Hydromorphological analysis and Spatio-temporal Dynamics of Land use in the Mulongwe River Watershed, in Uvira, Democratic Republic of Congo

Mukasani Benjamin[1]; Espoir Bagula Mukengere[2] ; Rubiga Shujah William[3]; Janvier Kabemba Nicolas[4] ; Bukuru Bitagirwa Romulus[5] ; Mulungulungu Ruguge Yves[6] ; Mushagalusa Imani Clément[7] ; Kubwimana Désiré[8] ; Nyongolo Luwawa Martin;[9]

[1]Faculty of Agronomic Sciences and Environment, University Notre Dame de Tanganyika, Uvira, DRC
[2]Faculty of Agronomic Sciences and Environment, Evangelical University in Africa
[3]Research Center for Natural Sciences and Environment, University of Burundi
[4]Multidisciplinary Consulting Firm Emergence RDC
[5]Department of Earth Sciences, Faculty of Sciences, University of Burundi
[6]Higher Institute of Rural Development (ISDR/Uvira)

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Abstract: This study examines the hydro morphological characteristics and land use changes in the Mulongwe River watershed in Uvira, Democratic Republic of the Congo, from 2002 to 2020. The analysis addresses the urgent need for sustainable watershed management, particularly as the region faces increasing pressures from human activities and climate variability. Located in eastern Congo, the watershed spans 112.19 km² and includes 29 sub-basins, flowing from the Mitumba Mountains to Lake Tanganyika. Its ecological richness and complex hydrographic network render it significant yet vulnerable to risks such as flooding, which are further exacerbated by land use changes. Utilizing high-resolution satellite imagery from Google Earth Pro (2002, 2020) and a 10-meter digital elevation model (DEM) from NASA's SRTM, the study employed Geographic Information Systems (GIS) through ArcGIS software for precise mapping and analysis. The DEM facilitated comprehensive topographic analysis, while the georeferenced images enabled detailed comparisons of land cover categories, including forest, agriculture, urban areas, and bare soil. The findings reveal a substantial change in land use between 2002 and 2020, with an overall increase of 23.78% in cultivated and urban areas, while forested regions have decreased. This trend reflects regional patterns in Sub-Saharan Africa, driven by population growth and agricultural intensification. The elongated shape of the watershed and its varied topography contribute to its vulnerability to hydrological changes, and the reduction of vegetation has amplified flood risks by altering runoff and water retention.

Keywords: *Hydro Morphology, Land use Dynamics, Mulongwe River Watershed, Geographic Information Systems (GIS).*

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I. INTRODUCTION

Sustainable management of freshwater resources is a crucial issue in the 21st century, faced with accelerating global changes and increasing anthropogenic pressure. Climate change, with its impacts on rainfall patterns and the increase in the frequency and intensity of extreme events (droughts, floods), exacerbates the vulnerability of aquatic ecosystems and compromises the water security of populations.(Costantini, 2023)Integrated and responsible

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management of watersheds, functional hydrological units, is therefore essential to preserve biodiversity, guarantee water availability and ensure the maintenance of ecosystem services.(Mufungizi et al., 2023; Raachi, 2007; Tomedi Eyango Tabi, 2017; VERSCHAEVE et al., s. d.)

The Mulongwe River watershed, located is distinguished by its ecological richness and its central role in the local water balance.(Ilunga, 2006; Ilunga et al., 1993; RUKAHUSA et al., 2022) The analysis of its hydro morphology and the dynamics of its land use is therefore essential to understand its vulnerability to anthropogenic and climatic pressures.

