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RESEARCH ARTICLE

LAND USE CHANGES IN THE SOLOMOUGOU WATERSHED FROM 1984 TO 2021 (NORTHERN CÔTE D'IVOIRE)

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Abstract

Human activities affected Land use changes bya complex dynamic process, whitch affects natural resources. Poro region in general, and the Solomougou watershed in particular, is characterized by favorable natural conditions for diversified agricultural production. Remote sensing shows the extent of land use change between 1986 and 2021. Diachronic analysis reveals a decline in natural formations (forests and savannahs) in favour of crops. Interpretation of the results shows the local causes of this change, highlighting farming and pastoral practices, economic factors, urban expansion, migratory flows and deforestation, which weakens the environment by stripping the surface layers. The brightness index of high-resolution Landsat images shows a strong degradation. All this raises questions about the future of farming in this region, whose products make an essential contribution to local and national markets.

Introduction:-

Land use's study is an ideal way of assessing the interactions between human and his environment. Information derived from land use analysis is always useful in identifying appropriate strategies to better manage land use status. In addition, monitoring changes in land use and land cover must be a priority for political decision-makers, for regional planning and for the study and understanding of the environment [1]. The development of remote sensing techniques and geographic information systems has made it possible to assess changes in land cover.Several methods have been invented and applied for this purpose, with varying levels of effectiveness ([2]; [3]). Among these, diachronic and multi-date analysis of land use is one of the most widely used, because it is a method that also takes into account the spatial distribution of changes ([4]; [5]). This approach is commonly applied by several authors ([6]; [7]; [8], [1], [9]). Worldwide, land use is one of the main drivers of deforestation and climate change ([10]). In Côte d'Ivoire, land use for agriculture is the main cause of deforestation. In fact, Côte d'Ivoire's agricultural-based economic policy has favoured the creation and extension of large agricultural areas, to the detriment of forest formations. Forest cover fell down from 14 million ha at independence (1960) to just 2 million ha in 1990 ([11]; [12]). The Solomougou watershed, is located in the north of Côte d'Ivoire in the Poro region, and is also affected by land degradation.A number of previous studies have addressed the problems of environmental degradation in northern Côte d'Ivoire ([11]; [13]; [14], [15]), and an update is needed. While it's well established that the evolution of landscapes is linked to mankind and the various techniques developed to exploit natural resources,

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land-use maps are essential tools for development planning and regional development. The aim of the present study is to analyze land use in the Solomougou watershed between 1986 and 2021, in order to assess the various trends in the evolution of the natural landscape during these periods.

Study area

Solomougou watershed covers an area of 367 km². It is located in the north part of Côte d'Ivoire, in Poro region with about 387 kilometers from Korhogo. It is bounded by longitudes 5°39' and 5°55' West and latitudes 9°7' and 9°27' North (Figure 1). The climate belongs to the humid tropical regime, whoseseasonal is governed by intertropical front (ITF) movement.Average annual temperatures range from 25°C in August to 29°C in March [16].Vegetation is dominated by savannah. Gallery forests and open forests are also found [17]. The population of the study area is estimated at 29633in 2021 [18]. It is essentially rural, with traditional agriculture the main activity.

