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Land use mapping in the Sébi-Ponty watershed, Senegal

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ABSTRACT: Measuring the spatial impact of human activities on ecosystems is an important step towards effectively managing the changes affecting these natural areas. The objective of this study is to determine land-use dynamics and changes in vegetation cover in the Sébi-Ponty watershed in the Dakar region. To this end, we defined seven land-use classes (tree crops, water, market gardening, agricultural areas, shrub savanna, bare soil, and built-up areas). Satellite data and Landsat images from three periods (1984, 2000, and 2016) were carefully selected and analyzed. Auxiliary data (GPS surveys, topographic maps, and interviews) were also used. The analysis of changes in the land-use classes was carried out using the integration of geographic information systems (GIS) with ArcGIS software and remote sensing techniques with ENVI software. The results obtained highlighted strong dynamics within the land-use classes. This dynamic is characterized by an increase in tree farming, market gardening, and construction at the expense of bare soil, shrub savanna, and agricultural areas. During the same period, the shrub savanna has significantly declined in vitality, indicating a trend toward degradation. The values of the confusion matrix and the kappa coefficient confirm this situation. These results highlight the relevance of our integrated approach, which is applicable to other similar studies.

KEYWORDS: Land use, dynamics, remote sensing, GIS, diachronic analysis, maximum likelihood.

1 INTRODUCTION

Land use in ecosystems has become a major environmental concern, in the context of a decisive disruption brought about by climate change [**1**]. It is one of the main factors leading to the degradation of various plant communities [**2**]. Globally, environmental degradation is a cause for concern due to the threat it poses to both ecosystem functioning and the well-being of human communities [**3,4**]. This degradation is all the more worrying given the increasingly intense climatic conditions and demographic pressures for access to resources [**5**]. The causes are both natural and anthropogenic [**6,7,8**]. Anthropogenic causes stem from various pressures related to rapid population growth, technological advancements, industrialization, agricultural expansion, and mining [**9,10**]. The resulting changes pose serious threats to the functioning of ecosystems and natural resources, particularly in the Sahel region [**11,12, 13, 14**]. This leads researchers [**15,5**] to conclude that understanding the challenges related to land cover and land use is crucial for effective environmental management. Therefore, studies are needed to measure the spatial and temporal extent of human impact on landscapes, in order to formulate proposals to mitigate the spatial impacts affecting natural areas [**16,17, 18**]. Numerous scientific studies utilize remote sensing and geographic information systems to assess the state and changes in land cover and land use [**19**]. This will allow for the evaluation of the effects of human and natural pressures on ecosystems [**4,10, 18**]. According to [**20,21**], and [**22**], numerous cartographic studies addressing various aspects have demonstrated the value of using satellite imagery at different spatial and temporal resolutions to monitor the dynamics of surface conditions. According to **[23],** the integration of remote sensing, geographic information systems (GIS), and expert systems constitutes a new field of research. [**24**] used GIS and weighted multi-criteria analysis based on satellite imagery to identify soils suitable for coffee and cocoa cultivation in Côte d'Ivoire; [**25**] used remote sensing to quantify changes in land cover and land use in the Welkom-Virginia gold region; [**26**] ont évalué la dynamique entre les différents types l'occupation et de l'utilisation des sols pour comprendre l'impact anthropique des activités d'extraction aurifère au Cameroun oriental de 1987 à 2017 en utilisant des images Landsat. This study aims to determine the dynamics of land use, the extent, and changes in land cover classes within the Sébi-Ponty watershed in the Dakar region. Since 1936, this area has contained a water retention basin with an annual capacity of 512,000 m^3

and a surface area of 27.14 ha, formerly used for drinking water supply. From 1984 onwards, the site became a market gardening, pastoral and fish farming production area for local consumption through irrigated plots with a total area of 33 hectares. In addition, this project has enabled the restoration of wildlife ecosystems. Given its potential and the activities developed there, the basin plays a crucial role in poverty reduction strategies for the surrounding populations. Consequently, the evolution of the space and its various uses around the basin is a major concern for public authorities. To achieve the stated objective, high resolution satellite data and images from 1984, 2000, and 2016 were used. Auxiliary data (GPS surveys, topographic maps, interviews) were also employed. The maximum likelihood classification method, combined with mapping techniques, contributed to the characterization of the main spatial entities in the area (tree crops, water, market gardening, agricultural spaces, shrub savanna, bare soil, and built-up areas) using ArcGIS and ENVI software. The results revealed a strong dynamic in land cover classes. This dynamic is characterized by the conversion of bare soil, shrub savanna, and agricultural spaces into tree crops, market gardening, and built-up areas. During the same period, vegetation cover has significantly decreased in vitality, indicating a trend toward degradation. The values of the confusion matrix and the kappa coefficient confirm this situation. These results underscore the relevance of our approach.

2 Materials And Methods

2.1 Study Environment

2.1.1 Presentation Of Watershed

The Sébi-Ponty reservoir is located in the commune of Diamniadio, in the Rufisque department of the Dakar region (Fig. 1a). This commune is a crossroads town between Thiès, Mbour, and Dakar. It is undergoing significant transformation with the Diamniadio urban center project. The population is estimated at 23,547 inhabitants [**27**]. The Wolof and Fulani ethnic groups are among the inhabitants, often leading to conflicts between herders and market gardeners. The reservoir serves the villages of Sébi-Ponty, Déni Malick Guèye, Déni Diarkhath, Nguent, and Déni Babacar Diop. It was constructed in 1936 to supply drinking water to the teacher training college. With a water surface area of 27.14 ha, the basin's retention capacity is 512,000 m3, allowing for the irrigation of plots covering an area of 33 ha located upstream, downstream, left bank and right bank (Fig.1b).

