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Quantification And Characterization of Changes In Land Use Types In The Menoua Watershed Between 1974 And 2018

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Abstract
The state of land use plays a major role in triggering hydrological processes at the plot or watershed level. Thus, its study takes a place of choice in the knowledge of the hydrological functioning of the catchment areas. The objective of this work is to quantify and characterize the land use of the Menoua watershed using high and medium resolution satellite data (Sentinel-2B and Landsat TM). To achieve this, supervised classification using the object-oriented approach and the diachronic comparison method were used. All the image processing operations were evaluated through the Kappa index widely used in the literature to evaluate the quality of classification operations. The calculation of this index revealed a classification rate of 97% for the year 2018 and 89% for the year 1978. The results obtained at the end of the classification process made it possible to characterize the spatio-temporal evolution of land use in the Menoua watershed for the 40-year period (1978 to 2018). The diachronic analysis of the images shows that, for the time step considered, the overall rate of change is negative for closed vegetation formations (-1.24%), and -0.99% and -0.89% for shrub savannah and grassy savannah respectively. On the other hand, it is positive for the built (2.59%), agrosystem (1.28%) and bare soil (1.24%) classes. From the overall analysis of the spatio-temporal evolution, it appears that the Menoua watershed is undergoing a profound anthropization, thus testifying to the strong imprint of man on the natural environment, which may at some point disturb the dynamic balance of this mountain ecosystem.

Keywords: *Dynamics, land cover, Sentinel-2B images, object-oriented approach, Menoua watershed.*

Résumé
L'état de l'occupation du sol joue un rôle prépondérant dans le déclenchement des processus hydrologiques à l'échelle de la parcelle ou du bassin versant. Ainsi, son étude revêt une place de choix dans la connaissance du fonctionnement hydrologique des bassins versants. Le présent travail se fixe ainsi, pour objectif, la quantification et la caractérisation de l'occupation du sol du bassin versant de la Menoua à partir des données satellitaires hautes et moyennes résolutions (Sentinel-2B et Landsat TM). Pour y parvenir, la classification supervisée par l'approche Orientée-objet, et la méthode de comparaison diachronique ont été mises à contribution. L'ensemble des opérations du traitement d'images a été évalué au travers de l'indice Kappa largement utilisé dans la littérature pour évaluer la qualité des opérations de classifications. Le calcul de cet indice a révélé un taux de classification de 97% pour l'année 2018 et de 89% pour l'année 1978. Les résultats obtenus au terme du processus de classification ont permis de caractériser l'évolution spatio-temporelle de l'occupation du sol dans le bassin versant de la Menoua pour la période de quarante ans (1978 à 2018). De l'analyse diachronique des images, il ressort que, pour le pas de temps considéré, le taux global de changement est négatif pour les formations végétales fermées (– 1,24%), et respectivement de -0.99 % et -0.89 % pour la savane arbustive et la savane herbeuse. Par contre il est positif pour les classes bâti (2,59%), agrosystème (1,28%) et sol nu (1,24%). De l'analyse globale de l'évolution spatio-temporelle, il ressort que, le bassin versant de la Menoua, connait une profonde anthropisation témoignant ainsi, de la forte empreinte de l'homme sur le milieu naturel, pouvant à un certain moment perturber l'équilibre dynamique de cet écosystème de montagne.

Mots clés: *Dynamique, occupation du sol, images Sentinel-2B, approche orientée-objet, bassin versant de la Menoua.*