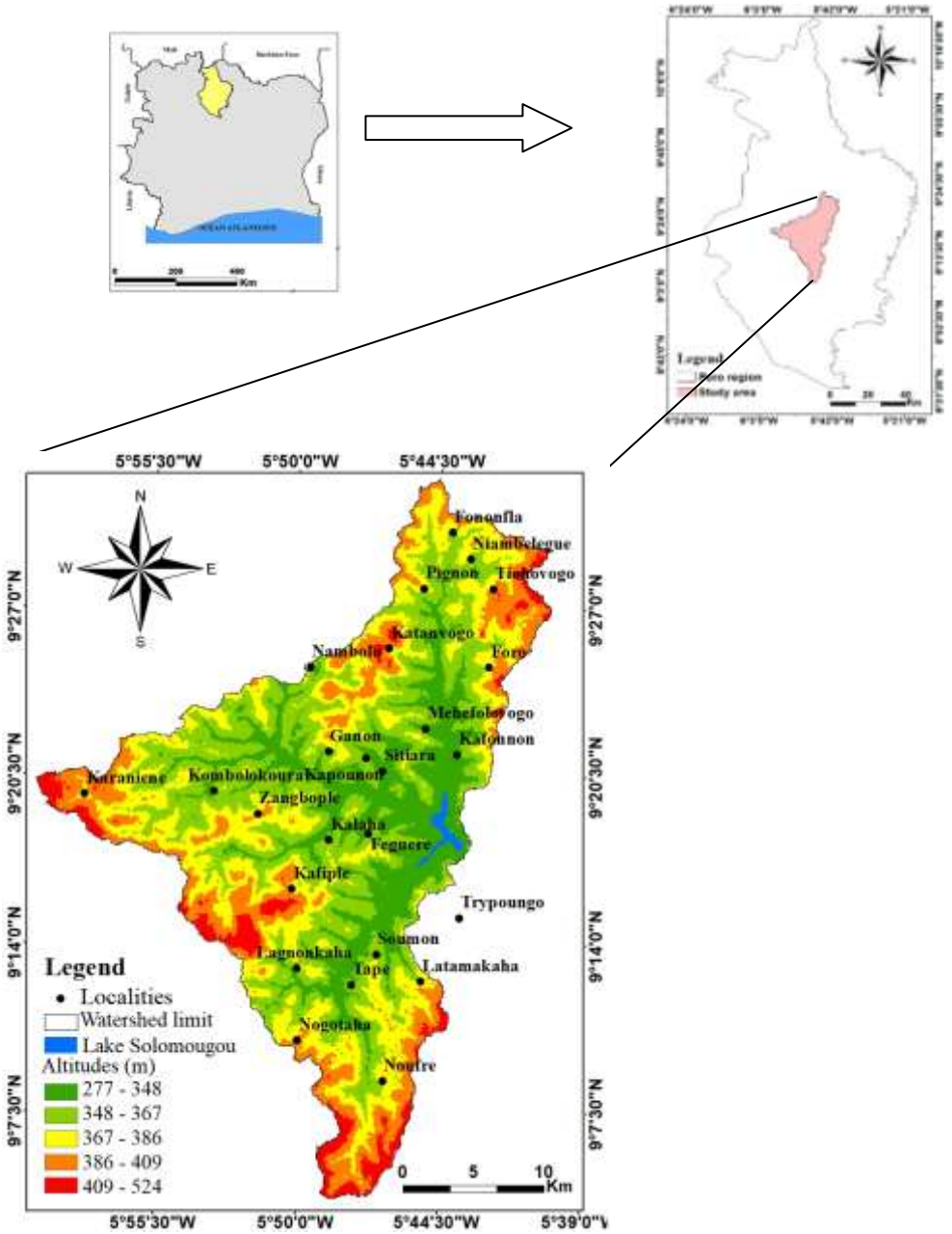


Figure 1:- Geographical location of the study area.

Material and Methods:-

Data Used

The monitoring of changes in land use in the Solomougou catchment is based on the analysis of three (3) LANDSAT images. These are TM (Thematic Mapper) images for the year 1986, ETM+ (Enhanced Thematic Mapper Plus) 2000 and OLI-TIRS (Operational Land Imager / Thermal Infrared Sensor) for the year 2021. These images were obtained free of charge from the USGS website (http: //earthexplorer.gov). The scenes were chosen during the dry season, when there is virtually no cloud cover.The characteristics of the satellite images used are shown in Table I below. In addition of Landsat images, field data were used. The field surveys mainly involved data collection, using a GPS receiver, of the sampling points used to classify the images. Land use units were also illustrated using a camera.

Tableau I:-Landsat image description.

Image	Scene (Path/Row)	Acquisition date	Resolution
TM	198-53	07/01/1986	30 m
ETM+	198-53	21/11/2000	30 m
OLI/TIRS	198-53	04/01/2021	30 m

Data processing

Cartographic processing of data

Landsat images's information extraction involved two phases. The first one was devoted to image pre-processing and the second to the actual processing.

Landsat images Preprocessing

Data pre-processing covers all operations carried out to make batches of data readable and superimposable. This involves geometric and radiometric corrections, mosaicking and extraction of the study area. Landsat TM, ETM+ and OLI images used in this study are already geo-referenced and have therefore already been geometrically corrected. Only radiometric corrections have been made to these images. This correction consists to convert digital pixel values into reflectance values.

