.73 ha.

The factors of deforestation expose the soil. In 1993, the building/bare soil and strip of sand had an area of 14364.2 ha and with a percentage of 6.27%. Thirty years later (2023), it has risen exponentially to 18,387 ha and a percentage of 8.03%, i.e. a difference of 4,022.8 ha, a percentage change in thirty years of 1.76%, a rate of annual increase of 8.93 ha/year and a simulation over the next thirty years of 268.18 ha. This clear progression is explained by the galloping demography of this study area.

The burns that did not exist in 1993, appear in 2023, with an area of 1098.08 ha and a percentage of 0.48%. That is a percentage change of 0.48%, with a growth rate per year of 2.44 ha/year and a simulation of 73.2 ha.

Table 3:-Evolution of vegetation in the Mayo-Sava Division from 1993 to 2023.

Land use	**1993 area (ha)**	**in (%)**	**2023 area (ha)**	**in (%)**	**evolution over 30 years in (ha)**	**evolution over 30 years in (%)**	**Rate of evolution in 1 year**	**Simulation in 30 years**
Steppe	126054.3	55.06	889218436	38.84	-37132.498	-16.22	-82.516	-2475.499
Grassland/Fields	15813.24	6.91	26471.7	11.56	10658.4581	4.66	23.685	710.563
Shrub Savannah	67088	29.30	60875.1	26.59	-6212.9	-2.71	-13.806	-414.193
Treesavannah	1820.012	0.79	29534.7	12.90	27714.6881	12.11	61.588	1847.645
Forest Gallery / Open Forest	3412.26	1.49	2697.6	1.18	-714.66	-0.31	-1.588	-47.644
Surface water/sand	381.758	0.17	947.79	0.41	566.032	0.25	1.257	37.735
Building / bare ground and strip of sand	14364.2	6.27	18387	8.03	4022.8	1.76	8.939	268.186
Burning			1098.08	0.48	1098.08	0.48	2.440	73.205
Total area	228933.814		228933.814					

Land cover in the Logoneand Chari Division from 1993 to 2023

The concise observation of figure 5a reveals that the vegetation in 1993 was almost homogeneous in the Logone and ChariDivision. Nevertheless, thirty years later (2023), we observe a fragmentation of this plant unit into several patches (fig. 5b). This figure also shows an increase in the number of colours by decreasing the size of the spots. The rupture of continuity of the lines of the vegetation and increase in the insulation of these spots and at the end, the appearance of burns. However, these burns did not exist in 1993. These results highlight the spatial influence of agricultural production activities and are consistent with the increase in the need for additional production factors (new agricultural land) to cope with the increase booming population in the area. The phenomenon of environmental fragmentation affects most regions and its importance has increased due to the development of human activities.