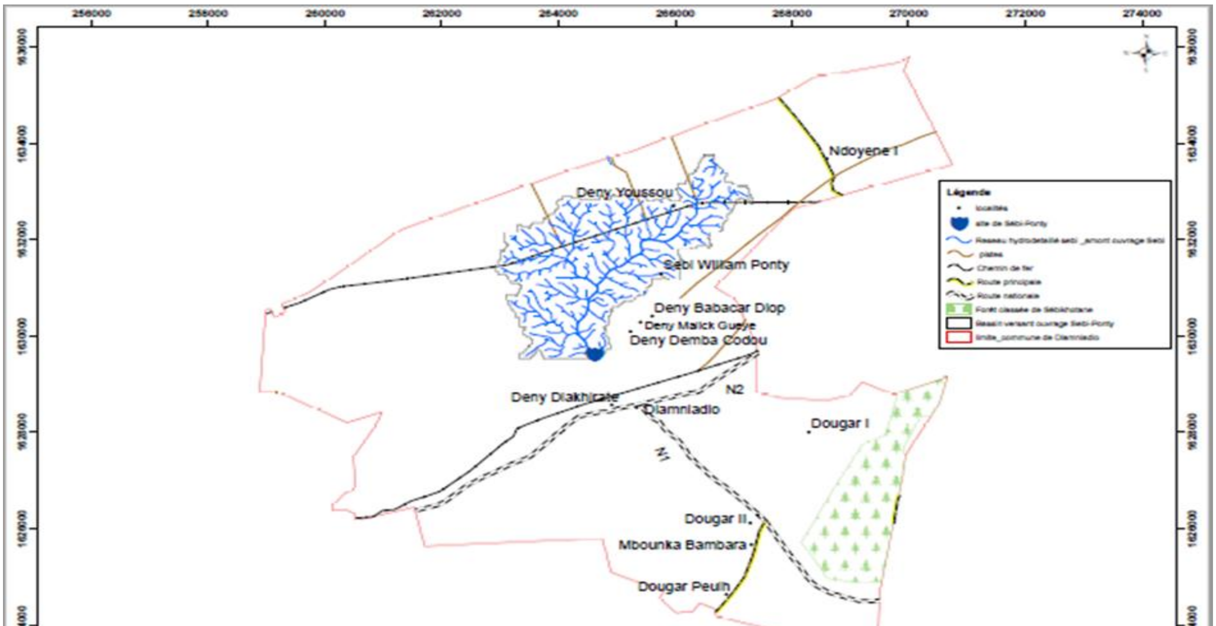

Fig. 1. a. Location of the Sebi-Ponty watershed

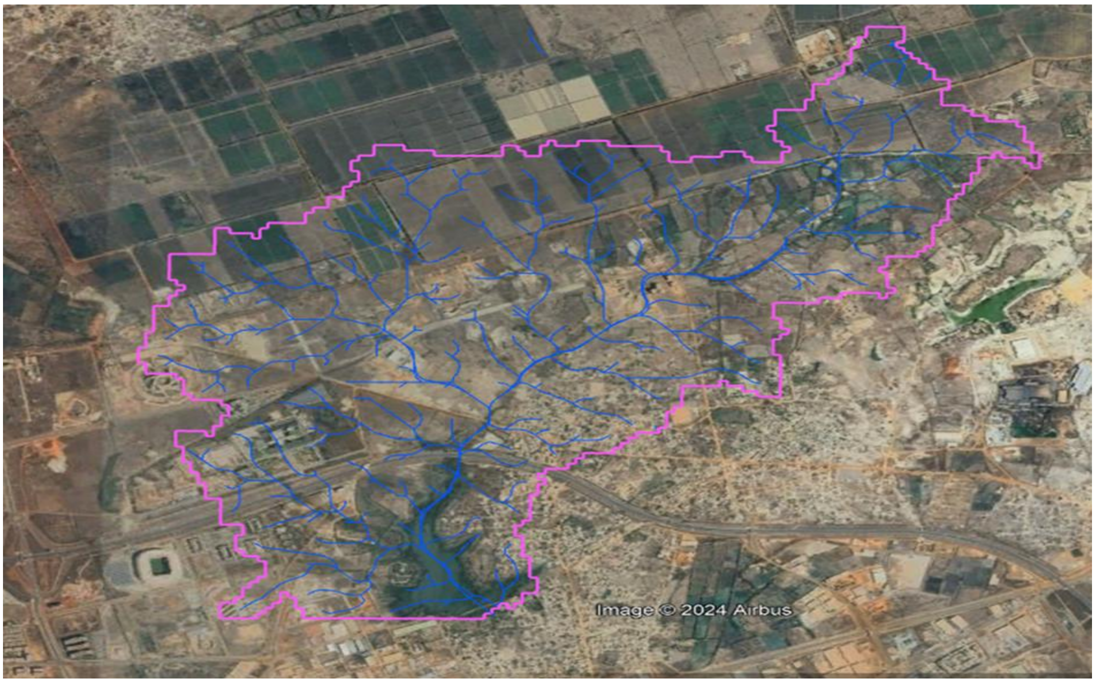

Fig. 1. b. Irrigation plots

2.1.2 PRESENTATION OF SOIL TYPES

In the Sébi-Ponty watershed, the soil units encountered are halomorphic soils, tropical ferruginous soils, hydromorphic soils, and calcimorphic soils (Fig. 2). Halomorphic soils cover a large part of the watershed, approximately 7.62 km^{2,} or 86.61%. These are saline soils whose formation is influenced by the presence of soluble salts (sodium and/or magnesium). Calcimorphic soils occupy 0.02 km^2 (0.24%). The Sébi-Ponty area belongs to the group of calcareous brown soils due to their calcium carbonate content, characterized by incomplete settling. In addition to these, there are deep pseudogley hydromorphic calcareous brown soils to the west of the perimeter. Tropical ferruginous soils cover approximately 0.70 km^{2,} or 7.94%, located west of the spillway and representing a small proportion compared to other soil types. These soils, developed on residual Quaternary dune formations, are sandy and rich in clay at depth. Hydromorphic soils cover approximately 0.20 km^{2,} or 2.24% (Table 1). These soils are suitable for several types of crops. The hydromorphic soils located downstream of the spillway are characterized by temporary waterlogging during certain periods of the year. These soils are suitable for various crops (orchards, market gardens).