Satellite image processing

Among the colour compositions carried out, the one using the original channels 3/4/7 from Landsat TM (1986), 5/4/2 from Landsat ETM+ (2000) and 2/5/6 from OLI (2021) was highly discriminating. For the most part, it has made it possible to distinguish the main types of land use in much greater detail, through the use of major or minor colourings and random or regular geometric shapes.Supervised classification was used in a frame work of this study. Using ENVI 5.1 image processing software, the classification process was carried out by defining the legend or filling in the ROI (Regions Of Interest); selecting the training plot samples; describing and filling in the various classes. The Maximum Likelihood algorithm, based on Bayes' rule, was chosen for image classification. This method calculates the probability of a pixel belonging to a given class rather than another. Pixels will be assigned to the class for which the probability is highest. However, if this probability does not reach the expected threshold, the pixel is classified as "unknown". The quality of the classification obtained was then assessed using the parameters calculated by the confusion matrix, i.e. overall accuracy and the Kappa coefficient [19]. Also known as a contingency table, the confusion matrix is a table displaying statistics on the classification accuracy of an image, in particular the degree of misclassification among the various classes. It is calculated with the values expressed in pixels and as a percentage. In addition, other synthetic measures of classification reliability can be calculated: accuracy for the user, accuracy for the producer, errors of omission and errors of commission [20]. Vectorisation is the final stage in image processing. This involved converting the classified images from raster mode to vector mode (polygons) in order to facilitate their management in GIS analysis software (ArcGIS 10.2.1).

Statistical processing of data and identification of changes

Land use dynamics were analysed by calculating the average annual rate of spatial expansion. The changes were determined over three (3) periods: 1986-2000, 2000-2021 and 1986-2021. An analysis based on the evaluation of the changes that have occurred within each occupation unit taken in isolation was carried out through the calculation of the average annual rate of spatial expansion, commonly used in studies of land use change [21].The formula in [22] in [23] was used. The variable considered here is the surface area (S). Thus, for S1 and S2, corresponding

respectively to the area of a land-use unit at dates t1 and t2, the average annual spatial expansion rate (T) is evaluated using the following formula:

$$\mathbf{T_{annuel}} = \frac{(\mathbf{lns_2} - \mathbf{lns_1})}{\mathbf{t} * \mathbf{lne}} * \mathbf{100Eq1}$$

Results and Discussion:-

Fieldwork and description of land use classes

In the field, a description of the different classes selected on the image was made and represented in Table II below.

Table II:- description of land use classes.

Classes	Description
Forests	Areas covered by degraded woodland, galleried woodland and stretching along watercourses
Savannah	Vegetation composed of trees and shrubs, scattered shrubs and thick grasses
Water	This class is made up of: lakes from agro-pastoral dams, rivers, etc.
Urban area / Bare soil	Urban areas, roads, areas where there is no vegetation or grass cover
Crops	Area planted with mangoes, cashews, avocados and market-garden cotton.

Classifications' validation and mapping results

Landsat images were interpreted to produce land cover maps for 1986, 2000 and 2021 (Figure 2). The overall accuracy is about 95.17% with 0.89 as Kappa coefficient in 1986, 94.24% in 2000 with 0.92 as Kappa index and 95.24% in 2021 with 0.93 as Kappa index.

These values mean that more than 95% of the pixels in the two images have been correctly classified in accordance with the ground truth data.In fact, various supervised classification accuracy indicators values obtained for the different images reflect good quality of the samples and, good match between the classification result and the spatial reality contained in the images.

These different coefficients are comparable with those found by other authors who have tackled the same subject. These are :

- [7] who found 0.95; 0.92 and 0.93 coefficients in his study on "Monitoring the dynamics of land cover using satellite imagery and geographic information systems: the case of Yamoussoukro regional office of Water and Forests (Côte d'Ivoire)".

-[24] who found as coefficient 0.90 in their land use dynamics study in Téssékéré municipality from 1984 to 2015 (Ferlo Nord, Senegal).

According to [25], classification is considered to be statistically good when the agreements correspond to 80% or more of the pixels in the reference plots.