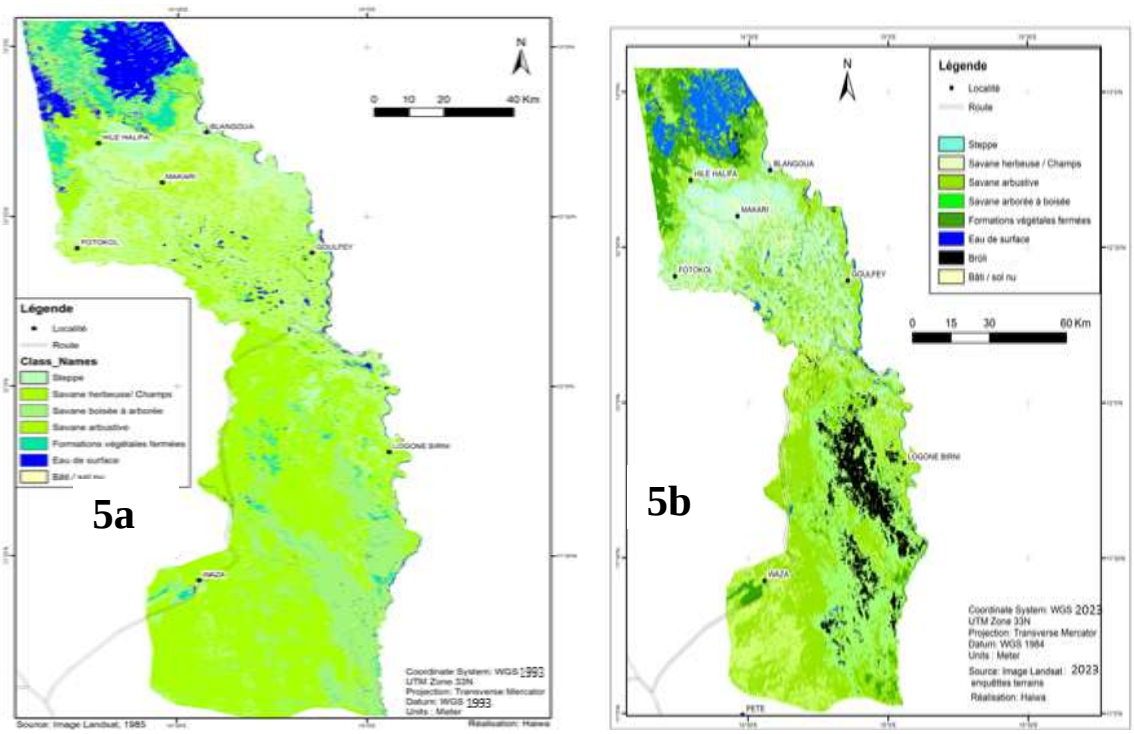

Figure 5:-Logone and Chari land cover maps in 1993 (a) and 2023 (b).

Level of evolution of vegetation in the Logone and Chari department from 1993 to 2023

Table 4 shows an overview of the types of plant formations in the Logone and ChariDivision. Out of a total of 1241617.7 ha, in 1993 the steppe occupied 204756 ha in the whole image. That is 16.49% of all vegetation. On the other hand, in 2023 it fell from 182,751 ha, which represents 14.72% overall, i.e. a regression of -22,005 ha and a percentage of -1.77%, an annual regression rate of -7.335 ha/year and a simulation within thirty years of -220.05 ha.

Most of the areas lost by land cover classes have been transformed into other types of plant formations. It is noted that the plant formations of this Divisionare degrading at a rapid rate. Thus, out of a total of 1241617.7 ha in 1993 the grassy savannah and fields occupied 86904 ha in the whole of the image, i.e. 7% of the whole vegetation. However, in 2023 the grassy savannah and fields increased to 156,332 ha which represents 12.59% overall. That is a total difference of 69,428 ha, with an evolution in thirty years of 5.59, an annual growth rate of 23.14 ha/year and a simulation within thirty years of 694.28 ha.

Overall, the area of land occupation of the Logoneand Chari Divisionby shrub savannah is 1,241,617.7 ha. Thus, in 1993, it represented 523,585 ha in the whole image. That is 42.17% of all vegetation. In addition, in 2023 it will increase from 602,684.83 ha. This represents 48.54% overall, a difference of 79,099.83 ha.

In 1993, the wooded savannah occupied an area of 244,833 ha. In 2023, it increased to 29058.6 ha, is a regression of -215774.4 ha. This regression may be due to multiple anthropogenic actions on wood resources in this study Division.

The gallery forests/open forests had an area of 50892.3 ha and a percentage of 4.10% in 1993. In 2023, it increased to 90477.9 ha. With a percentage of 7.29%. That is a difference of 39585.6 ha.

The area of surface water in Logone and Chari Divisionis decreasing over the years. Indeed, in 1993, it was 67909.9 ha, with a percentage of 5.47%. Thirty years later (2023), it suffered a regression of 66537.17 ha.
The culminating factors (agriculture, overgrazing and population explosion etc.) bare the ground. In 1993, the building/bare soil and a strip of sand had an area of 62737.5 ha and a percentage of 5.05%. Thirty years later (2023), it has fallen by 37998.6 ha and with a percentage of 3.06%, i.e. a difference of -24738.9 ha, a regression percentage of 1.99%.

The burns that did not exist in 1993, thirty years later, appear in 2023 with an area of 75,777.6 ha and with a percentage of 6.10%, i.e. a percentage change of 6.10%.

Table 4:-Evolution of vegetation in the Mayo-Sava Division from 1993 to 2023.

Land use	1993 area (ha)	in (%)	2023 area (ha)	in (%)	evolution over 30 years in (ha)	evolution over 30 years in (%)	Rate of evolution in 1 year	Simulation in 30 years
Steppe	204756	16,49	182751	14,72	-22005	-1,77	-7,335	-220,05
Grassland/Fields	86904	7,00	156332	12,59	69428	5,59	23,142	694,28
Shrub Savannah	523585	42,17	602684,83	48,54	79099,83	6,37	26,366	790,998
Treesavannah	244833	19,72	29058,6	2,34	-215774,4	-17,38	-71,924	-2157,744
Forest Gallery / Open Forest	50892,3	4,10	90477,9	7,29	39585,6	3,19	13,195	395,856
Surface water/Sand	67909,9	5,47	66537,17	5,36	-1372,73	-0,11	-0,457	-13,727
Building / bareground	62737,5	5,05	37998,6	3,06	-24738,9	-1,99	-8,246	-247,389
Burning			75777,6	6,10	75777,6	6,10	25,259	757,776
	1241617,7		1241617,7					