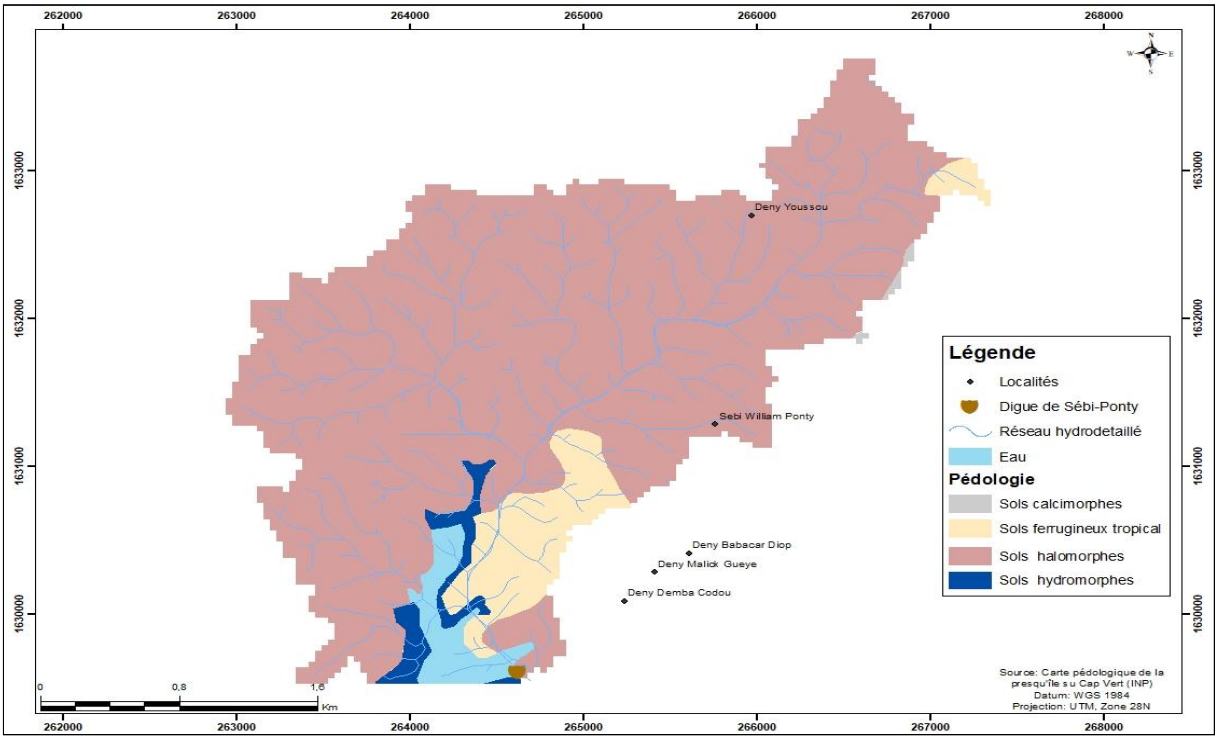

Fig. 2. Soil map of the watershed

Table 1. Area of soil units

Soil types	Partial area (Km^2)	Area (%)
Halomorphic soil	7,62	86,61
Calcimorphic soil	0,02	0,24
Water	0,26	2,97
Tropical ferruginous soil	0,70	7,94
Hydromorphic soil	0,20	2,24
TOTAL	8,8	100

2.1.3 PRESENTATION OF THE DIGITAL TERRAIN MODEL

Figures 3a and 3b respectively present the 3D Digital Terrain Model (DTM) of the Sébi-Ponty watershed and its map. The figures show that the topography decreases from north to south. The maximum elevation is 54.1 m, located in the north (upstream) and slightly in the center, and the minimum elevation is 22 m, specifically in the south (downstream) and slightly in the center. The total topographic difference is therefore 32.1 m.