Much research has explored the complex interactions between hydro morphology, land use and hydrological risks in different regions of the world. For example, Soro and his co-authors highlighted the decrease in precipitation and aquifer recharge, as well as the transformation of land uses in the Upper Bandama watershed in Côte d'Ivoire.(Soro et al., 2014)Similarly, Moussa et al. (2020) observed an alarming increase in runoff and erosion in the Niamey region of Niger, with negative consequences for land degradation and food security.(Boubé, 2022)The study by Frédérique & Delalande (2008) on the potential freshwater reserves of volcanic lakes in southwestern Tanzania highlights the importance of integrated management of these resources in the face of environmental dynamics.(Frédérique & Delalande, 2008)These studies, although significant, mainly focus on West and East Africa. The Mulongwe River watershed, despite its importance, remains relatively understudied. This study aims to fill this gap by specifically analyzing the hydromorphological characteristics and spatio-temporal dynamics of land cover between 2002 and 2020 of the Mulongwe River watershed. The results of this research will contribute to a better understanding of the processes involved and will help identify sustainable management strategies for the preservation of water resources and ecosystems in the watershed.

II. MATERIALS AND METHODS

➢ *Location of the Study Area*

The Mulongwe River watershed is located in the eastern Democratic Republic of Congo, in the province of South Kivu, more precisely in the territory of Uvira. This basin is bounded by the highlands of Minembwe to the west and flows into Lake Tanganyika to the east. It covers an area of approximately 25.5 km long, playing a crucial role in the supply of drinking water for the local population, providing more than 70% of the water consumed in the region. The Mulongwe River, which originates in the Mitumba Mountains, is the main watercourse of the basin. Its hydrographic network is essential for the regulation of water resources and the management of aquatic ecosystems.

The watershed benefits from a tropical climate, characterized by a rainy season and a dry season, influencing flow regimes and the availability of water resources.

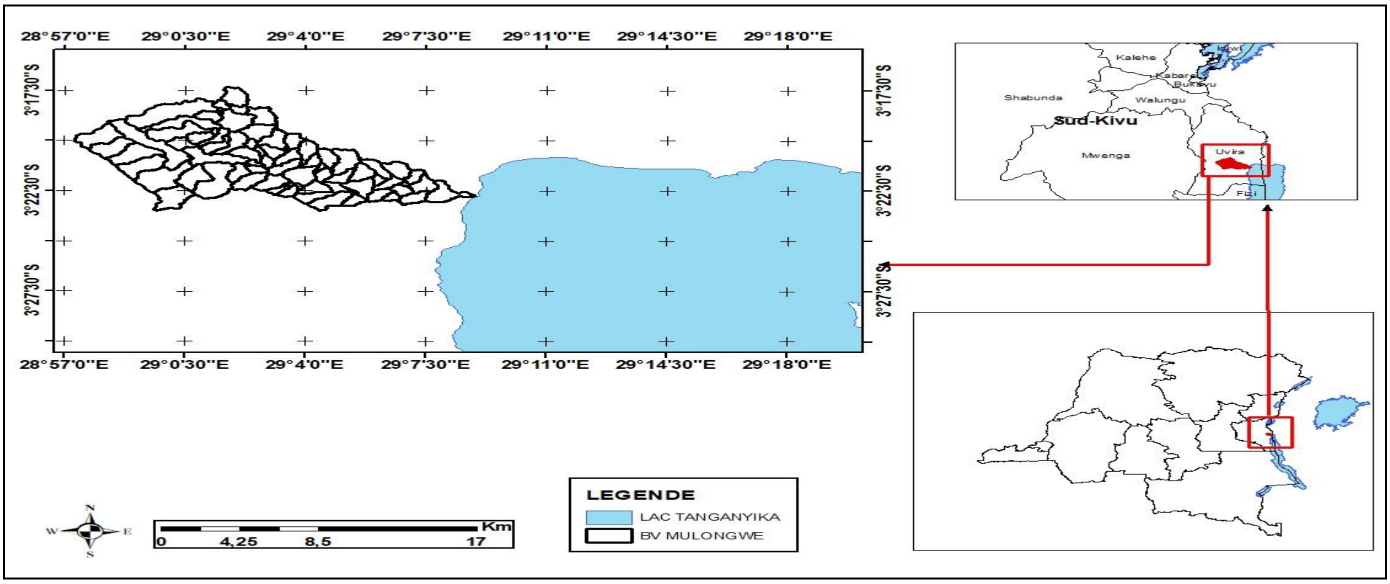

Fig1 Location Map of the Mulongwe River Watershed

➢ *Collection of Geospatial Data*

A Digital terrain model (DTM)

- A 10-meter resolution digital terrain model was obtained from NASA Shuttle Radar Topography Mission (SRTM) data. This DEM was used to analyze the watershed topography, delineate its boundaries, and extract essential morphometric features such as slope, aspect, and drainage network.