Land cover in the study area and simulation over 30 years

Multi-date analyses of Landsat TM and ETM+ satellite images from 1993 and 2023 show the extent of the influence of human activities in the study areas. The area (ha) and the percentage (%) of the vegetation vary exponentially according to years and Divisions. The simulation adopted in our work depends on the climate, the rate of demographic explosion and the living conditions. Thus, within thirty years if these parameters remain the same, we will record the information summarized in Table 16. In 1993, the Mayo-KaniDivisionhad an area of 453,390.14 ha. That is a percentage of 97.58%. Thirty years later (2023), this area has dropped drastically from 372,139.191 ha and with a percentage of 80.09%, a difference of 81,250.949 ha and 17.49%. In thirty years if nothing is done, the area of vegetation in the Mayo-Kani will be 40,625.475 ha, or a percentage of 45.11%. In Mayo-Danay, the area in 1993 was 502,749.39 ha, with a percentage of 86.78%. In thirty years (2023), it has been regressed by 459,225.76 ha, i.e. a percentage of 79.27% with a regression of 81,250.949 ha and 7.51%. Within thirty years if nothing is done, the area of vegetation in this Divisionwill be 21,761.815 ha, or a percentage of 64.25%.

Regarding Mayo-Sava, the area in 1993 was 198,374.572 ha, or a percentage of 86.64%. Thirty years later (2023), it has been reduced by 182,029.244 ha, i.e. a percentage of 79.51%, with a regression of 16,345.328 ha and 7.13%. Within thirty years if nothing is done, the area of vegetation in Mayo-Sava Divisionwill be 8172.6642 ha, or a percentage of 65.25%.

As for the Logone and ChariDivision, the area of 1993 was 1024066.3 ha, with a percentage of 82.48%. After thirty years (2023), it has been reduced by 904972.33 ha, a percentage of 72.89%, with a regression of 119093.97ha and a percentage of 9.59%. Within thirty years if nothing is done, the area of vegetation of Logone and Chari Divisionwill be 59,546.985 ha, i.e. a percentage of 53.71%.

Table 5:-Evolution of vegetation in the study area.

Main treatments	1985 in ha	1993 in %	2015 in ha	2023 in %	area in 30 years	% in 30 years	Simulation by 2030 (ha)	Simulation by 2030 (%)
Mayo Dana	502749.39	86.78	459225.76	79.27	43523.63	7.51	21761.815	64.25
Mayo Kani	453390.14	97.58	372139.191	80.09	81250.949	17.49	40625.475	45.11

Mayo Sava	198374.572	86.64	182029.244	79.51	16345.328	7.13	8172.6642	65.25
Logone and Chari	1024066.3	82.48	904972.33	72.89	119093.97	9.59	59546.985	53.71

Discussion:-

Understanding the dynamics of the vegetation cover in this study region requires a careful analysis of how the vegetation has evolved over the past decades. It evolves according to management methods imposed by man and climatic variability. The evolution of land use in this area is not a general evolution as a whole. This evolution of deforestation does not affect all vegetation. These results are similar to those of [13] who found on Mount Ngaoundal that there is progression of other types of plant formation (open forests, open forests and shrubby savannahs) to the detriment of others. In addition, the vegetation of the study area is undergoing a regressive evolution due to the phenomenon of deforestation. This result confirms those of [35,29] which showed that the phenomenon of environmental fragmentation affects most regions and its importance has increased due to the development of human activities; it has been recognized as a major ecological risk.

Tree/wooded savannahs and open forests, when degraded, are mainly converted into more marginal and less wooded formations such as shrub savannahs or into crop and fallow areas. These results are contrary to those of [28] who detected an additional gradual greening of the Sahelian grasslands since the mid-1980s. This difference would be due to the disparity of our study stations and the year of study [32].