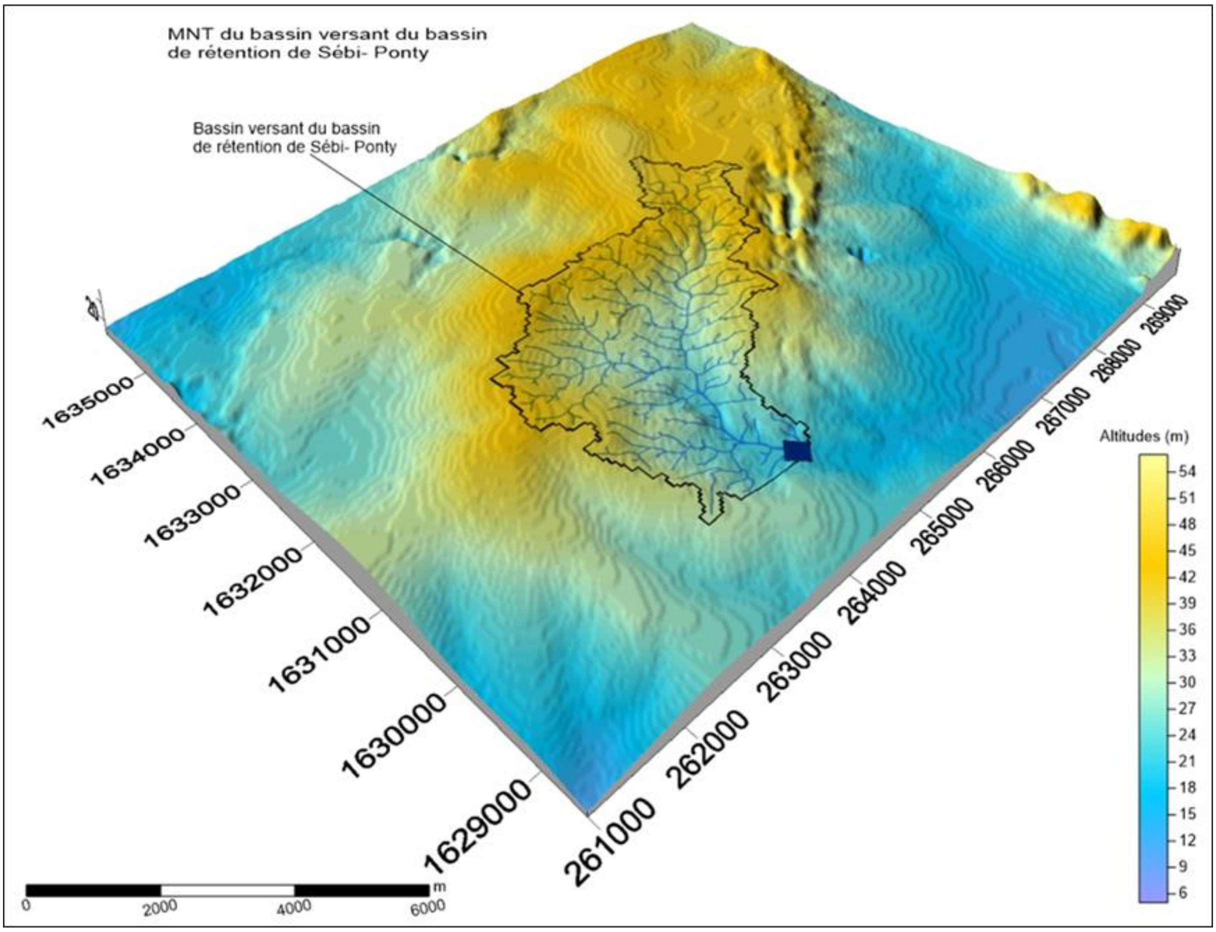

Fig. 3. a. 3D Digital Terrain Model (DTM)

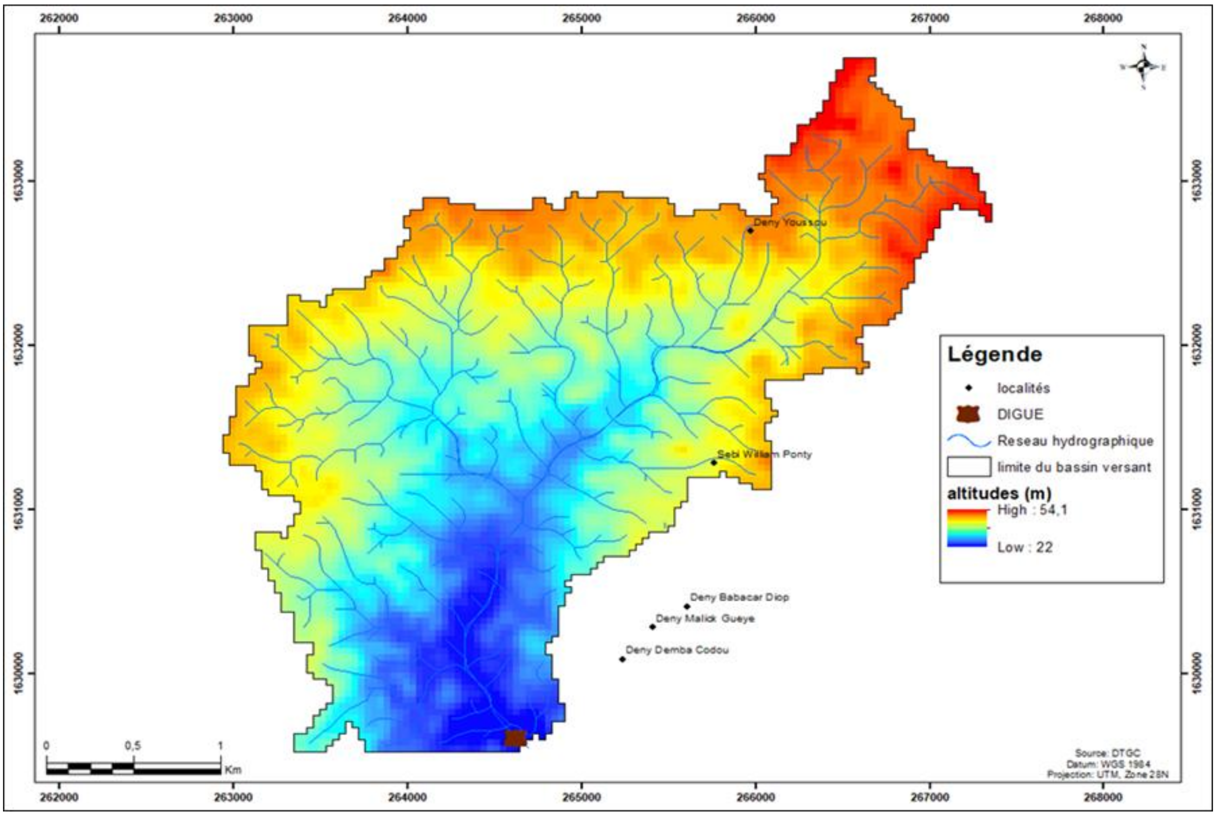

Fig. 3. b. Digital Terrain Model Map

2.1.4 PRESENTATION OF CHARACTERISTIC ALTITUDES

Table 2 presents the altitude variables and the 3D numerical elevation model of the Sébi-Ponty watershed. The maximum altitude represents the highest point in the watershed, while the minimum altitude represents the lowest point, generally at the outlet. These altitudes allowed us to determine the altitudinal range of the Sébi-Ponty watershed. The average altitude is Hmoy = 26 m, which is lower than the median altitude Hmed = 30 m. The average slope of the Sébi-Ponty watershed is therefore irregular. It is very steep upstream, where high terrain predominates, and becomes gentler downstream, where low plateaus and plains dominate.

Table 2. Altitude parameters of the Sébi-Ponty basin

Parameters	Symbols	Units	Value
Maximum altitudes	H_{max}	m	54,1
Minimum altitudes	H_{min}	m	22
Altitude at 5% of the total surface	$D_{5\%}$	m	49
Altitude at 95% of the total surface	$D_{95\%}$	m	28
Average altitude	H_{moy}	m	26
Median altitude	H_{med}	m	43

2.1.5 PRESENTATION OF THE DIGITAL ALTITUDE MODEL

Figures 4a and 4b respectively present the 3D Digital Elevation Model and its map. The areas between the contour lines are represented as different color classes, from the high altitude class, whose highest point is 54 m, to the low-altitude class, whose lowest point is 22 m. The DEM has four elevation bands equidistant from each other at 8 m intervals. The high-altitude areas are located in the north (upstream) and slightly in the center of the basin; the low altitude areas are located in the south (downstream) and slightly in the center. The relief is essentially dominated by stepped plateaus.