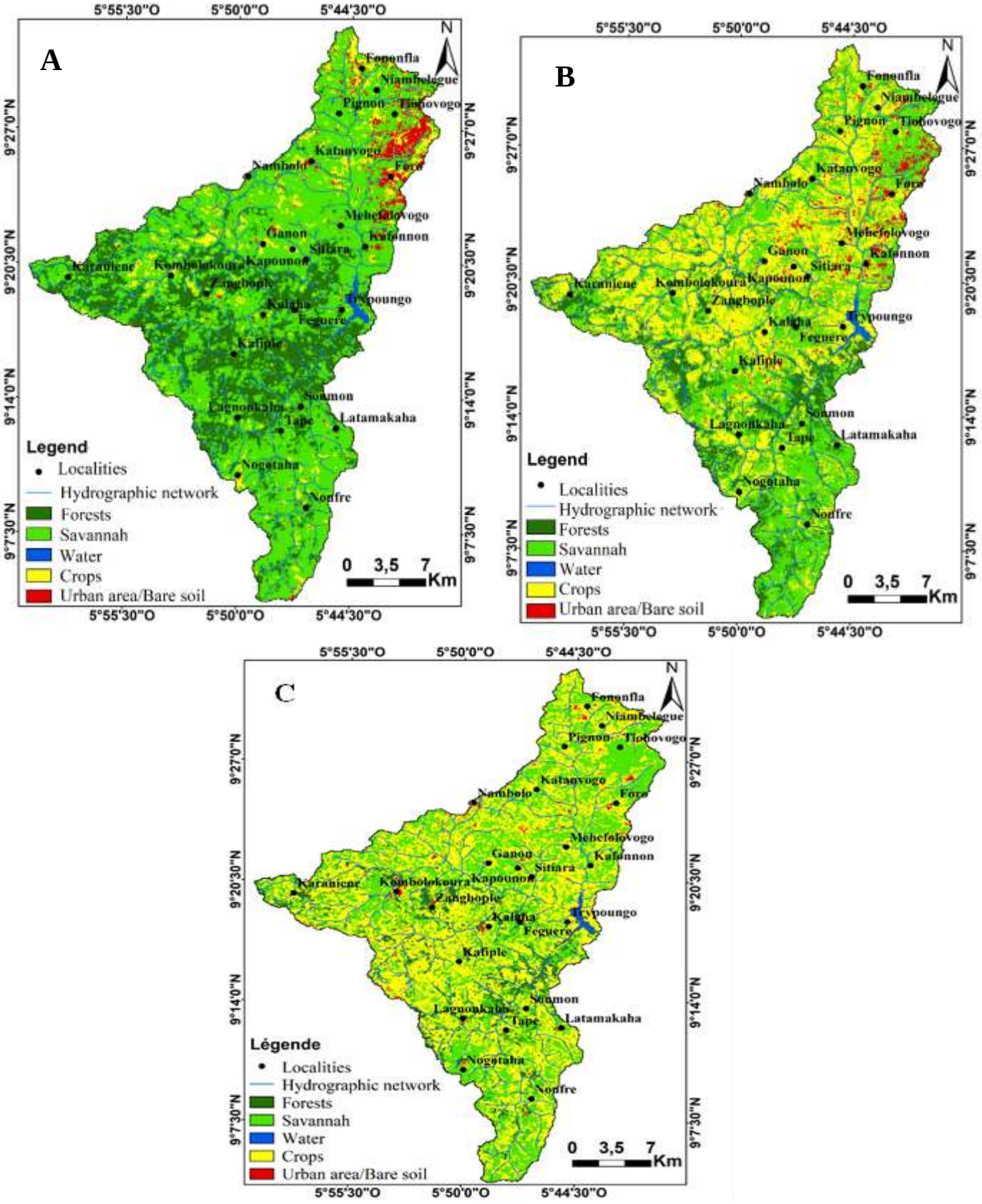


Figure 2:- Land use dynamics of Solomougou lake catchment A) 1986; B) 2000; C) 2021.

Land use dynamics analysis

Land use analysis trends shows the changes that have taken place between the different periods: 1986-2000; 2000-2021 and 1986-2021 (Figure 3). In additional the average annual rate of spatial expansion, the transition matrix and the rate of change have therefore been calculated on the basis of the units. areas units. There will be a major increase in cropland at the expense of savannah and forest between 1986 and 2021.