INTRODUCTION

The state of the occupation plays a preponderant role in the triggering of hydrological processes at the plot or watershed scale. Indeed, it conditions the processes of infiltration and runoff of water, through the surface states (Chalier J-B, 2007). As such, its study or characterization has a place of choice in the understanding of the hydrological functioning of watersheds, but also for its development in general. In this perspective, many studies have developed methods, means and tools for its characterization. However, due to its potential, remote sensing is more and more put forward for its study, and this, since the launching of the first earth observation satellites. This has been reinforced with the advent of high spatial resolution satellites (HRS). In parallel to this technological evolution, methods of processing data from remote sensing have also undergone a notable evolution. Thus, we have progressively moved from undirected to directed classifications, from the pixel approach to the object-oriented approach. The latter also avoids the pitfalls of pixel-to-pixel classification and as such has a better performance than pixel classification (Puech, 2004; Weih and Riggan, 2010). Although fairly recent, it has already proven itself, in terms of the efficiency it has shown, in numerous works (Maréchal, 2012). In line with this perspective, the present study aims to quantify and characterize the changes in land use in the Menoua watershed between 1978 and 2018 using this new approach.

I. METHODOLOGICAL APPROACH

A. Study area

The Menoua watershed (Fig. 1), which is the subject of this study, covers an area of 395.62 km² and is located between 9°56'0" and 10°6'30" East longitude and 5°22'0" and 5°36'30" North latitude. Located in the Western region of Cameroon, it is part of the large hydrographic basin of the coastal rivers. It is an essentially mountainous basin, whose main activity is agriculture, mainly because of the very fertile volcanic land in the area. Climatically, the ambient climate is a humid tropical mountain climate of the Cameroonian type, characterized by two (02) seasons. This climate, which is influenced by the ocean, is characterized by a long rainy season lasting seven months (mid-March to October) and a short dry season lasting five months from November to mid-March. The rainy peaks are observed during the months of August and September. On the human level, it is characterized by a high human density, a fairly heterogeneous population. The majority of the population is made up of the Bamileke (indigenous people), the Fulani, the Babanki, the Tikar and the NSO. In addition, because of the establishment of the University of Dschang, there are also people from all over the territory, but also from the rest of the sub-region.

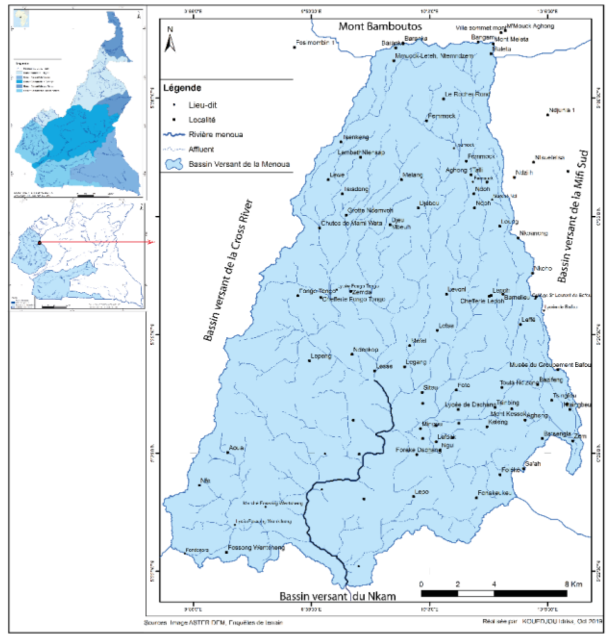


Fig. 1 Location of the study area

B. Data

Several data were mobilized for the present study. These are geospatial data from various sources and of various types, as well as GPS data.

Satellite data

For the realization of the present study, we used images from two sensors, namely

- The Sentinel 2B image

It was acquired in November 2018 from the Theia platform. The choice to focus on this image is justified because of their free access and characteristics very appreciable (10 m spatial resolution for the visible bands).

- Landsat TM (Thematic Mapper) images

They allowed us to have information on the land cover for the year 1978. They are made of 07 spectral bands, with a resolution of 30 m for the visible bands. They have been downloaded from the Earth Explorer site at https://earthexplorer.usgs.gov/

The GPS data

They were collected in the field with a GPS receiver. They are representative of the types of occupation detected in the field and were used to guide the choice of training plots and to validate the classification carried out.