➢ *Satellite Images for Land Use*

For land cover analysis, very high resolution satellite images were obtained via Google Earth Pro for the years 2002 and 2020. This approach was chosen for its ability to provide detailed and up-to-date data of the Mulongwe River watershed. The data collection and processing process was as follows:

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- Year 2002: An image dated June 30, 2002 was selected. This image, provided by DigitalGlobe via Google Earth, offers a spatial resolution of approximately 1m, allowing precise identification of elements of the urban and peri-urban landscape.
- Year 2020: A more recent image, dated August 15, 2020, was chosen; this image, also provided by DigitalGlobe, has an improved spatial resolution of approximately 1 m, thus providing an even higher level of detail.

The images were downloaded using Google Earth Pro's high-resolution registration tool, taking care to maintain a constant viewing altitude to ensure uniform scale. These very high-resolution images allowed for detailed visual interpretation of the different land cover classes.

The use of images from two dates (2002 and 2020) made it possible not only to map the 2020 land use, but also to analyze the changes that occurred over a period of 18 years, thus covering an important phase of the recent urbanization of Uvira.

➢ *Data Processing*

The processing of the collected data was carried out using ArcGIS 10.4.1 software, a powerful geographic information system (GIS) widely used in environmental research. This crucial step in the methodological process allowed the preparation and analysis of spatial data to meet the objectives of the study. Data processing involved several key steps:

➢ *Extraction from the Mulongwe River Watershed*

The extraction of the Mulongwe River watershed was carried out using ArcGIS 10.4.1 software, specifically using the Arc SWAT (Soil and Water Assessment Tool) extension. This extension, developed for hydrological analysis and watershed modeling, offers powerful tools adapted to our research objective. The extraction process followed the following steps:

- Preparation of the DEM: Importing the 10-meter resolution SRTM Digital Terrain Model (DTM) into ArcGIS and checking and correcting any errors or depressions in the DEM using the Arc SWAT “DEM reconditioning” tool.
- Watershed Delineation: Using Arc Swat’s Watershed Delineation tool to automatically define the watershed network and sub-basins.
- Definition of the outlet point of the Mulongwe River watershed.

➢ *Extraction of Soil Data*

Soil data were extracted from the Soil and Terrain Database for Central Africa (SOTWIS) database using ArcGIS geoprocessing tools. The process involved:

- Using the "Clip" tool to clip soil data according to watershed boundaries
- Application of the "Extract by Mask" tool to extract soil property values specific to our study area.

This targeted extraction ensures that subsequent hydrological analyses are based on accurate and relevant soil data for the Mulongwe watershed.

➢ *Georeferencing of Satellite Images*

High-resolution images obtained via Google Earth Pro for the years 2002 and 2020 were georeferenced in ArcGIS 10.4.1. The georeferencing process consisted of the following steps:

- Identification of at least 4 ground control points (GCP) for each image, using stable and easily identifiable elements (road intersections, notable buildings, etc.)
- Application of a second-order polynomial transformation to minimize distortions
- Resampling images using the nearest neighbor method to preserve original radiometric values
- Checking the accuracy of georeferencing by calculating the root mean square error (RMSE), aiming for a value less than 0.5 pixels

This precise georeferencing allows an exact superposition of images with other spatial data layers, thus facilitating the diachronic analysis of land use and integration with hydrological data.