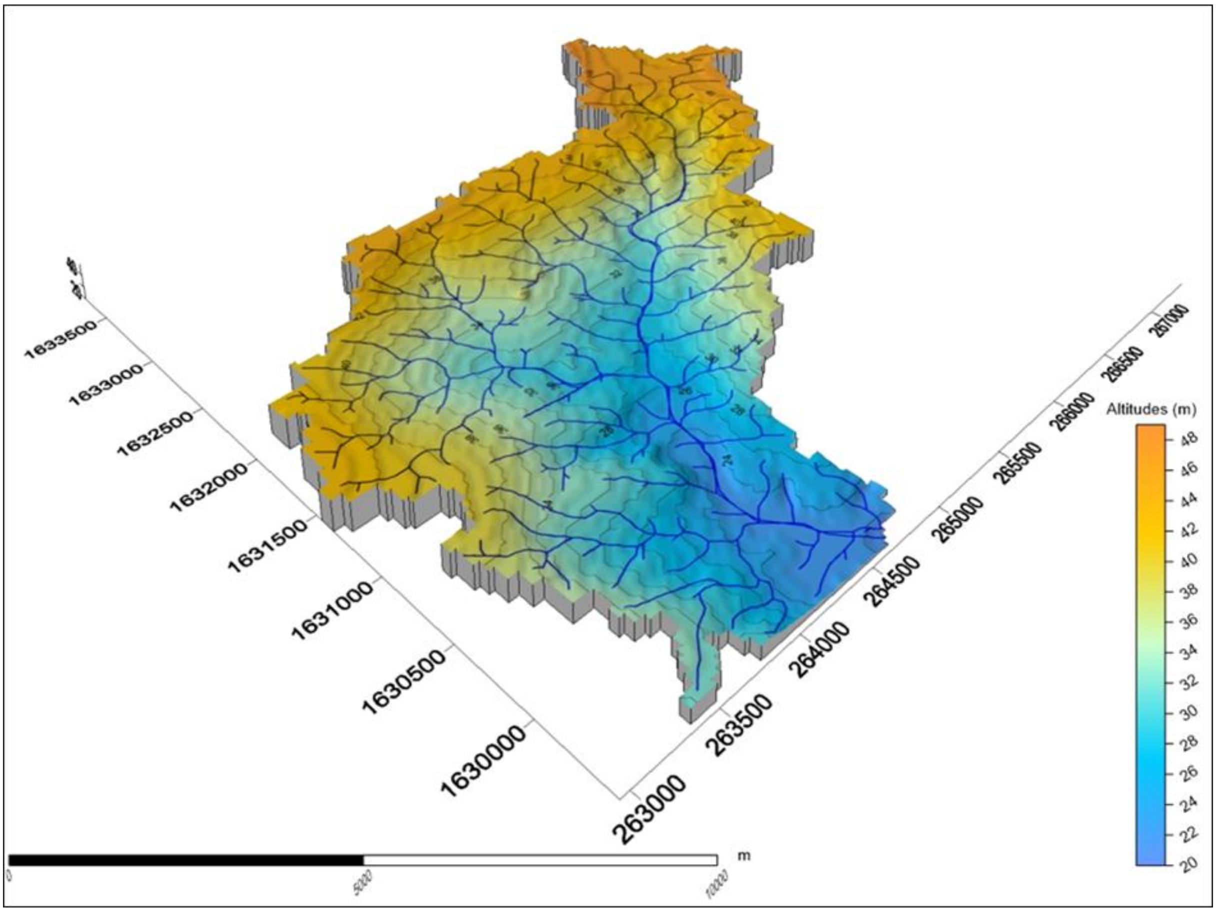

Fig. 4. a. 3D digital elevation model

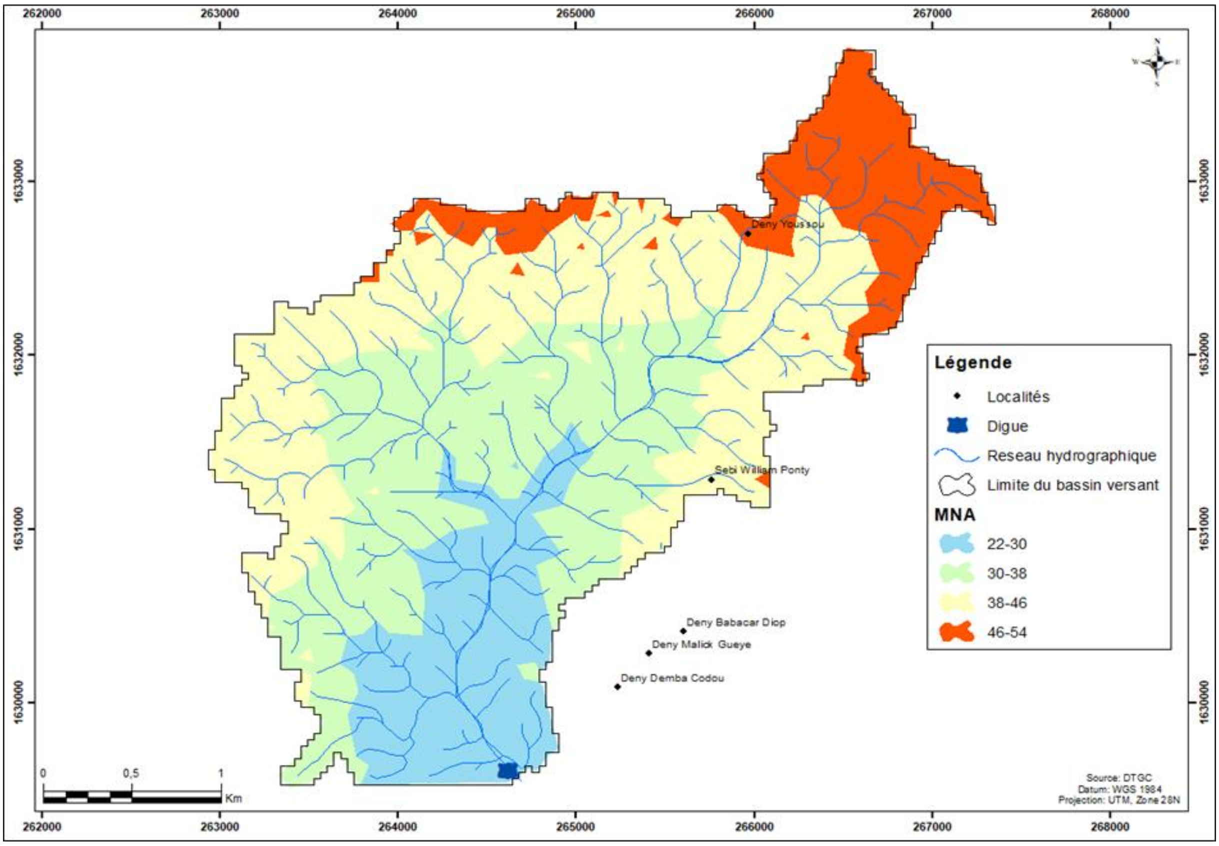

Fig. 4. b. Map Digital Elevation Model

2.2 DATA USED

In this study, we used satellite data and Landsat images from NASA (National Aeronautics and Space Administration) and the USGS (United States Geological Survey). We focused on the availability of high-resolution images of the site and the acquisition period. Therefore, the following dates were chosen: May 11, 1984, March 27, 2000, and April 9, 2016; the Sébi-Ponty site is located in scene 205-50. The year 1984 was characterized by drought, while 2000 saw a slight return of rainfall to normal levels. The images were selected during the dry season to minimize exaggerated vegetation cover due to herbaceous plant growth. The dates are characterized by ground cover related to the density of woody vegetation. Furthermore, another advantage of the dry season is the low cloud cover. Field observations of vegetation types and cultivated areas were carried out in November 2016. Auxiliary data (GPS surveys, 1/50000 topographic map, interviews with farmers) were obtained from fieldwork conducted between February and March 2016**.**

2.3 DATA EXPLOITATION

We processed the data using three procedures: preprocessing, georeferencing, visual interpretation, and pseudo-directed classification. The use of multi-date images necessitated atmospheric correction, as recommended by [**28,29**]. The images were geometrically corrected (georeferenced), and a calibration of the bands used for this purpose was performed. Image preprocessing, including calibration, color composite creation, and directional classification, relied on the capabilities of the ENVI software. According to [**30**], it is essential that the images used exhibit the most homogeneous characteristics possible so that differences resulting from their comparison are associated with actual changes in the state of the land. The creation of land cover and change maps was made possible using GIS tools such as ArcGIS. No radiometric correction was performed on any of the images used. To avoid discrepancies due to differences in Landsat sensors and to optimize image overlay for diachronic analysis, the 1984 and 2000 data were calibrated against the 2016 image, which served as a reference. This calibration was corrected using landmarks identified on the topographic map and GPS surveys collected in the field, allowing for necessary corrections to improve the maps. To detect changes over time, we initially used an unsupervised classification method to facilitate the selection of different land cover classes. In this study, seven classes were chosen and compared with external data providing information on the nature of land cover.