C. Methodology for processing satellite data

a) Mapping of land cover types

The characterization of the state of land use in the Menoua watershed was based on the satellite image classification process. To achieve this, certain preliminary steps were taken. These operations, better known as image pre-processing, include everything from assembling the bands to creating the color compositions to extracting the study area.

1) The pre-processing operations of satellite images

Several operations were conducted in the process of pre-processing of these images to facilitate their subsequent use. These included the conversion of radiance values into reflectance using Sen2Cor software, and then contrast enhancement of the images for visual improvement and to facilitate band analysis (Donnay, 2000). After these operations, we performed a combination of spectral bands; then an extraction of the study area and finally, colored compositions in order to better discriminate objects and better visualize land use types. These last steps were carried out using Erdas Imagine software.

The classification process

Classification is a process of sorting and grouping pixels of an image, which allows to pass from satellite images to land use maps. It consists in performing a correspondence between the elements of an image scene, generally materialized by their radiometric values, and classes known a priori (or not) by a user (Kouedjou, 2015). Classification thus aims at a cartographic representation as close as possible to reality from the spectral values of the pixels forming the source image, and this, according to a previously defined nomenclature (Aoudou, 2010).

Choice of the classification method

To perform this operation, we chose the Object-Oriented method. The choice of the object-oriented method used in this study is justified by the spatial and spectral heterogeneity of the landscapes or objects that make up this watershed. Indeed, the interweaving of rural and urban landscapes characteristic of this watershed, and the diversity of spectral responses associated with them, explain this spatial and spectral heterogeneity. Given this complexity, the object-oriented approach appears to be the most appropriate, as opposed to the pixel approach. According to Boon and Rochon (1992), the interest of this type of classification lies in the fact that it uses information based on the spectral characteristics of the pixels that make up the objects, but also on information related to the geometry of the objects (size, structure, perimeter, orientation), the texture (arrangement and frequency of the variations in color within the object) or the topology (neighborhood relationship). This approach combines two main processes: segmentation and classification.

The segmentation of the image refers to the creation of segments that correspond to individual regions or groups of image elements based on criteria of spectral and spatial homogeneity. At the end of this operation, the pixels are grouped into meaningful pixel groups. The objects thus formed contain not only the value and statistical information of the pixels with which they are constituted, but also include texture, shape and topological information in an attribute table (Hadjadj Mohamed, 2011). This process was done using the Ecognition software, and the algorithm chosen is the "multi resolution" segmentation because more used in the literature (Pedro, 2007; Baatz and schape, 2000., Maréchal, op.cit., Baatz et al., 2004, Boon., Rochon, 1992). The parameters used for the segmentation are the following: Scale: 50; Color: 0.9; Shape: 0.1; Regularity and compactness: 0.5.

After this segmentation process, the next step is to create the thematic classes. Thus, 10 occupancy classes were defined taking into account the field reality (Table 1).

TABLE 1. THEMATIC CLASS DESCRIPTION

Thematic Class	Description
Outcrop, burned, shaded	Area crossed by the flames, where the exposure of the bedrock can be observed
Agrosystem	Plantation of cocoa and coffee trees, combined with crops such as palm trees, banana trees and, in some places, sweet potatoes
Built-up area	All built-up areas (buildings, housing, paved roads)
Surface water	River, lake
Agro-pastoral space	Area of agricultural and livestock practices
Eucalyptus live hedge and stand Eucalyptus	plantations in the form of stand or live hedge
Bare soil	Uncovered land such as dirt roads, stadiums or sand deposits
Grassy savannah	Grass-dominated savannah
Anthropogenic shrub savanna	Shrub-dominated savanna
Closed plant formations	Plant formations consisting of forest galleries, forest groves and sacred forests

b) Post classification

After having carried out the classification, the next step is to evaluate the accuracy of the classification in order to validate it. This validation was done through the ground truth and the kappa index. This is an index used in remote sensing and allows to estimate the accuracy of a classification (Anonyme 2013, Anaba 2010).