➢ *Data Analysis*

- Data analysis for hydrometric parameters and land use dynamics:

The digital terrain model was imported into the arcGis 10.1 software for specific analysis. The manipulations carried out were carried out using the clipping and extraction functionalities available under a GIS, with the ArcSWAT extension for shapefiles and rasters respectively; by the raster of the Mulongwe River watershed, the spatial analysis tool, spatial analyst tools through the contours unit made it possible to extract the contour lines from the SRTM; the editing extensions made it possible to calculate the morphometric parameters such as the area and perimeter of the Mulongwe watershed. These operations resulted in the creation of a detailed map of the Mulongwe River hydrographic network as well as the topographic map of the Mulongwe watershed. The georeferenced images were classified using MultiSpecWin64 software. This step allowed to define different land use classes, such as inhabited areas, areas of crops and low vegetation, areas of dense vegetation as well as bare soil.

From the classified images and the delineated study area, a land cover map for each study year was produced in ArcGIS 10.4. This map represents the spatial distribution of different land cover classes in the Mulongwe River watershed (Verma et al., 2022). Using the Tabulate Intersection tool in ArcGIS, a transition matrix was calculated to compare the land cover classifications between the starting year 2002 and the ending year 2020. This made it possible to determine the rate of change, as given by Akpoyètè et al., 2018a; Kpedenou et al., 2016; Mamane et al., 2018; Ousmane et al., 2020; Nguekam et al., 2020.

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$$Tg = \frac{S2-S1}{S1} X\ 100$$

With: With S1 the surface area of a surface unit class at date t1; S2 the surface area of the same surface unit class at date t2.

➢ *Morphometric Characteristics of the Mulongwe River Watershed*

Following the analyses, two maps were produced, allowing the calculation of the morphometric parameters of the Mulongwe River basin. The hydrographic map highlights that the Mulongwe River is made up of 29 sub-basins, giving this river a hierarchy of order 4 according to Strahler's Order. This highlights the intrinsic complexity of its hydrographic network. The main characteristics of the watershed are revealed as follows: a total area of 112.19 km², a perimeter of 80,425 km. The topographic or contour map provides information on the elevation variations extending from 774 m (at the minimum level) in the sub-basin of the downstream part to 3279 m (at the maximum level) in the sub-basin of the upstream part. As for the shape compactness coefficient, determined using the formula of American hydrologist Robert E. Horton

$$C = \frac{4\pi A}{P * P}$$

➢ With :

- A: Watershed area
- P: Watershed perimeter
- π: Value of pi (3.14159)

The calculated value is approximately equal to C≈0.2179. This measure, indicating the compactness of the watershed shape, suggests a relatively elongated or irregular configuration of the watershed. These data provide a comprehensive overview of the topography and configuration of the Mulongwe River watershed, thus enriching our understanding of its hydrological environment.

