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EVALUATION OF THE SPATIO-TEMPORAL DYNAMICS OF THE FÉTORÉ SUB-BASIN BETWEEN 1990 AND 2020

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ABSTRACT

The Fétoré sub-basin, a tributary of the Konkouré River, is located in the Fouta-Djalon massif, an area known as the "water tower of West Africa." For several decades, this territory has faced increasing pressure from human activities specifically agricultural expansion, land clearing, and urbanization compounded by climate variability. These factors contribute to gradual headwater degradation and disrupt the basin's hydrological functioning.

This study analyzes the spatiotemporal dynamics of land use in the Fétoré sub-basin between 1990 and 2020/2022 to identify key changes and their underlying drivers. The methodology combines basin delineation using a digital elevation model, supervised classification of Landsat satellite imagery, result validation via a confusion matrix and Kappa coefficient, and change analysis using a transition matrix and field surveys.

The results reveal a continuous decline in natural vegetation cover, whereas open forests have expanded significantly, rising from 20.12 % in 1990 to 41.15 % in 2022. Cropland and fallow land, bare rock, and water bodies have also changed. These transformations, driven primarily by population pressure, agricultural expansion, and rainfall variability, exacerbate the hydrological vulnerability of the sub-basin and the Fouta-Djalon headwaters. They highlight the need to implement appropriate integrated management and restoration strategies.

Keywords: Spatio-Temporal Dynamics; Land Use; GIS; Fétoré Sub-Basin; Fouta-Djalon; Climate Change.

1 INTRODUCTION

The Fouta Djallon highlands constitute one of West Africa's main water towers: more than eight thousand streams originate there, feeding transboundary basins that irrigate a large part of the sub-region, from Senegal to Niger, passing through The Gambia and Guinea-Bissau. The Fétoré sub-basin, a tributary of the Konkouré, located in the commune of Timbi Madina (Pita prefecture), is fully integrated into this regional dynamic: its forest formations and wetlands play a crucial role in regulating the hydrological regime and supplying water to the riverside communities.

For several decades, however, this mountain range has been subjected to a dual pressure: human-induced and climatic. Shifting cultivation, the expansion of cultivated areas at the expense of forest cover, overgrazing, population growth, and the urbanization of centers like Timbi Madina are significantly altering the landscape. These pressures combine with increased rainfall variability, which exacerbates soil erosion, the silting up of waterways, and the degradation of headwaters. A joint FAO-WFP-ECOWAS mission conducted in 2024 on the headwaters of the Senegal River, which also originate in the mountain range, observed an advanced state of degradation requiring concerted conservation measures, illustrating the current relevance and urgency of the problem across the entire range.

The spatio-temporal dynamics of land cover in watersheds have been the subject of a growing number of studies in West Africa over the last decade, jointly employing remote sensing and geographic information systems (GIS). In Mali, Maïga et al. (2020) showed, in the Banankoro basin, a 5.96 % decline in gallery forest between 1987 and 2019 due to the combined effects of agriculture and gold mining, while Magassa (2023) documented advanced biophysical deterioration of the Lake Wégnia wetland, attributable to the combination of socio-economic and environmental factors. In Benin, Alamou et al. (2023) established, for the Alibori basin, a continuous expansion of agricultural land at the expense of natural formations between 1980 and 2020, while Adetona et al. (2024) observed, in the Zou River basin at the Domé outlet, the conversion of more than half of the forests and savannas into fields and plantations between 1991 and 2020, with a projected decline in natural formations by 2050. In Senegal, Faye and Dièye (2022) linked land-use change in the Soungrougrou River basin to increased water erosion of the soil. In Guinea itself, in the Siguiri prefecture, an integrated remote sensing analysis revealed, between 1992 and 2022, a 16.27 % decline in dense vegetation and a 28.75 % increase in degraded areas due to gold mining, confirming that these degradation dynamics are not unique to neighboring countries but are also observed within Guinea.