Once the validation is done, the raster file obtained at the end of the classification is converted into vector for better handling, and then imported into a GIS software to be able to perform the dressing in order to pass from a sketch to a map. This step is followed by the export of the classification result in vector form in a GIS software.

D. Quantifying the rates of change

The study of the dynamics allows to have a clear apprehension of the different trends in the landscape transformation processes. And to achieve this, it is necessary to quantify the rate of change between the areas of the land use classes for the considered time limit. For this purpose, two (02) equations were used, namely: the equation proposed by FAO (1990) for the calculation of the global rate of change (Tg) and by Bernier (1992) for the calculation of the average annual rate of change (Tc). These formulas are as follows:

$$Tg = \frac{S2-S1}{S1} * 100 \qquad Tc = \frac{lnS2-lnS1}{(t2-t1)*lne} * 100$$

With : S1: the area of a surface unit class at date t1

S2 : the surface of the same class of surface unit at date t2

Tg : the overall rate of change and Tc the average annual rate of change

Ln: the neperian logarithm; e the base of neperian logarithms (e= 2.71828)

RESULTS

a) Evaluation of classification accuracy

The accuracy of the classification operations performed for the defined dates was evaluated using the Kappa index as mentioned above. However it is necessary to remember that the accuracy for each date is a function of the quality of the images used which explains the variations observed in table (2).

TABLE 2. VALUE OF THE KAPPA INDEX FOR THE YEARS 1978 AND 2018

Years	**Kappa index**
1978	0,86
2018	0,97

Source: GIS database

The overall average accuracy for all years is 0.91. The accuracy of the 1978 classification is the least accurate (0.86) and is probably due to the poor quality of the images used. While, for the year 2018, it is 0.97 which is justified by the use of Sentinel 2B images, having not only a better spatial resolution, but also spectral. According to Pontius (2000) cited by Anaba (op.cit.), in a study of land use, when the Kappa index evaluated is above 75% as in this case, the classification is very good.

b) Land use status for 1978 and 2018

The land use status analysis was based on maps showing the land use status of the study area for each of the years 1978 and 2018. The surface area of each type of land use is presented and compared to the total surface area of the study area for each year. Then, a summary table presenting the evolution of these areas by land use class for the different dates is produced.

1) The state of land use in 1978

The state of land use in the Menoua watershed in 1978 is shown in Fig. 2.

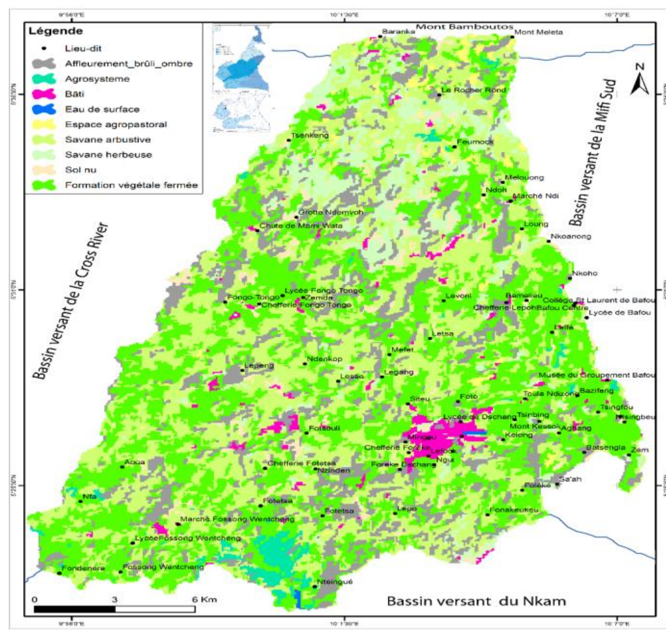
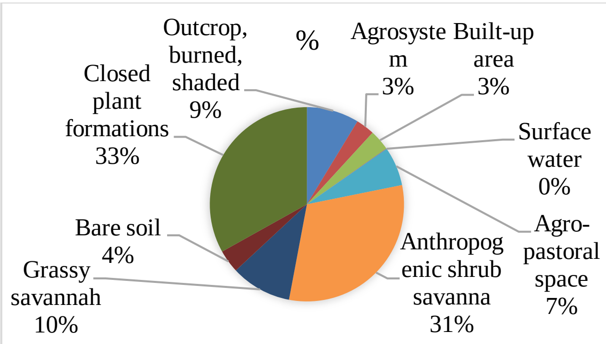