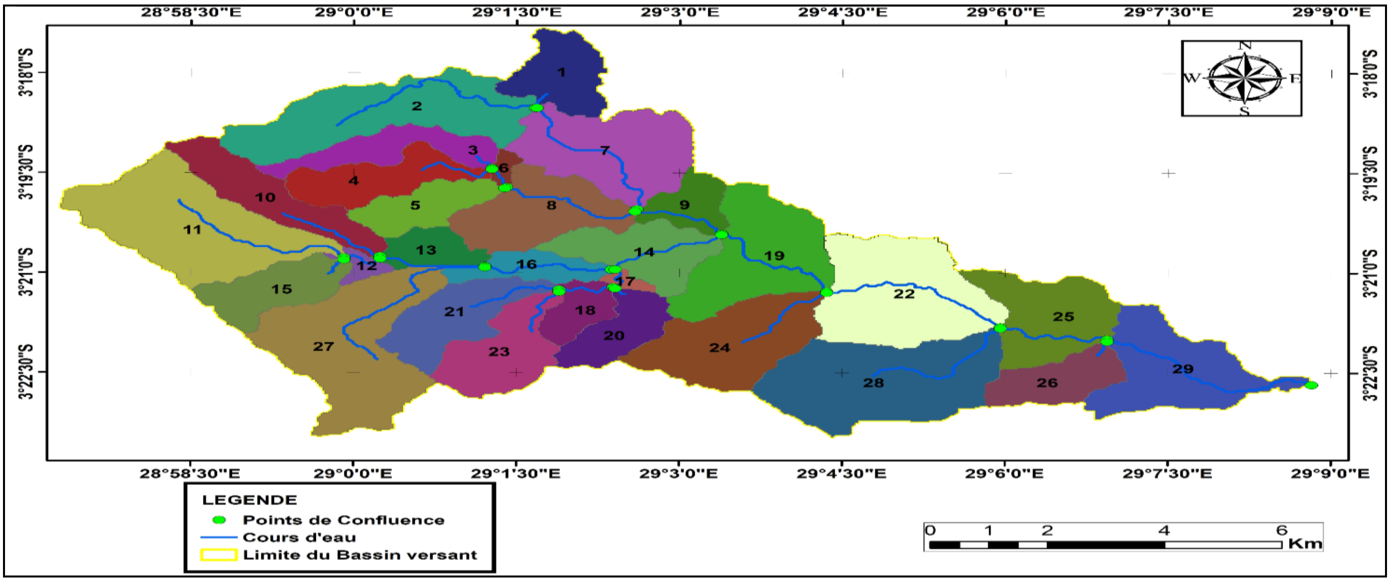

Fig 2 map of the Hydrographic Network of the Mulongwe River Basin

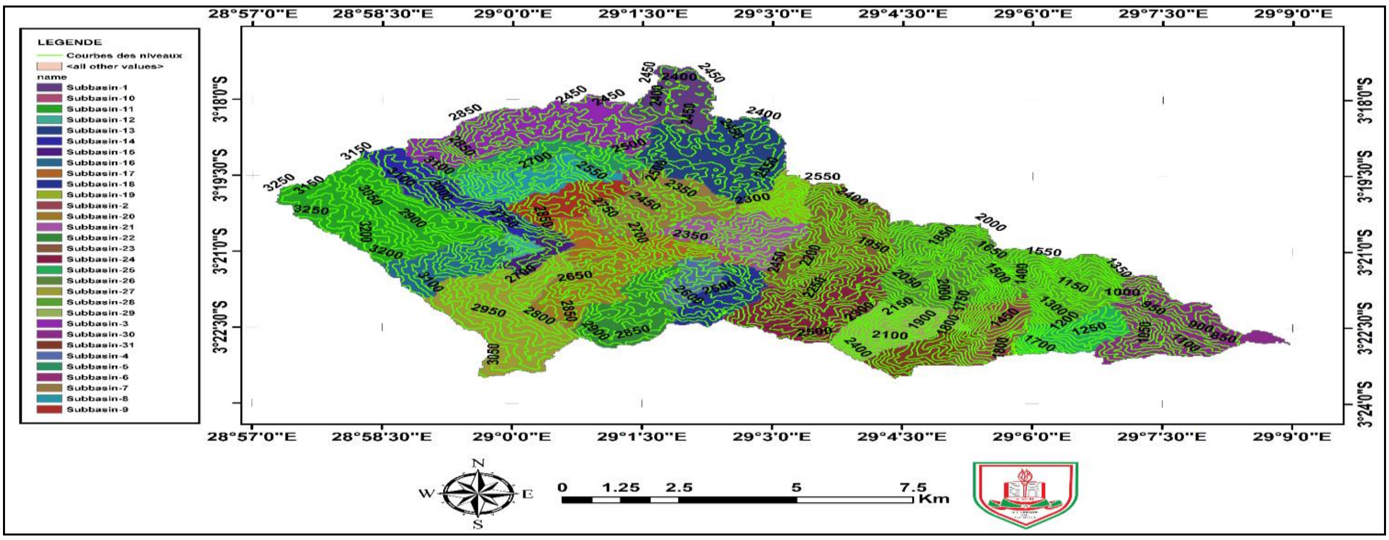

Fig 3 Topographic map of the Mulongwe River Watershed

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➢ *Land use Dynamics in the Mulongwe River Watershed*