This review shows that while land-use dynamics in West African watersheds are now well documented in several neighboring countries and even in some mining regions of Guinea (Maïga et al., 2020; Faye & Dièye, 2022; Alimou et al., 2023; Magassa, 2023; Adetona et al., 2024), quantified and spatially referenced data on land-use change remain fragmented at the sub-watershed scale of the Fouta Djallon massif itself, particularly for the Fétoré. This gap limits local and national stakeholders' capacity to effectively guide integrated water resource management and degraded land restoration policies, even though the most recent field observations (FAO-WFP-ECOWAS mission, 2024) confirm the urgent need for action across the entire massif. In this context, the central problem of the present study is: what is the extent, pace, and nature of land-use changes in the Fétoré sub-basin between 1990 and 2020, and what are the main explanatory factors?

The overall objective of this study is to assess the spatio-temporal dynamics of land cover in the Fétoré sub-basin over the period 1990-2020, using an approach combining remote sensing and geographic information systems (GIS). More specifically, it aims to (i) delineate the sub-basin and characterize its morphometric parameters using a digital terrain model (DTM); (ii) map land cover at different reference dates (1990, 2000, 2010, and 2020) by supervised classification of satellite imagery; (iii) quantify the changes that have occurred between land cover classes using a transition matrix; and (iv) discuss the anthropogenic and climatic factors underlying these transformations, in light of trends observed in neighboring basins. The scope of the study is limited to the hydrographic perimeter of the Fétoré sub-basin; it constitutes a state of affairs which can be used for subsequent work on prospective modelling or decision support in the management of water resources in Fouta-Djalon.

2 MATERIALS AND METHODS

2.1 Study area

The research took place in the Fetoré sub-basin, located in the Fouta Djallon highlands of Guinea, within the upper watershed of the Konkouré river system. This area encompasses the territories of the rural communes of Timbi Tounni and Timbi Madina in the Pita prefecture. The Fetoré River drains a highland watershed where runoff, erosion, and infiltration are strongly influenced by seasonal rainfall. The study monitored changes in land use dynamics over three dates: 1990, 2010, and 2022, representing a thirty-two-year period. This time frame addressed several concerns. First, it allowed the use of available, high-quality satellite imagery that was sufficiently homogeneous to allow for comparison without being affected by excessive cloud cover. Furthermore, the length of the period under consideration provides the necessary perspective to identify structural trends, beyond annual or seasonal fluctuations. Finally, these three decades coincide with profound transformations of the territory, marked by the intensification of agricultural practices, urban sprawl, and the increasing effects of climate variability—all factors likely to have left lasting traces in land use.