3 Results And Discussion

3.1 Land Use Status In 1984

Figure 5a presents the 1984 land cover map. It shows significant vegetation cover, primarily shrub savanna, representing the largest land cover class with an area of 358.73 hectares, or 40.79% of the sub-watershed. In 1984, arboriculture and market gardening were already well-developed in the area. These two land cover units occupied 65.51 and 19.76 hectares, respectively. The construction of the watershed in 1936 allowed for water retention over an area of 10.45 hectares. This water retention facilitated the development of market gardening, especially during the dry season. Agricultural areas occupy the northern part of the sub-watershed with 247.77 hectares and constituted the second largest land cover unit in the sub-watershed in 1984.

3.2 Land Use Status In 2000

Figure 5b illustrates the distribution of land cover units in 2000. Spatial changes in the different units are evident. The area of agricultural land decreased by 5.12% of the sub-watershed. The same trend is observed for market gardening, the area of which decreased by 5.63 hectares, representing a loss of 1.64%. This decrease benefited arboriculture, which saw an increase of 254.42 hectares, or 28.93%, corresponding to an increase of 188.90 hectares, or 21.48%. The lack of water in 2000 was mainly due to the deterioration of the retention basin resulting from a lack of maintenance. Similar to arboriculture, the area of buildings also increased, while bare soil, shrub savanna, and agricultural land decreased.

3.3 Land Use Status In 2016

Figure 5c shows the spatial distribution of land use in 2016. The area of shrub savanna decreased by 5.33%. Concurrently, market gardening and arboriculture increased by 29.06 hectares and 10.32 hectares respectively, representing growth of approximately 3.30% for market gardening and 1.18% for arboriculture. The area of agricultural land decreased from 202.76 hectares in 2000 to 200.41 hectares in 2016, a reduction of 5.38%. The significant improvement in rainfall since the 2000s has greatly contributed to water retention in the retention basin. Thus, the increase in the area covered by water in 2016 (1.16%) reflects a positive impact of the retention basin rehabilitation. In conclusion, the overall trend in land use dynamics is progressive for arboriculture, which recorded a growth rate of 22.66%. Improved water resource availability in 2016 boosted market gardening by 2.66%.