Most of the areas lost by the land cover classes affected by the regressive dynamics have been colonized by grassy savannahs and fields. For this purpose, to maintain or reduce and even reverse the trend; a solution must be considered because the net change in area is very worrying. It is within this framework that [11] was able to show that the heterogeneity of herbaceous plants throughout the Far North is explained by the influence of the phytogeographical and climatic framework of the region, which constitutes a constraint. for post-cultivation vegetation and its dynamics. This explains the variety of fallow facies. The extension of the shrubby savannah is explained by two antagonistic phenomena. It results on the one hand from the degradation of wooded formations and on the other hand from the aging of fallow land characterized by an increasingly important ligneous cover [16,27]. These are the remains of the reconstitution of the wooded vegetation cover following more or less recent human exploitation. This increase could be explained by the fact that the wood resources protection system is in progress. In this study area, the government, NGOs and some farmers contribute effectively to the conservation of the savannah. This is felt by the increase in the level of reforestation, the conservation of sacred forests, agroforestry and the establishment of the Kalfou forest reserve. This clear progression can be explained by the fact that in this zone, protected areas and reforested areas are felt and the presence of dangerous animals (lions, elephants and snakes) constitutes a blockage. Thus, in the forest reserve of Kalfou, the fear of these animals prevents local residents from collecting natural resources there. Because several collectors of firewood have been victims and therefore access to this place causes a fright. These results are identical to those of [36] who worked in the forest of eastern Cameroon. The demographic explosion of the Cameroonian population calls for more needs in the field of nutrition (agriculture and firewood), clothing and housing (construction of houses). This leads to an increase in pressure on natural resources, thus causing deforestation.

Figure 3a shows that the vegetation in 1993 was homogeneous in the Mayo-KaniDivision. On the other hand, thirty years later (2023), we observe a fragmentation of this plant formation into several patches. This division is characterized by an increase in the number of colours, the reduction in the size of the spots by the break in continuity and the increase in the isolation of these spots and in the end the appearance of burning is very visible in figure 3b. These burns did not exist in 1993. However, the image of 2023 differs from that of 1985 by the appearance of an additional class: burnt areas. This result confirms that of [35] who showed that the phenomenon of environmental fragmentation affects most regions and its importance has increased due to the development of human activities. This phenomenon has been recognized as a major ecological risk. The evolution of deforestation does not affect all vegetation, but there is an increase in other types of plant formation to the detriment of others.

The steppe, which is also characterized by a semi-arid climate and sometimes forms the transition with the desert areas, settles quickly over time compared to other types of plant formations. These results are contrary to those of [16] who found an additional progressive greening of the Sahelian grasslands in 1980. This difference would be due

to the disparity of our study stations and our years of study. Careful observation shows that the plant formations of this study area are deteriorating at a significant rate because the demographic explosion is galloping. To feed this growing population, cultivated agricultural areas are increasing throughout the Sahel by creating new fields. Fallow periods are decreasing (sometimes disappearing) and crop yields are decreasing, thus forcing farmers to increase agricultural land each year [15]. According to this same author, logging and charcoal production partly explain the gradual transformation of gallery forests/clear forests into other less dense and more marginal formations (grassy savannahs and steppes). This regression is explained by the fact that the forest galleries and open forests have been attacked by loggers and farmers. These results are in agreement with those of [34] who found that the forest reserve of Laf-Madjam lost in 15 years almost a third of its vegetation cover to the benefit of crops.

To this end, there are sometimes fires caused by pastoralists with the aim of encouraging green pastures, farmers light fires to develop the fields and the practice of hunting to lead game to traps. Failure to control these fires generates significant damage to the survival of biodiversity each year. In general, fire favours herbaceous plants, especially grasses, at the expense of trees by opening up plant formations and creating a space offering enough light for their development [4].

An observation of figure 4 reveals that the vegetation in 1993 was almost homogeneous in Mayo-SavaDivision. But thirty years later (2023), there is a fragmentation of these plant formations into several patches. There is also an increase in the number of colours, with the reduction in the size of the spots, the break in the continuity of the lines of the vegetation and the increase in the isolation of these spots and finally the appearance of burns. However, image 4a shows us that this burning did not exist in 1993. This situation suggests in particular that the vegetation fires used by the populations as a tool for managing farms and as a hunting technique are increasingly gaining ground more spatially. These results confirm that of [6] which showed that the phenomenon of environmental fragmentation affects most regions and its importance has increased due to the development of human activities. The evolution of deforestation does not affect all vegetation, but there is an increase in other types of plant formation to the detriment of others. These results are in agreement with those of [17,14] which stipulated that the grassy areas would be the result of an irreversible degradation of the dense forest through the clearing and burning practiced since the Neolithic period by the cultivators. The maintenance of the Sahelian savannahs, and probably those of all of Central Africa, would be linked to the combination of paleoclimatic, edaphic and anthropic factors [30].In other words, the savannahs would be of paleoclimatic origin, but which would be maintained by the combined action of sandy soil with low water retention capacity and annual fires made by man. When the wooded savannah is threatened, we arrive at a modification of the physiognomy of the floristic and edaphic composition and savanisation or even desertification [7]. This clear regression could also be explained by the fact that the pressure to extract natural resources is growing. These results corroborate those of [33] in the Ngaoundere area which also showed that the gallery forests were attacked by farmers and loggers. This clear progression is explained by the fact of the intensification of bush fires and to this is added the phenomenon of the BOKO HARAM nebula which set fires in the villages. This has negatively impacted the vegetation in this area of Cameroon.