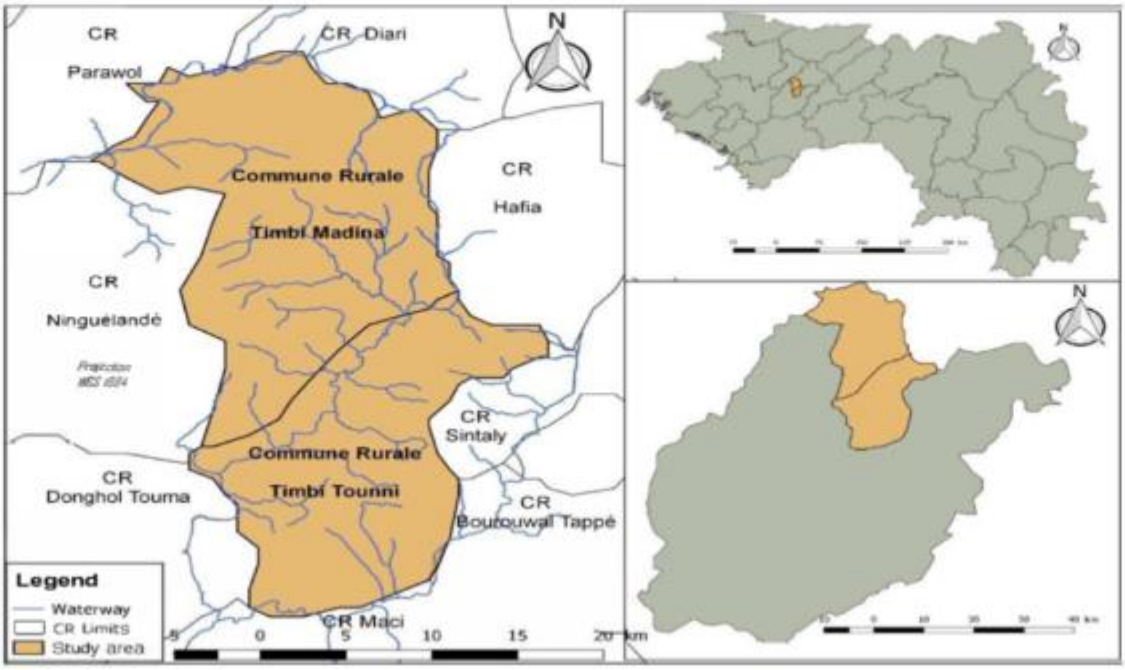

Figure 1: Study Area

2.2 Acquisition of satellite data

To cover the entire study period, we used data from Landsat and SPOT sensors, whose spatial and temporal resolutions are well-suited to the scale of the Fétoré watershed. Images were acquired via the USGS portal (EarthExplorer) for Landsat data and the CNES portal for SPOT scenes. The main characteristics of these images are presented in Table 1.

Table 1: Characteristics of the satellite images used

Satellite / Sensor	Date of acquisition	Spatial resolution
Landsat 5 (TM)	1990	30 m
Landsat 5 (TM)	2010	30 m
Landsat 8 (OLI/TIRS)	2022	30 m
SPOT 5 (HRG)	2010	10 m (multispectral)
SPOT 7 (NAOMI)	2022	6 m (multispectral)

SPOT images were used as a complement to refine the validation of classes in heterogeneous areas.

2.3 Image Preprocessing

Rigorous preprocessing was applied to all scenes to ensure their intertemporal comparability:

- **Radiometric correction:** conversion of digital levels into reflectance at the top of the atmosphere (TOA);
- **Geometric correction:** georeferencing based on 1/50,000 topographic maps, with a root mean square error (RMSE) of less than 0.5 pixels;
- **Atmospheric normalization:** applied via the 6S model to minimize the effects of atmospheric scattering and absorption.

2.4 Land cover classification

A supervised classification was performed on each image using the maximum likelihood algorithm, implemented in the ENVI software. The chosen nomenclature comprises 8 classes, consistent with the study objectives and the ecological reality of the sub-basin:

- Open forests
- Gallery forests
- Shrubby savannas
- Crops and fallow land
- Bare rocks
- Bodies of water
- Built surfaces
- gallery forest (distinguished from gallery forests for linear formations)

For each date, training samples were delimited from very high resolution images (Google Earth, panchromatic SPOT) and field knowledge.

2.5 Validation of classifications

The quality of the classifications was validated using two complementary approaches:

- **Statistical validation**: calculation of the confusion matrix and the Kappa index for each year. Only results with a Kappa ≥ 0.85 were retained.
- **Field validation**: field trips were organized in 2022, with GPS readings of control points (200 points) to verify the correspondence between the assigned class and the observed reality.

2.6 Diachronic analysis and quantification of changes

The three classifications (1990, 2010, 2022) were integrated into a Geographic Information System (GIS) using ArcGIS Pro. A *post-classification comparison analysis* was conducted, which involves comparing land cover pixel by pixel between two dates. This approach allowed us to:

- Calculate the areas (in hectares and as a percentage) for each class at each date
- quantify the gains and losses between classes (transition matrix);
- map the areas of stability, regression and progression for each type of occupation.

2.7 Integration of socio-environmental data

To explain the observed trends (particularly the decline of gallery forests and the expansion of built-up areas), semi-structured interviews were conducted with 60 key informants (technical services, village chiefs, farmers, herders). The topics covered included:

- agricultural practices and bushfires;
- The evolution of water availability;
- land pressure and urbanization.

All the data (classifications, topography, surveys) were synthesized into thematic maps (Figures 5.1, 5.4, and 5.5) and trend graphs. The map outputs were standardized in terms of projection (UTM zone 28N) and legend to facilitate visual comparison.