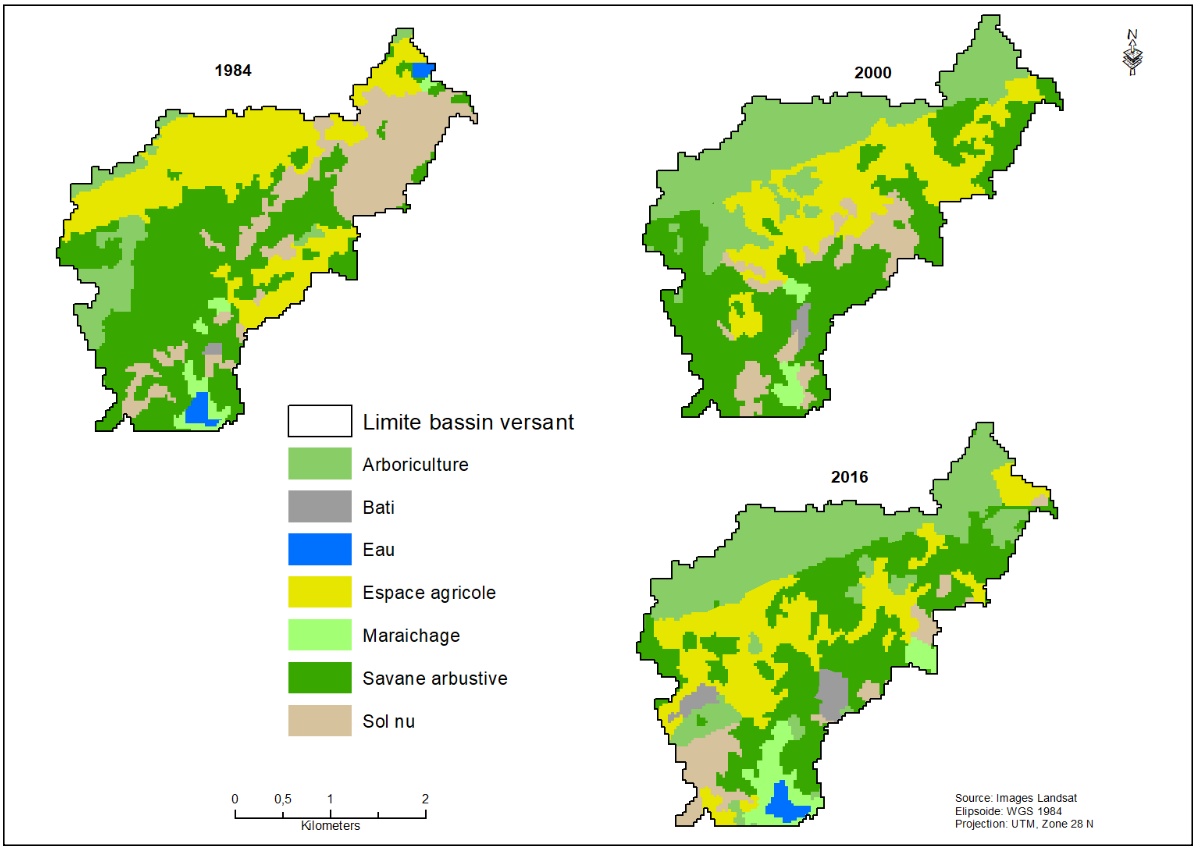

Fig. 5. Land use map of the Sébi-Ponty catchment area in 1984 (A), 2000 (B), 2016 (C)

3.4 Evolution Of Land Use Units

The results from the maximum likelihood directed classification were exported in vector format to ArcGIS software for final cartographic processing, specifically for layout and area calculation. Seven land cover classes were identified. Calculations performed on the land cover maps allowed for the determination of the area of each class during these years (Table 3). Analysis of the table shows that from 1984 to 2000, the area of agricultural land decreased by 5.12%. The same trend is observed for the market gardening class, whose area decreased by 5.63 hectares, representing a loss of 1.64%. This decrease benefited arboriculture, which saw an increase of 254.42 hectares, or 28.93%, corresponding to an increase of 188.90 hectares, representing a growth of 21.48%. The lack of water in 2000 was primarily due to the deterioration of the retention basin resulting from a lack of maintenance. Similarly, the area of shrub savanna decreased between 2000 and 2016, losing 5.33% of its surface area. Concurrently, market gardening and arboriculture increased by 29.06 hectares and 10.32 hectares respectively, representing growth of approximately 3.30% for market gardening and 1.18% for arboriculture. The area of agricultural land decreased from 202.76 hectares in 2000 to 200.41 hectares in 2016, a reduction of 5.38%. The significant improvement in rainfall since the 2000s has greatly contributed to water retention in the basin. Thus, the increase in the area covered by water in 2016 (1.16%) reflects a positive impact of the rehabilitation of the retention basin.

Table 3. Evolution of land use units

Land use classes	Area					
	1984		2000		2016	
	Hectare	%	Hectare	%	Hectare	%
Arboriculture	65,51	7,45	254,42	28,93	264,80	30,11
Built	2,25	0,26	5,95	0,68	23,41	2,66
Water	10,45	1,19		0,00	10,24	1,16
Agricultural area	247,77	28,17	202,76	23,05	200,41	22,79
Market gardening	19,76	2,25	14,13	1,61	43,19	4,91
Shrubby savannah	358,73	40,79	327,97	37,29	281,12	31,96
Bare ground	175,1	19,91	74,3	8,45	56,38	6,41
Total	879,55	100	879,55	100	879,55	100

3.5 Land Cover Change Rate

Figure 6 shows the land cover changes in the Sébi-Ponty sub-watershed from 1984 to 2016. Tree farming saw an increase of 22.66%. Improved water availability in 2016 boosted market gardening by 2.66%. Agricultural areas also experienced fluctuations in cultivated land, decreasing from 247.77 ha (28.17%) in 1984 to 200.41 ha (22.79%) in 2016, a reduction of 5.38%. Shrub savanna and bare soil also declined, by 8.82% and 13.50% respectively, while built-up areas increased by 2.41%.