The concise observation of figure 5a reveals that the vegetation in 1993 was almost homogeneous in Logone and ChariDivision. Nevertheless, thirty years later (2023), we observe a fragmentation of this plant unit into several spots (fig. 5b). This figure also shows an increase in the number of colours by decreasing the size of the spots. The rupture of continuity of the lines of the vegetation and the increase in the insulation of these spots and in the end the appearance of burns. However, these burns did not exist in 1993. These results highlight the spatial influence of agricultural production activities and are consistent with the increase in the need for additional production factors (new agricultural land) to cope with the increase booming population in the area. The phenomenon of environmental fragmentation affects most regions and its importance has increased due to the development of human activities. This phenomenon has been recognized as a major ecological risk.

The need for rural populations to extend food and industrial production areas (cotton-growing) mainly explains this phenomenon. In addition, following our investigations in the field, the place of cotton cultivation has evolved considerably in agricultural production systems. Indeed, cotton, which was once essentially a crop associated with food crops, has now become a speculation exclusively installed in pure culture and above all the engine of the economy of savannah areas. Consequently, each year, the agricultural surfaces and the zones with agricultural right-of-way increase. Due to the infertility of the land, people migrate from time to time in search of new land [5].Theseagricultural settlers most often erect hamlets in the heart of plant formations, where they settle to practice agriculture (cultivation practices very often destructive of plant resources) and other income-generating activities.

Thus, the areas which generally contain the bulk of the agro-sylvo-pastoral potential are thus subject to human and animal pressure resulting in the extension of land for overgrazing crops, transhumance and clearing [22,12]. For [15,25], the production system based on burning is another factor of aggravation of the destruction of forest resources. The burns that did not exist in 1993, thirty years later, appear in 2023 with an area of 75,777.6 ha and with a percentage of 6.10%, i.e. a percentage change of 6.10%. Thus, in wooded areas, the practice of fire is also associated with the felling of trees to obtain firewood and the production of charcoal.In addition, we sometimes observe fires voluntarily lit mainly for the regeneration of green pastures (case of stockbreeders), during the preparation of fields (farmers), the cleaning of firebreaks (plantations) and the practice of collective hunting by encircling fire. Failure to control these fires generates significant damage to both fauna and flora each year. To this is added the phenomenon of the BOKO HARAM nebula which set fires everywhere in the agglomerations and savannahs to free the passage. This has had a negative impact on wood resources. Overall, the simulation of the percentage changes in deforestation is very accentuated in Mayo-Kani. Through our investigations, we observe that deforestation is a function of ethnicities, cultures and traditions. The fact that the level of evolution of deforestation is not very accentuated in Mayo-Sava would be justified by the fact that mountain people have been used to leaving trees in their fields since the night of time. The fact that the temperature is very high in the area prompts them to plant or leave the trees in the fields for the need of shade.

Conclusion:-

The diachronic analysis of satellite images shows that the vegetation in 1993 was homogeneous in the four Divisions. However, thirty (30) years later, we observe a fragmentation of this plant unit into several spots, with an increase in the number of colours, a decrease in the size of the spots by the break in continuity and the appearance of burning. Multi-date analyses of Landsat TM and ETM+ satellite images from 1993 and 2023 show the extent of the influence of human activities in the study areas. The area (ha) and the percentage (%) of the vegetation vary exponentially according to years and Divisions. The simulation adopted in our work depends on the climate, the rate of demographic explosion and the living conditions. Thus, within thirty years, if these parameters remain the same, we will record the information summarized in Table 16. Overall, the simulation of the percentage changes in deforestation is very accentuated in the Mayo-Kani. Through our investigations, we observe that deforestation is a function of ethnicities, cultures and traditions. The fact that the level of evolution of deforestation is not very accentuated in Mayo-Sava is justified by the fact that mountain people have been used to leaving trees in their fields since the night of time. The fact that the temperature is very high in the area prompts them to plant or leave the trees in the fields for shade.

Author contributions

Haiwa Gilbert conducted the field study and wrote the manuscript. **Djibrilla Mana**, **Ondoua Joseph Marie**, **Tchobsala** and **Ngakou Albert** read and made suggestions and comments in order to improve the scientific quality of the document.

Declaration of data availability

All data used in the article and in materials and methods have been referenced in the article.

Further information

No additional information for this article.

Conflict of interest

The authors declare that they have no conflict of interest.

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