The diachronic land use analysis was done between 2002 and 2020 and two land use maps were released. The 2002 land use provides a crucial insight into past environmental dynamics in the Mulongwe River catchment. By focusing on different land use classes such as settled areas, agricultural areas, forest areas, and others, this map reveals land use patterns at a key moment in the basin's history. This spatial representation helps identify areas subject to significant anthropogenic pressures, such as increasing urbanization or agricultural land conversion, which can have a significant impact on the basin's hydrology. As for the 2020 land use map, it illustrates recent changes in land use patterns in the Mulongwe River catchment. By highlighting urban, agricultural and forested areas, this map provides a valuable insight into the evolution of the local environment. These data are crucial for assessing the impact of human activities on the hydrology of the basin and for informing flood management strategies. Comparison with the previous map allows for tracking landscape transformation trends, helping to guide conservation and sustainable development efforts.

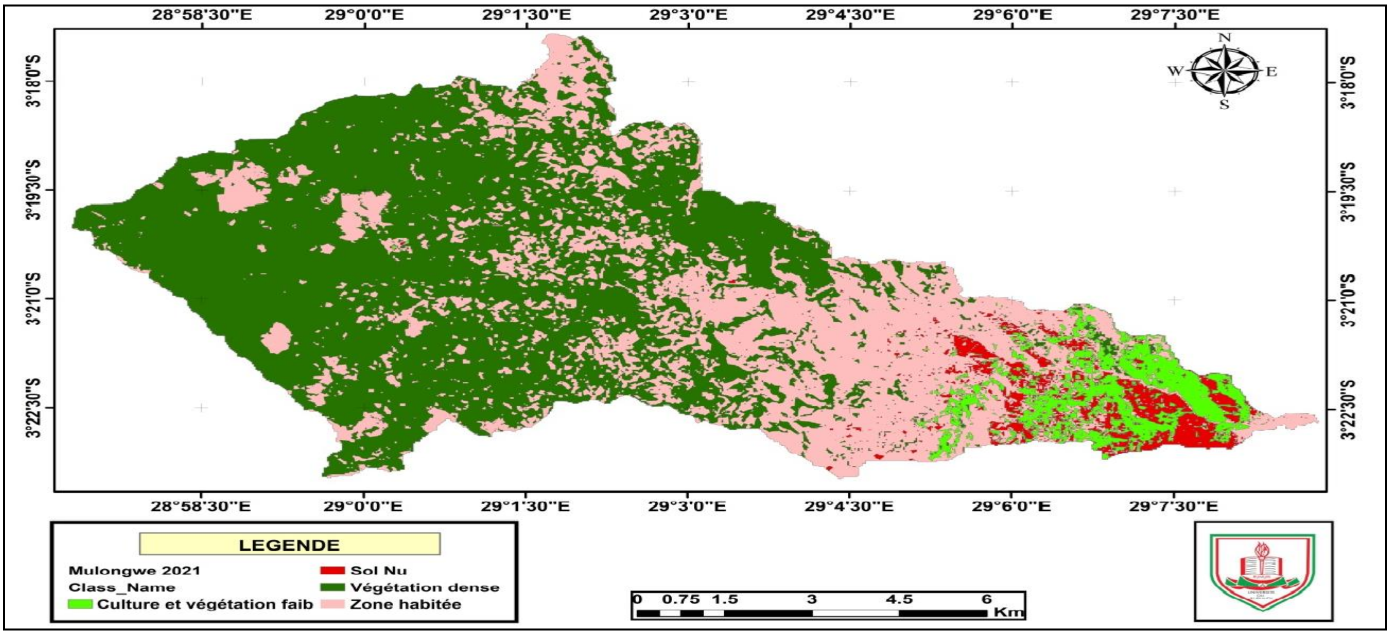
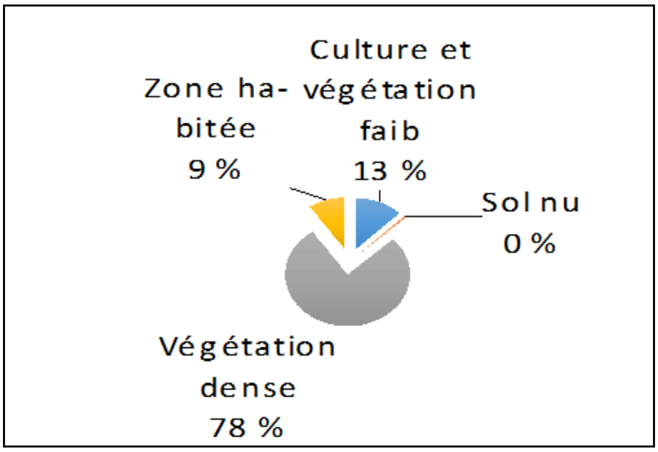