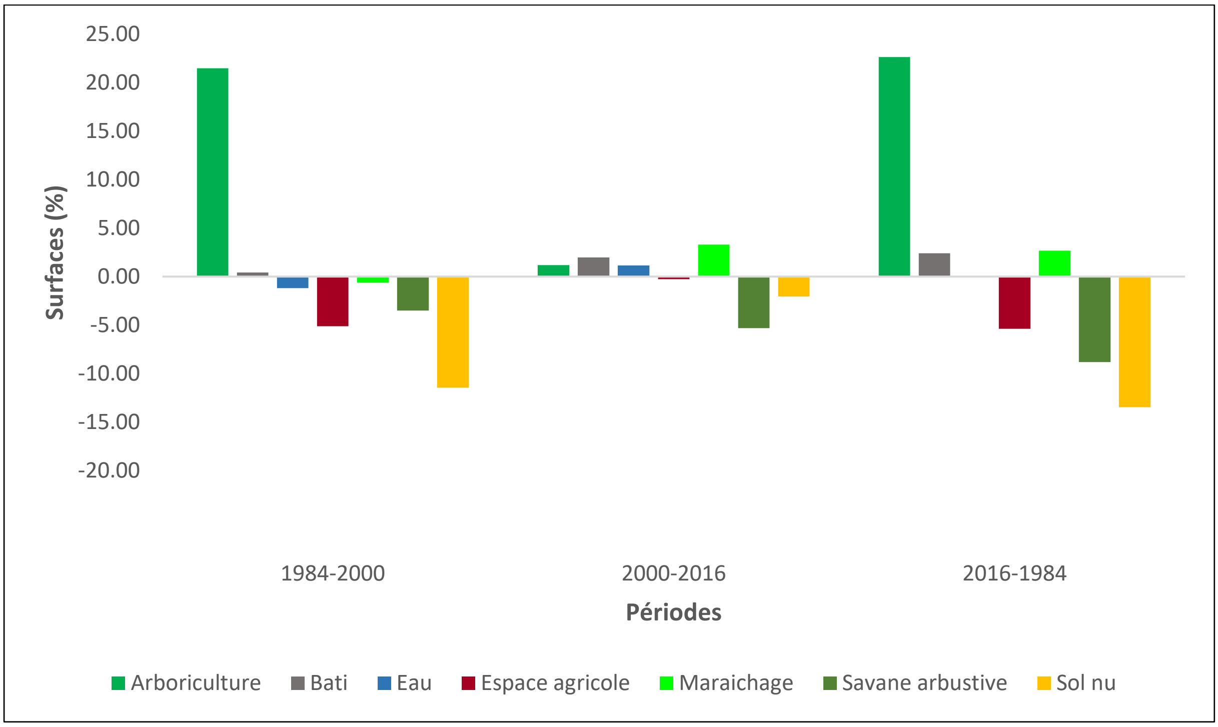

Fig. 6. Land cover change rates in the Sébi-ponty sub-watershed

3.6 Validation Of Land Use Classes

The validation of the results obtained by supervised classification from the training plots was carried out by determining confusion matrices and calculating Kappa coefficients. This operation made it possible to check the quality of the results obtained, to assess the potential risks of confusion, and to evaluate the ability to better differentiate land cover classes [**31**]. The results obtained from the confusion matrices are satisfactory, with accuracy percentages exceeding 84% and Kappa coefficients greater than 0.80 for all the processed images (Table 4). These results made it possible to identify the land cover classes with a different legend depending on the sub-watershed. The nomenclature and definitions of the vegetation cover classes are based on the nomenclature of [**32, 33, 34, 35**]

Table 4. Accuracy of Landsat image classification

Years / Sub-basin	1984		2000		2010	
	Kappa	Precision	Kappa	Precision	Kappa	Precision
Sébi-Ponty	0.83	86 %	0.85	88 %	0.87	89 %

4 Conclusion

This study aims to contribute to the efficient assessment of landscape dynamics in the Sébi-Ponty watershed. Our objective is to determine the extent and changes in the land cover classes defined for this purpose. To achieve this, satellite data and high-resolution Landsat images from three dates: May 11, 1984, March 27, 2000, and April 9, 2016 were used. Auxiliary data (GPS surveys, topographic maps, and interviews with farmers) were also employed. The images were selected during the dry season to minimize over-representation of vegetation cover and to ensure low cloud cover. Color composite and directional classification, combined with geographic information systems, were used to determine land cover dynamics and changes in vegetation cover within the site. This work was made possible through the use of ArcGIS and ENVI software. The results obtained are consistent and revealing. In 1984, fruit growing and market gardening occupied 65.51 and 19.76 hectares respectively. The construction of the watershed in 1936 made it possible to retain water over an area of 10.45 hectares. This water retention facilitated the development of market gardening, especially during the dry season. Agricultural areas covered 247.77 hectares and constituted the second largest land use unit in the sub-watershed in 1984. In 2000, the area of agricultural land decreased by 5.12%, market gardening decreased by 5.63 hectares, a loss of 1.64%, while fruit growing increased by 254.42 hectares, or 28.93%, corresponding to an increase of 188.90 hectares, representing a rise of 21.48%. The lack of water in 2000 was due to the deterioration of the retention basin caused by a lack of maintenance. Overall, from 1984 to 2000, tree cultivation and built-up areas increased while bare soil, shrub savanna, and agricultural land declined. In 2016, shrub savanna decreased by 5.33%; market gardening and tree cultivation increased by 29.06 hectares and 10.32 hectares respectively, representing a 3.30%

increase for market gardening and a 1.18% increase for tree cultivation; agricultural land decreased by 2.35 hectares, or 5.38%. The increase in the area covered by water in 2016 (1.16%) reflects a positive impact of the retention basin rehabilitation. In summary, from 2000 to 2016, the overall trend in land-use dynamics was progressive for arboriculture, which recorded a growth rate of 22.66%. Improved water resource availability in 2016 boosted market gardening by 2.66%. Ultimately, the results obtained highlighted a significant spatial shift in land-use classes. These changes are characterized by an increase in arboriculture, market gardening, and buildings at the expense of bare soil, shrub savanna, and agricultural areas. During the same period, vegetation cover has considerably declined, indicating a trend toward degradation. The results obtained from the confusion matrices are satisfactory, with accuracy rates exceeding 84% and kappa coefficients greater than 0.80 for all processed images, validating our results even though we are aware of the limitations of our approach, which does not account for changes in climatic conditions. Therefore, to ensure the validity of the identified changes, it will be necessary to study other sectors and remote sites. Whatever the outcome, continuous monitoring of land cover class transformations appears important for defining environmental management programs adapted to local realities. The results would allow stakeholders to measure the impacts of their operations and find the best ways to rehabilitate degraded areas. In this regard, we recommend the establishment of an observatory dedicated to this issue.

Acknowledgment

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Appendix

Overview Of The Retention Basin