3 RESULTS AND DISCUSSION

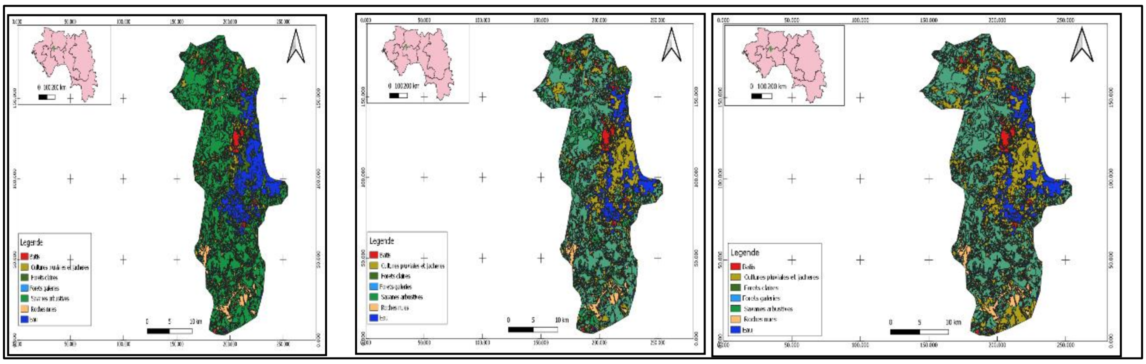

Figure 2: Land cover dynamics in the Fétoré sub-basin in 1990, 2010 and 2020

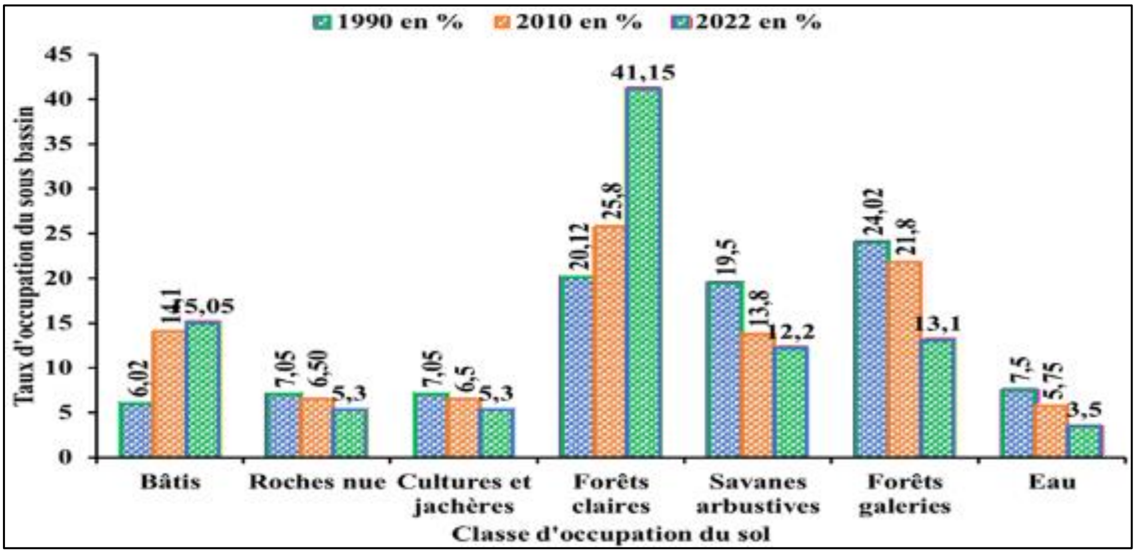

Figure 3: Changes in land use over time

This graph illustrates the evolution of the different land cover classes over three periods (1990, 2010 and 2022) in the study area (CR of Timbi Tounni and CR Timbi Madina).