Fig 4 Land use or the Study Area in 2020

For the overall rate of change, two diagrams reproduced in Figure 8, give the 2002 trends of land cover in the Mulongwe River catchment. In the pie chart, each land cover class is presented proportionally: cultivated and sparsely vegetated areas represent about 13%, bare soil occupies about 0.5%, densely vegetated areas cover nearly 78%, while inhabited areas represent about 9%. These proportions provide an immediate visual overview of the relative distribution of different land cover types in 2002. In 2020, Figure 9, a notable change in land cover in the Mulongwe River catchment is observed compared to 2002. This transformation, essential in the context of flood hydrological modeling, has significant implications for the hydrological dynamics of the region. Changes in the proportions of different land cover classes, such as cultivated areas, settled areas, and vegetation extents, can influence the hydrological response of the watershed to precipitation and extreme events.



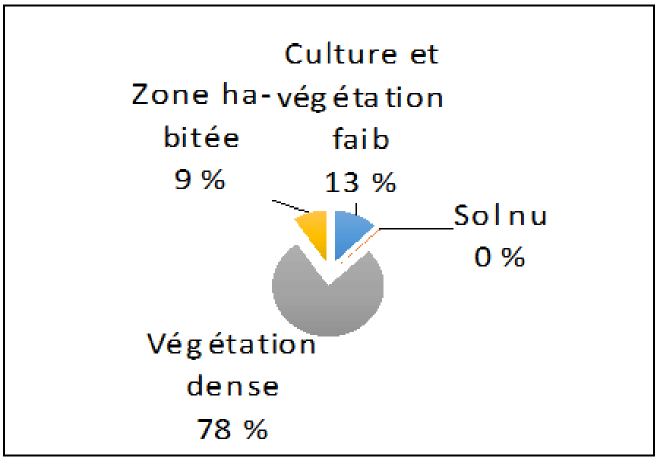


Fig 4 Diagrams Representing the 2002 Land use Classes in Percentage

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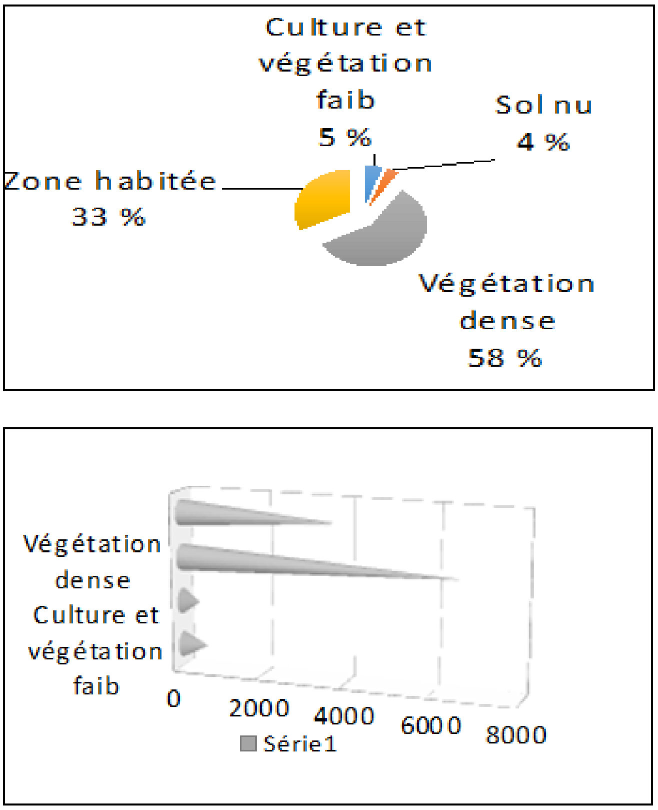