Fig. 2 Land use map for the year 1978

The analysis of Fig. 2. shows that the state of land use for the year 1978 is characterized by a preponderance of the physical elements of the environment distributed as shown in figure 3. From this figure, the observation that emerges is that the landscape in 1978 was dominated by natural vegetation formations with a preponderance of closed vegetation formations (33%) while surface water represents less than 1% (0.09%).



Source: GIS database, 2019

Fig. 3 Distribution of different land use types in 1978

The concomitant analysis of figures 2 and 3 shows that, agrosystems are concentrated in the south and west of the watershed. They cover an area of 12,372 km2, or 3.10% of the total area. As for the built-up area, it is found mainly in the southeast of the watershed, in the county seat. A structuring element of the anthropic landscape, it represents approximately 4% of the total area of the watershed at this date. The agropastoral space covers an area of 25.75 km ² or 6.46% of the total area of the study area. These areas are spread over all the topographic units of the basin. As for plant formations, they represent the dominant element of the landscape, are made up of shrub savannah, grassy savannah, and closed plant formations.

A remnant of a once existing montane forest, as well as a wooded savanna, the shrub savanna remains only in places, although it bears the traces of human activity. Very dense in the western part of the watershed, it is increasingly scattered over the rest of the watershed. It occupies nearly 124 km² of the watershed and represents 31% of the area. It is characterized by Pennisetum purpureum, Terminalia sp, Albizia gummifera, ... As for the grassy savannah, it occupies an area of 40 km ² and represents 10.11% of the total area of the watershed. Sometimes used as a grazing area by pastoralists, it is found mainly on the peaks and slopes. It is characterized by species such as Sporobolus, Imperata cylindrica, Pennisetum purpureum, Melinis minutiflora, and Hyparrhenia, ... In most places it bears traces of overgrazing activity and is sometimes presented in the form of a "terrace" due to the importance of cattle activity. In some places it is regularly burned to renew the grass. As for the closed plant formations, they cover a larger part of the basin, i.e. 131 km², and represent 33% of the total area. Mainly made up of raffia, Chinese bamboo and certain forest species, they are found in narrow valleys, in sacred forests and in forest reserves. Their existence is still made possible by their inaccessibility or the sacred nature of certain sites.

2) Status of land use in 2018

Figure 4 obtained following the processing of the Sentinel 2B image, shows the state of land use in the Menoua watershed for the year 2018.