Analysis of changes by land use class shows:

- The evolution of built-up areas is characterized by a moderate decline between 1990 and 2010, falling from 6.02 % to 5.5 %, before a strong acceleration from 2022 onwards, where they reach 14.1%, proof of recent but very dynamic urbanization.
- Cropland and fallow land have remained at relatively stable levels (7.05 % in 1990, 6.5 % in 2010, 5.3 % in 2022). Exposed rock areas decreased slightly from 7.05 % in 1990 to 6.5 % in 2010, then to 5.3 % in 2022, as did bodies of water (7.5 %, 5.75 %, 3.5 %). This decrease may be linked to the drying up of watercourses, water withdrawals for agricultural use, and climate change.
- An increase in the gallery forest.
    - Open forests have increased significantly, rising from 20.12 % in 1990 to 25.8 % in 2010, and then to 41.15 % in 2022.

These increases reflect an intensification of urbanization and agricultural activities, to the detriment of natural formations.

- A reduction in the areas occupied by natural vegetation
    - Open forests gradually decreased from 19.5 % in 1990 to 13.8 % in 2010, then to 12.2 % in 2022.
    - Shrub savannas decreased from 19.5 % in 1990 to 13.8% in 2010, then fell to 2.2 % in 2022.

- Gallery forests have experienced a sharp decline from 7.5% in 1990 to 5.75 % in 2010, then to 3.5 % in 2022.

This trend reflects deforestation and the degradation of forest ecosystems, often linked to human activities (agriculture, urbanization, logging).

- Open forests constitute the most significant and rapidly growing category, increasing from 20.12 % in 1990 to 25.8 % in 2010, reaching 41.15 % in 2022. Shrub savannas are experiencing a significant decline, falling from 19.5 % in 1990 to 13.8 % in 2010, reaching only 2.2 % in 2022.
- Gallery forests, meanwhile, are also experiencing a worrying decline, decreasing from 24.02 % in 1990 to 21.8 % in 2010, then falling to 13.1 % in 2022.
- Crops and fallow land have decreased slightly (7.05 % in 1990, 6.5 % in 2010, 5.3 % in 2022), as have bare rocks (7.05 %, 6.50 %, 5.3 %) and bodies of water (7.5 %, 5.75 %, 3.5 %).

3.1 Topographic map of the study area

The figure below illustrates the topographic map of the Fétoré sub-basin, which shows the geographical positioning, the altitude reading and the slope, and the morphological and hydrological context.

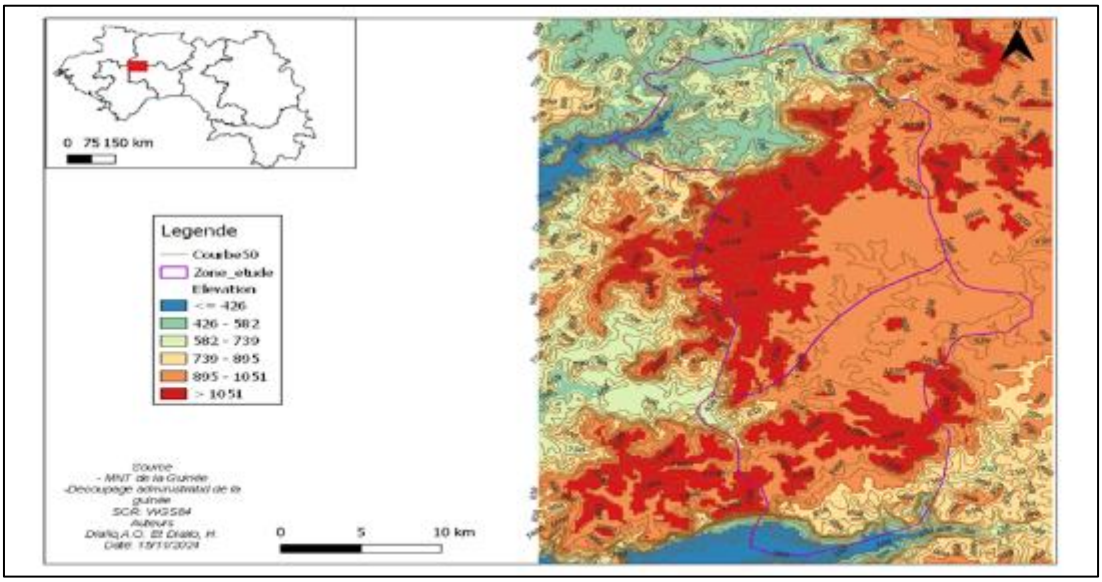

Figure 4: Topographic map of the study area.