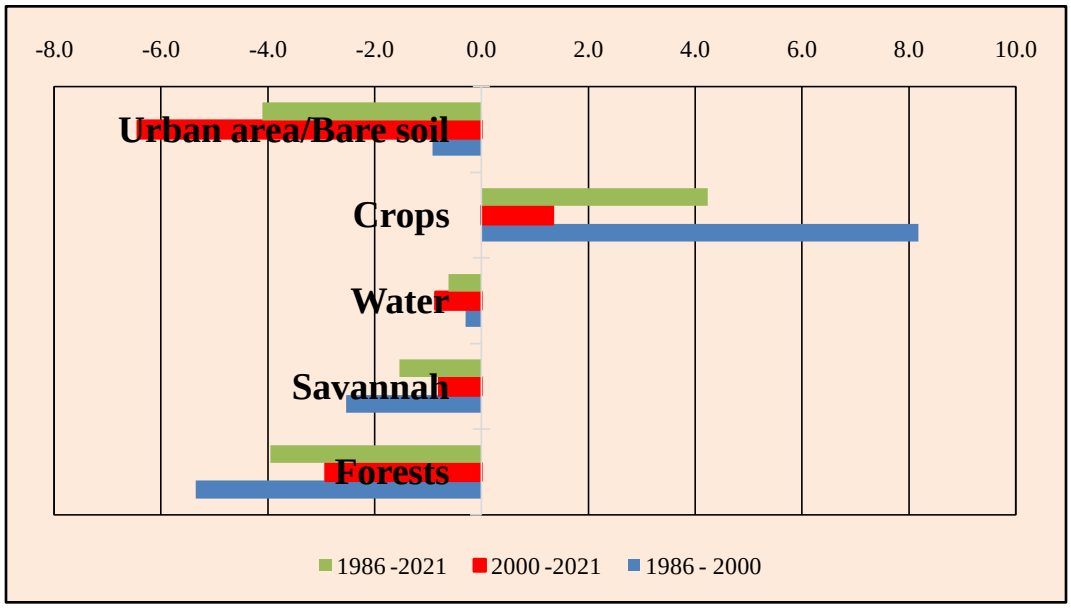
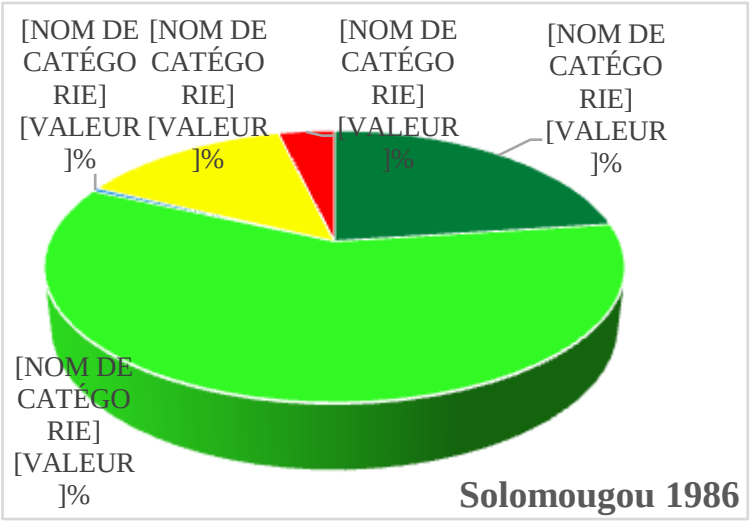
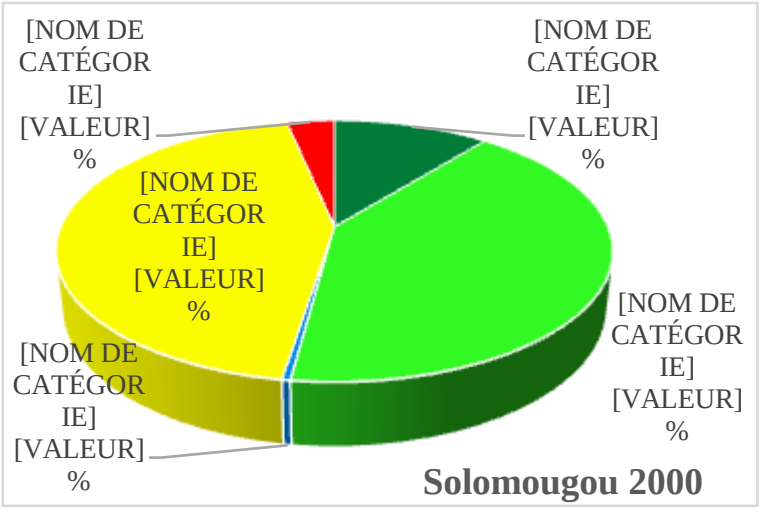


Figure 3:- Classification of spatial changes in occupancy classes from 1986 to 2021.