Fig 5 Diagrams Representing the 2020 Land use Classes in Percentage

III. DISCUSSION OF RESULTS

First, regarding the morphometric parameters, the values obtained are broadly consistent with those determined in other studies on the morphological analysis of tropical watersheds. Indeed, the area of 112.19 km2 is within the range of basin sizes generally studied, between a few tens to a few hundred km2. Similarly, the compactness coefficient of 0.2179 calculated here is similar to the average values reported, typically between 0.1 and 0.3 for elongated basins such as this one.(DIABANGOUAYA & SITOU, 2016; Faye et al., 2021; Mashauri et al., 2023). Furthermore, the detailed characterization of the hydrographic network in 29 sub-basins echoes the analyses carried out on other complex tropical basins, also presenting strong reliefs.(Mufungizi et al., 2023) The joint use of GIS and the SWAT module has proven to be relevant for accurately understanding the geomorphology of the study area, as highlighted in various studies applying this methodology.(Ardiansah et al., 2023; Jodar-Abellan et al., 2019; Nu-Fang et al., 2011). Concerning land use dynamics, our results highlight a significant expansion of cultivated areas and urban areas between 2002 and 2020, to the detriment of forest areas. This observation is consistent with trends observed elsewhere in sub-Saharan Africa, under the combined effect of population growth and the intensification of agricultural practices.(Soro et al., 2014)The quantification of the overall rate of change of 23.78% over the period of analysis places this evolution among the notable transformations documented in other contexts of Haiti for example.(7. Zurcher Mardy, Jean-Philippe Waaub, Sebastian... - Google Scholar, s. d.)

Thus, despite local specificities, the results obtained in this study broadly correspond to existing knowledge on the morphometry of tropical basins and on the recent dynamics of land use in sub-Saharan Africa. This consistency validates the relevance of our methodological approach combining GIS, remote sensing and morphometric analysis to characterize this watershed.

IV. CONCLUSION

This study provided an in-depth exploration of the hydro morphological characteristics and land use dynamics in the Mulongwe River watershed, located in the Democratic Republic of Congo. Given the urgent need for sustainable watershed management in the context of environmental change, our research relied on rigorous methods to fill a significant gap in the existing literature, where few studies had been devoted to this region.

The results obtained show that the Mulongwe River watershed covers an area of 112.19 km², with a complex hydrographic network formed by 29 sub-basins, thus revealing the richness of its aquatic ecosystem. The compactness coefficient of 0.2179 indicates an irregular configuration, a factor that can influence water flow dynamics and, consequently, water resources management.

The diachronic analysis between 2002 and 2020 highlighted notable changes in land use, with a significant increase in cultivated areas and urban areas, while forest areas have decreased considerably. The overall change rate of 23.78% highlights increasing pressure from human activities on the environment, reflecting trends observed in other regions of sub-Saharan Africa. This finding underlines the urgency of adapting land and water resource management strategies to address these challenges.

Our results are consistent with existing knowledge on morphometry and land use in tropical basins, thus validating the methodological approach employed, which combines the use of geographic information systems (GIS) and remote sensing. In the future, further research should be conducted to deepen our understanding of the interactions between land use changes, climate impacts and water resource availability. This study thus constitutes an essential starting point for the implementation of sustainable management strategies in the Mulongwe River watershed and beyond.

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