This figure is a topographic map of the study area (surrounded by a purple line) showing the elevation with contour lines and colored areas representing different altitudes.

Contour lines (also called isohypses) are indicated by thin brown lines and are labeled with elevation values. These contour lines indicate specific elevations, marked by numerical values. On this map, they show elevations at regular intervals. Closely spaced contour lines indicate a steep slope, while more widely spaced lines indicate a gentler slope.

The map legend indicates different elevation ranges:

- The areas colored in red and orange indicate higher elevations, exceeding 1051 meters for the red areas.
- The areas in blue indicate the lowest altitudes, from 0 to 426 meters.

4 DISCUSSION

The diachronic analysis of Landsat and SPOT images between 1990 and 2022 reveals profound landscape transformations in the Fetoré sub-basin. The remarkable increase in open woodland, from 20.12 % in 1990 to 41.15 % in 2022, is an unexpected result that deserves to be considered in light of trends observed elsewhere in West Africa. Indeed, most studies conducted in the region document a decline in forest cover due to the combined effects of agricultural pressure and urbanization. For example, in the Kara basin in northern Togo, *Hlover et al.* (2024) highlighted a reduction in forest area between 1972 and 2005, followed, however, by a slight increase until 2021, suggesting a trend toward conservation in certain areas. Similarly, in the W Transboundary Biosphere Reserve in Benin, *Samba et al. (2021*) observed a dramatic regression of forest formations, the area of which decreased from 84.57 % in 1998 to 24.52 % in 2018, while mosaics of fields and fallow land increased from 15.29 % to 75.13 % over the same period.

The increase in open woodland observed in our study area could be explained by several factors. On the one hand, it could reflect a process of conversion of shrub savannas and fallow land into denser wooded formations, a phenomenon already documented by Hlover et al., who noted a trend toward savanna-to-forest conversion in the Kara River basin. On the other hand, this positive development could result from conservation policies or natural regeneration facilitated by a temporary reduction in human pressures on certain parts of the territory. However, caution is advised when interpreting these figures, as the distinction between open woodland and wooded savannas can sometimes be challenging in remote sensing, particularly in tropical environments where transitions are gradual.

In contrast to the expansion of open forests, our results show a marked decline in shrub savannas (from 19.5 % in 1990 to 2.2 % in 2022), gallery forests (from 24.02 % to 13.1 %), and water bodies (from 7.5 % to 3.5 %). This trend is part of a general movement observed across West Africa, where the degradation of natural ecosystems is widely documented. *Kiribou et al. (2024*) report that, in the drylands of West Africa, Sahelian savannas, open forests, and gallery forests declined by 23 %, 40.79 %, and 23.92%, respectively, between 1975 and 2013, while agricultural land and built-up areas expanded by 91.8 % and 115 %, respectively. This convergence of trends suggests that the Fetoré sub-basin is experiencing pressures similar to those affecting other West African regions, despite local specificities.

The decline in water cover, from 7.5 % to 3.5 % in 32 years, warrants particular attention. This phenomenon could result from the drying up of watercourses due to climate variability, water withdrawals for agricultural irrigation, and changes in the basin's hydrological regime. In the Sahelian Tougou watershed in Burkina Faso, a study showed that the spatio-temporal dynamics of surface conditions are a determining factor in the hydrological response, and that the impact of land-use changes on runoff outweighs that of climate variability. This observation underscores the need to integrate surface condition dynamics into hydrological models for the sustainable management of water resources.