Solomougou catchment, reveal an increase of crop land, which influences the water by increasing infiltration. Figure 4 shows a graphical representation of each land use class in the Solomougou catchment. This figure shows that forest, savannah and water declined from 1986 to 2000, and savannah decrease from 58.86% in 1986 to 41.3% in 2000.Water and bare soil/ urban areaincrease respectively from 0.44% in 1986 to 0.4% in 2000, and from 3.74% in 1986 to 3.3% in 2000. The occupancy rate for crops rose from 14.07% in 1986 to 44.2% in 2000, an increase of 30.13% between 1986 and 2000.Crop occupancy rate increase from 14.07% in 1986 to 44.2% in 2000, therefore an increase of 30.13% between 1986 and 2000.From 2000 and 2021, a considerable reduction in forest and savannah was observed compared to the other classes, range from 4.60% to 5.8%.Crop land increased by 12.77% in 1986. bare soil / urban area decreased by 2.33%. From 1986 to 2021, natural formations (forests and savannahs) decrease to the detriment of man-made formations (savannahs). Forests decrease from 175.04 to 47.48 km², a decrease of 16.68%, savannahs also decrease from 450.29 to 271.54 km2, a decrease of 23.37%, while crops increase from 107.67 to 435.79 km², an increase of 42.89%. Water alsodecrease from 3.4 to 2.77 km².





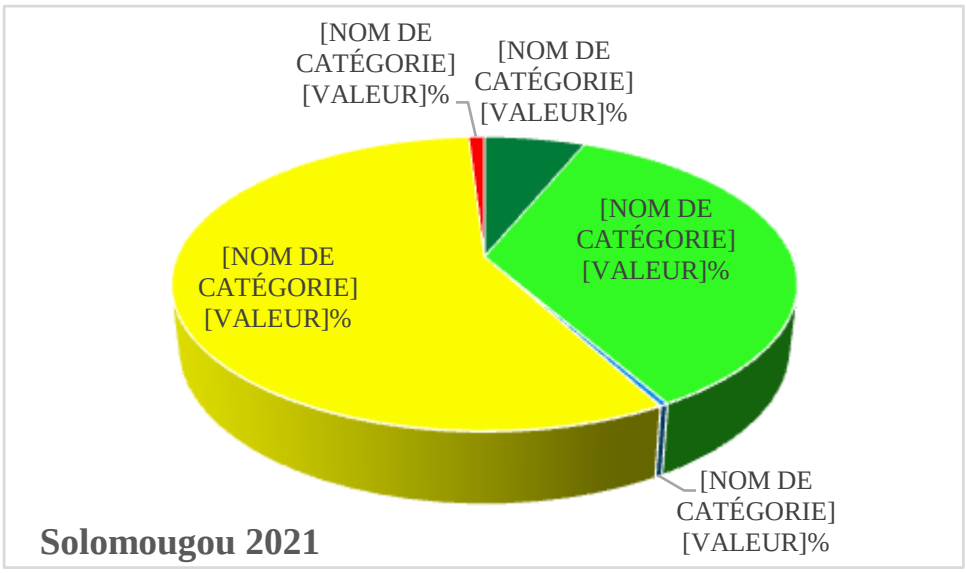


Figure 4:- Spatial distribution of land use classes in 1986, 2000 and 2021 in the Solomougou catchment

Areas and average rate of spatial expansion

Table III summarises the different land use units, surface area and average annual rate of spatial expansion during the periods between 1986-2000, 2000-2021 and 1986-2021.

A detailed examination of Table III shows that :

-From 1986 to 2000, positive rates show an increase in crop area (8.18%). In the same period, negative values indicate that land cover units such as forests, savannahs, water and bare habitats/soils declined respectively by 5.35%, 2.54%, 0.30% and 0.92% per year.

- From 2000 to 2021, the table shows annual decreases to 2.92%, 0.79%, 0.86% and 6.43% respectively for forest, savannah, water and bare soil / urban areas, while an average annual increase to 1.33% in crop areas is observed.

- From 1986 to 2021, natural formations (forests and savannahs) declined in area to the detriment of man-made formations (savannahs). Forests decrease from 175.04 to 47.48 km², a decline of 16.67%, and savannahs decrease from 450.29 to 271.54 km², a decline of 23.37%, while crops increase from 107.67 to 435.79 km², an increase of 42.89%. Water alsodecrease from 3.4 to 2.77 km².

Tableau III:-Areas and rates of change from 1958, 1986 and 2021.