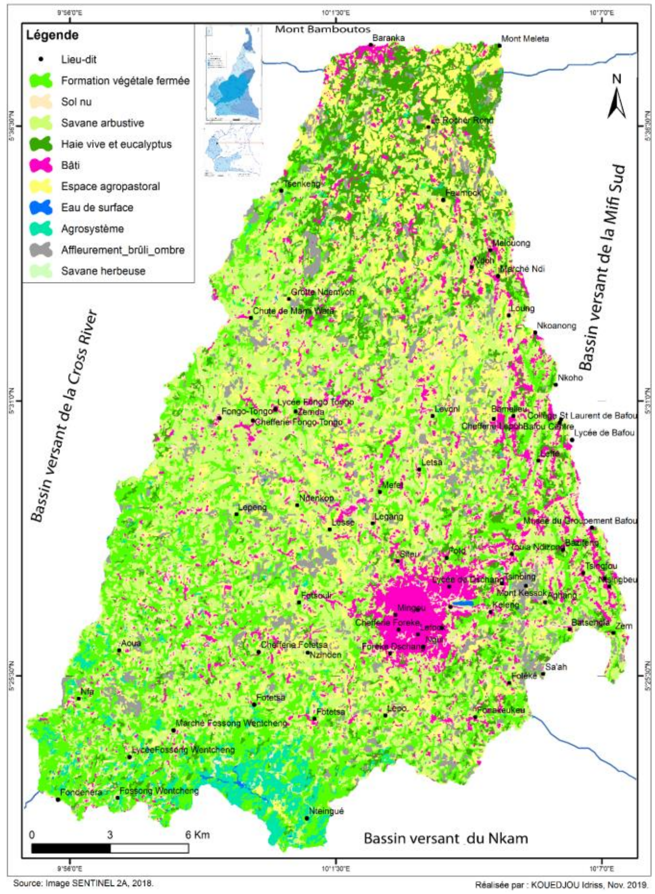


Fig. 4 Map of land use in 2018

The analysis of the state of land use in 2018, shows that, it is characterized by agrosystems that 5% of the total area of the watershed and are concentrated mainly in the south of the watershed closest to its outlet. In addition to this element, we have the built. It represents 9% of the total area of the basin and presents several physiognomies. Much more concentrated in the South-East of the basin it presents a grouped form. It is also found in the north of the watershed, but in a more dispersed manner. As a whole, it presents a mixed form, we find constructions in definitive, semi-definitive and temporary materials. Its development has been greatly influenced by the establishment of the University of Dschang, the main university structure in the entire western region. In addition to this element, we have the agropastoral space. It is found scattered throughout the watershed, although pastoral activity is much more concentrated upstream of the basin, on the peaks and sides of the mountains. This is to reduce agropastoral conflicts. This area covers 15% of the total surface of the watershed.

The land use in 2018 is also characterized by closed vegetation formations that represent the 17% of the total surface of the basin. Some of them still exist today, due to the sacred nature of some sites and the inaccessibility linked to the steep slopes. In addition to these closed plant formations, we have the living hedges and stands of eucalyptus. They include mainly the eucalyptus stands arranged either in the form of lines used to delimit agricultural plots and those organized in the form of groves. At this date, they represent 6% and are located mainly upstream of the watershed. Table 3 summarizes the land use data for the study period.

TABLE 3. AREA OF LAND USE CLASSES IN 2018.

Class	Area (km²)	%
Outcrop, burned, shaded	26,68	6,69
Agrosystem	20,66	5,18
Built-up area	38,9	9,76
Surface water	0,77	0,19
Agro-pastoral space	70,76	17,75
Eucalyptus live hedge and stand Eucalyptus	23,69	5,94
Anthropogenic shrub savanna	83,53	20,96
Grassy savannah	28,23	7,08
Bare soil	25,08	6,29
Closed plant formations	80,24	20,13
	398,54	100

Source: GIS database

Analysis of table 3 shows that overall, land use is largely dominated by natural vegetation formations, which represent 192 km² or approximately 49%. However, it is necessary to recall that in this area, in addition to the sacred forests, other vegetation formations bear traces of exploitation by man and as such, there are no longer natural vegetation formations in the strict sense of the term. Next are the anthropized surfaces (buildings, agro-pastoral areas, agrosystems), which represent 33% of the area, or 130.32 km². Anthropogenic plant formations such as stands of Eucalyptus, although important, represent only 6% of the area. Finally, surface water and bare soil appear in a scattered but not negligible way. They represent 6, 53% of the total area. As for surface water, the communal lake of Dschang and the Menoua River in its downstream part near the outlet of the watershed represent it.