The dramatic increase in built-up areas, from 6.02 % in 1990 to 14.1 % in 2022, constitutes one of the major transformations of the landscape. This trend has accelerated particularly since 2010, reflecting a recent but very dynamic urbanization process. This phenomenon is not isolated and is part of a broader regional dynamic. *Lawal et* al. (2026) documented a 258.21 % expansion of built-up areas in the Gusau metropolis in Nigeria between 1994 and 2024, with an increase from 991.83 ha to 3,554.01 ha. Similarly, Bah (2023) showed that in Ratoma (Conakry, Guinea), the built-up area increased from 1,860 ha in 1986 to 3,952 ha in 2022, while vegetation decreased from 2,560 ha to 99.27 ha over the same period.

This rapid urbanization is generally attributed to population growth and the lack of appropriate urban planning. In the case of the Fetoré sub-basin, this expansion of built-up areas likely occurs at the expense of agricultural and natural spaces, contributing to landscape fragmentation and ecosystem degradation. Interviews conducted with local populations confirm this increasing land pressure, corroborating the results obtained from remote sensing.

The transformations observed in the Fetoré sub-basin result from a combination of biophysical and socio-economic factors. Field surveys identified land clearing, bushfires, agriculture, and livestock farming as the main drivers of change. These findings are consistent with regional literature that highlights the predominant role of agriculture in deforestation and land degradation in West Africa. Declining agricultural yields, climate uncertainty, and a lack of economic alternatives are pushing communities to expand their cultivated areas, often at the expense of natural habitats.

Climate variability is a second major explanatory factor. Changes in rainfall patterns, with more frequent and intense periods of drought, directly affect water availability and vegetation regeneration. Studies conducted in the Sahel show that dry periods are accompanied by a significant reduction in vegetation cover and an expansion of bare soil. In our study area, the decline in water bodies could therefore reflect both the effects of human water withdrawals and those of climate change.

The approach combining remote sensing, field validation, and socio-environmental surveys has proven relevant for understanding the complexity of spatio-temporal dynamics. Supervised maximum likelihood classification, with a Kappa coefficient greater than 0.85, provides good reliability of the results. Post-classification analysis, commonly used in studies of this type, allows for precise quantification of transitions between land cover classes.

However, some limitations must be highlighted. The spatial resolution of Landsat images (30 m) does not allow for the fine discrimination of certain vegetation types or the identification of small-scale changes. Furthermore, intertemporal comparisons can be affected by seasonal differences in image acquisition or by atmospheric variations that are not fully corrected. Finally, the diachronic analysis, based on only three dates (1990, 2010, and 2022), does not account for all the inter-annual fluctuations that could shed light on certain specific changes.

These results directly challenge the management of natural resources in the Fétoré sub-basin. The simultaneous decline of gallery forests and bodies of water, in the face of rapid urbanization, argues for a more coherent territorial planning approach. Kiribou (2024) emphasizes this point: without a robust interface between research and public policy, the spatial indicators produced by remote sensing risk remaining ineffective in influencing sustainable land management strategies in the Sahelian and Sudanian-Sahelian zones.

The expansion of open woodlands, on the other hand, is a more difficult signal to interpret. If it is confirmed in the long term, it could open up interesting prospects for the ecological restoration of the sub-basin. However, its sustainability is not guaranteed: population growth and the expansion of agricultural land could quickly reverse this trend. It would therefore be useful to test it over time, for example using predictive models of Markov chains or neural networks capable of simulating possible landscape trajectories and providing concrete information to land-use planners.

5 CONCLUSION

This study aimed to assess the spatio-temporal dynamics of land cover in the Fétoré sub-basin, a tributary of the Konkouré River in the Fouta-Djalon massif, between 1990 and 2020. It employed an approach combining digital terrain modeling, remote sensing, GIS, and field surveys to determine the extent, pace, and explanatory factors of these changes. The main results obtained are as follows: The Fétoré sub-basin has morphometric characteristics (area, compactness index, drainage density, average slope) typical of the high plateaus of Fouta-Djalon, which are conducive to rapid runoff in the event of denudation of the vegetation cover;

The classifications of satellite images carried out for 1990, 2000, 2010 and 2020, validated by confusion matrix and Kappa index, made it possible to map six land cover classes with a precision deemed satisfactory;

Diachronic analysis reveals a continuous regression of forest formations and wooded savannas over the period, in favor of cultivated land and, to a lesser extent, bare soils and dwellings, with a noticeable accentuation of this trend in recent decades;

The transition matrix highlights that most of the loss of forest cover has been converted directly into agricultural land, while the increase in bare soil/housing reflects the growing urbanization of the municipalities of Timbi Madina and Timbi Tounni.