	Area						Rate of change		
	1986		2000		2021		1986-2000	2000-2021	1986-2021
Classes	Km²	%	Km²	%	Km²	%	Tc	Tc	Tc
Forest	175,04	22,88	82,69	10,81	47,48	6,20	-5,35	-2,92	-3,95
savannahs	450,29	58,86	315,57	41,25	271,54	35,5	-2,54	-0,79	-1,53
Water	3,40	0,44	3,26	0,43	2,77	0,36	-0,30	-0,86	-0,62
Crops	107,67	14,07	338,33	44,22	435,79	56,97	+8,18	+1,33	+4,24
bare soil / urban areas	28,60	3,75	25,15	3,29	7 ,42	0,97	-0,92	-6,43	-4,1
Total	765	100	765	100	765	100			

Transition matrix

Directed classification is followed by a statistical report, the confusion matrix (tables IV, V and VI). It is used to assess the classification carried out. Overall accuracies obtained after classification are 95.17%, 94.12% and 95.24% respectively for the 1986, 2000 and 2021 images. The Kappa coefficient, which is another measure of the accuracy of the classification, was 0.89 for 1986 image, 0.92 for 2000 image and 0.93 for 2021 image, reflecting a good match between the cartographic results and the truth on the field. However, there was some confusion between certain land cover classes.In 1986 image, the greatest confusion (4.27%) was between savannah and forest, which could be explained by the fact that these two features have the same reflectance in places.For 2000 image, the greatest confusion (7.87%) was between crop and savannah classes. This confusion is linked to the fact that, from a radiometric point of view, they behave in the same way. As for 2021 image, forest, savannah, water and bare soil/urban area classes have the best mapping accuracy rates, 98.61%, 95.91%, 99.58% and 98.39% respectively. however, the cartographic accuracy rate recorded for the crops class, although high, remains the lowest (93.18%).

Table IV:- Confusion matrix for the classification of Landsat TM image (1986)Global accuracy =95,17 %, Kappa= 0,89

Classes	Forest	savannahs	Water	Crops	bare soil / urban areas
Forest	**96,44**	4,27	0	0	0
Savannahs	3,56	**94,23**	0,49	1,46	0
Water	0	0	**99,51**	0	0
Crops	0	1,13	0	**98,12**	1,64
Bare soil / urban areas	0	0,38	0	0,42	**98,36**
Total	100	100	100	100	100

Table V:- Confusion matrix for the classification of Landsat ETM+ (2000).

Classes	Forest	savannahs	Water	Crops	bare soil / urban areas
Forest	**97,39**	5,78	0	0,22	0
Savannahs	1,74	**90,28**	0,04	7,87	0
Water	0	0	**99,96**	0	0
Crops	0,87	3,73	0	**91,85**	0
Bare soil / urban areas	0	0,21	0	0,06	**100**
Total	100	100	100	100	100

Global accuracy =94,24 %, Kappa= 0,9

Table VI:- Confusion matrix for the classification of Landsat OLI (2021).

Classes	Forest	savannahs	Water	Crops	bare soil / urban areas
Forest	**98,61**	1,32	0	1,9	0
Savannahs	1,13	**95,91**	0	2,9	0
Water	0	0	**99,58**	0	0
Crops	0,26	2,77	0,12	**93,18**	1,61
bare soil / urban areas	0	0	0,3	2,01	**98,39**
Total	100	100	100	100	100

Global accuracy =95,24 %, Kappa= 0,93

Conclusion:-

Diachronic study carried out on Landsat satellite images from 1984, 2000 and 2021 produced three land use maps.These maps show that the Solomougou catchment has undergone a change in land use, showing five classes or units of land use and their evolution. During 35 years (from 1986 to 2021), natural formations (forests, savannahs) decrease while land crop is increasing. Forests and savannahs, were respectively estimated at 22.88% and 58.86% as total surface area of the Solomougou catchment in 1975, have been reduced to 6.20% and 35.5% in 2021.In addition, land crops, which was estimated at 14.07% in 1986, has gradually increased to reach 56.97% of area in 2021.bisides, the increase of land crop, we note the increase of urban area /bare soil from 1986 to 2021. This type of land use was not findfrom 1986 to 2000. Savannah formations have gradually given way to human activities.

Agriculture, bush fires, overgrazing and climatic variations are the main causes of the conversion of these landscape units. Land crop are over-exploited, and are becoming less and less productive.

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Conflicts of Interest
The authors declare no conflict of interest.

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