c) Summary of land cover changes between 1978 and 2018

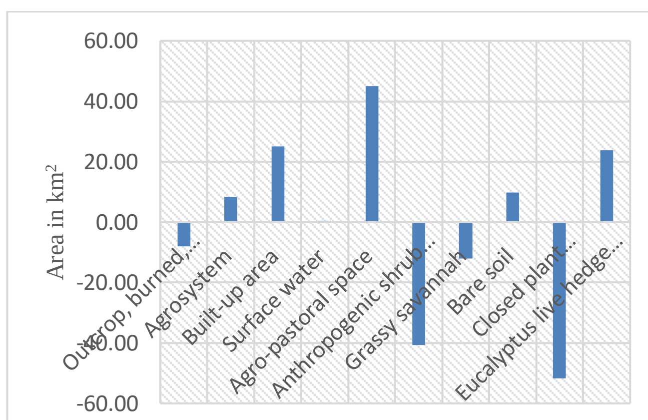
Table 4 and figure 5 present the balance of the evolution of the surface states between 1978 and 2018, i.e. a period of 40 years. They present respectively the surface areas of the surface states at different dates and the variations of these areas during the same period.

TABLE 4. BALANCE OF LAND USE CHANGE BETWEEN 1978 AND 2018

Land use class	Area (1978)		Area (2018)	
	km²	%	km²	%
Outcrop, burned, shaded	34,7232	8,71	26,68	6,76
Agrosystem	12,372	3,10	20,66	5,18
Built-up area	13,7812	3,46	38,90	9,76
Surface water	0,3456	0,09	0,77	0,20
Agropastoral area	25,7504	6,46	70,76	17,75
Anthropogenic shrub savanna	124,11	31,14	83,53	20,96
Grassy savannah	40,3052	10,11	28,23	7,08
Bare soil	15,2844	3,84	25,08	6,29
Closed plant formations	131,868	33,09	80,24	20,13
Eucalyptus live hedge and stand Eucalyptus	-	-	23,69	5,94

Source: GIS database

Examination of this table shows that two (02) main trends emerge. The first trend is largely regression or degradation of open and closed vegetation formations, which have declined considerably, with the greatest loss of 50 km² for closed vegetation formations (Figure 5). These closed vegetation formations are converted into savannah formations, either agrosystems, eucalyptus stands or agropastoral areas.



Source: GIS database, 2019

Fig. 5 Loss and gain of land cover areas between 1978 and 2018.

The second trend is that of progression. It concerns classes such as built-up areas, agrosystems, agropastoral areas and bare soil, which will be analyzed in the following lines.

The built-up area has been extended by more than 20 km². This extension has been to the detriment of natural areas and agro-pastoral areas located on the outskirts of the old city core. This has resulted in the destruction of plant formations. In addition to the built-up area, the eucalyptus stands have also increased by almost 20 km² over the last 40 years. The increase in the area occupied by these stands was favored by SONEL (National Electricity Company) which used them as a physical support for electrification (electric poles), by the FNFP (National Forest and Fish Fund), by ONAREF (National Office for Forest Regeneration) and by Cameroon Tea Estates (C.T.E) of Djuttitsa. Their extension is also justified by their high regeneration capacity and because of the multiple uses made by the populations.

d) Summary of the evolution of the rate of change between 1978 and 2018

Table 5, which summarizes the rates of change in land use between 1978 and 2018, presents a rather mixed picture with an average of 1.38%.

TABLE 5. AREA AND RATE OF CHANGE OF OCCUPANCY CLASSES BETWEEN 1978 AND 2018.

Land use class	**Area en km²**		**TC (%)**	**Tg (%)**
	1978	**2018**		
Outcrop, burned, shaded	34,72	26,68	-23,17	- 0,66
Agrosystem	12,37	20,66	66,95	1,28
Built-up area	13,78	38,90	182,25	2,59
Surface water	0,35	0,77	123,55	2,01
Agro-pastoral space	25,75	70,76	174,79	2,53
Anthropogenic shrub savanna	124,11	83,53	-32,70	- 0,99
Grassy savannah	40,31	28,23	-29,96	- 0,89
Bare soil	15,28	25,08	64,11	1,24
Closed plant formations	131,87	80,24	-39,15	- 1,24
Eucalyptus live hedge and stand Eucalyptus		23,69		7,91

Tc: average annual rate of spatial expansion; Tg: overall rate of change.