The results obtained reveal several major trends, namely:

- **Unexpected progression of open forests**: the area of open forests has seen a dramatic increase, rising from 20.12 % in 1990 to 41.15 % in 2022. This positive development, which contrasts with the regressive trends observed in other West African regions, could reflect a process of reconversion of shrub savannas and fallow land into denser wooded formations.
- **Alarming decline in natural formations**: shrub savannas have fallen from 19.5 % in 1990 to 2.2 % in 2022, while gallery forests have declined from 24.02 % to 13.1 % over the same period. These declines demonstrate the ongoing degradation of forest ecosystems due to human activities.
- **A worrying decrease in water bodies**: water surfaces have seen a significant reduction, falling from 7.5 % to 3.5 % between 1990 and 2022. This trend could be attributed to the drying up of watercourses, agricultural withdrawals, and the effects of climate change.
- **Rapid expansion of built-up areas**: the built-up area has experienced spectacular growth, increasing from 6.02 % in 1990 to 14.1 % in 2022, with a marked acceleration after 2010, reflecting recent but very dynamic urbanization.
- **Relative stability of crops and fallow land**: this class recorded a slight decrease, from 7.05 % in 1990 to 5.3 % in 2022, suggesting a stagnation or even a decline in agricultural areas in favor of other land uses.
- **Identified explanatory factors**: field surveys identified land clearing, bushfires, agriculture, and livestock farming as the main drivers of the observed changes, in addition to the effects of climate variability and land pressure related to urbanization.

The identified explanatory factors such as demographic pressure, agricultural expansion, rainfall variability, and local urbanization converge with those documented in other West African watersheds subject to comparable pressures (Mali, Benin, Guinea);

These transformations weaken the hydrological regulation role of the Fétoré sub-basin, with potential implications for the water supply of transboundary basins that depend on the Fouta-Djalon massif.

This study nevertheless has some limitations which should be highlighted: the uneven availability of good quality radiometric satellite images over the entire period 1990-2020, particularly during the rainy season; the lack of field validation data for the earliest dates, which then relies on expert interpretation; and the spatial resolution of the Landsat images (30 m), which can limit the detection of fine changes at the parcel scale.

These limitations open up several avenues for future research: the use of higher-resolution images (Sentinel-2) to refine recent mapping; prospective land-use modeling, for example using Markov chains coupled with a cellular automaton, to project trends to 2040-2050; and a deeper investigation of the link between land-use dynamics and changes in the flow rates of the Fétoré River, to more precisely quantify the hydrological impact of observed changes. These approaches would help equip local and national stakeholders to define integrated management and restoration strategies for the sub-watersheds of the Fouta Djallon massif.

The results obtained open up several perspectives for deepening the understanding of the dynamics at play and guiding management actions:

- **Prospective modelling**: the use of predictive models such as the Markov matrix, cellular automata or artificial neural networks would make it possible to anticipate the future evolution of the landscape and to evaluate different development scenarios.
- **Higher resolution analysis**: the use of very high spatial resolution images (Sentinel-2, Pleiades, or drones) could refine the characterization of landscape units and improve the detection of fine-scale changes.

Among these limitations, the 30m spatial resolution of Landsat images, although suitable for the watershed scale, remains insufficient to finely discern certain plant facies or to detect localized mutations, particularly in transition zones where the boundaries between formations are often tenuous.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflict of interest. The authors certify that this study was conducted independently and that there are no conflicts of interest to declare. No financial support, commercial collaboration, or personal relationship existed that could have influenced the design, data collection, analysis, or interpretation of the data, or the writing of the manuscript. All authors contributed equally to this work and approve the final version submitted for publication.

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