Source: GIS database analysis, 2019

From the analysis of table 5, it emerges that the "built" and "agro-pastoral space" classes are those with the highest Tc and Tg values over the last four (4) decades. This increase is also noticeable for the "agrosystem", "bare soil" and "hedge and eucalyptus" classes (Figure 13). On the other hand, savannahs and closed vegetation formations have experienced a significant regression of 2% on average.

E. DISCUSSIONS

The land cover maps obtained from the directed classification of Landsat TM and Sentinel 2B images, using the object-oriented method, allow us to highlight the changes in land cover types in the Menoua watershed between 1978 and 2018. Given the overall accuracy (0.86) for the Landsat image and 0.97 for the Sentinel 2B image, this classification can be valid according to Pontius' recommendations. The supervised classification method via the object-oriented approach used in this study is one of the most recent and widely used methodologies for mapping land cover types. Indeed, this method gives better results than the usual pixel-based approach (Wilhauck, 2000; Kagamata et al., 2005; Maréchal, 2011). However, the quality of these results remains strongly dependent on the nature of the geospatial data used.

From the analysis of the results obtained at the end of the classification process, it appears that the dynamics of the natural environment in the Menoua watershed is regressive on the whole. The overall rate of change shows that the regressions concern mainly natural plant formations. Even if in some places, we observe a relative stability of some of them, due to their sacred character. In addition, an in-depth analysis of the maps shows that the most important dynamics are observed around urban centers and along communication routes. This observation is consistent with that made by many authors, such as Tchotsoua (2006) in Central Adamaoua, Anaba et al (2019) in the upper watershed of the Bini, and Koffi Djagnikpo Kpedenou et al (2016) in the prefecture of Yoto (southeast Togo), as well as by Mama et al (2003).

The artificialization of this natural environment is mainly due to the significant demographic growth observed after the economic crisis of 1985 (Kaffo, 2000; Kamga, 2002), but also due to the creation of the University of Dschang in 1993. Indeed, the population of this commune increased from 17814 inhabitants in 1976 to 35717 in 1987 and then to 63838 in 2005 (RGPH 1976, 1987, 2005). This demographic growth has resulted in an increase in built-up areas, an increase in construction materials, new mouths to feed, and above all an increase in the need for wood energy taken directly from the natural environment. Several authors have also identified these factors as being responsible for the degradation of the natural environment. These authors include Lavigne (2001); André et al, (2001); Tchotsoua et al, (2010); Tchotsoua (2006), Aoudou (1999), Anaba (2011, 2019). It should be noted, however, that tradition contributes to the preservation of certain natural landscapes, such as sacred places, which are true refuges for species and, as such, contribute to their preservation.

CONCLUSION

The objective of this study was to conduct a diachronic analysis of the evolution of land use types in the Menoua watershed over a 40-year period (1978-2018). To achieve this goal, remote sensing and Geographic Information Systems were used to analyze the land use status. The supervised classifications of Landsat TM and Sentinel 2B images have allowed to highlight the state of land use for the years 1978 and 2018 respectively. From the analysis of these maps, it appears that the Menoua watershed is characterized by a regressive dynamic of its natural landscapes. Natural vegetation formations are those that have been most impacted and are gradually being replaced by agrosystems, eucalyptus stands and agricultural areas. Close to urban centers, they are under assault by populations for various reasons (need for building space, need for wood energy). As such, urban growth translated spatially by urbanization remains the main factor responsible for the erosion of these natural landscapes in the Menoua watershed.

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