

Morphometry analysis of the Lurio River basin, Mozambique: a tool for sustainable water resource management

Isac Toaya Mussama^{1*}, Hélio Geraldo Ubisse², Raul Flávio Hilario^{1,3}, Gervásio Castro Morais Magaia⁴, Tânia Andicene⁵

1. Federal University of Tocantins (UFT), Brazil 2. Mutasa Higher Institute (ISMU), Mozambique 3. Higher Institute of Educational Sciences (ISCED), Mozambique 4. Zambeze University (UniZambeze), Mozambique 5. Catholic University of Mozambique (UCM), Mozambique

*Corresponding author.

E-mail address: isacmussama7@gmail.com

Abstract: Sustainable water resources management requires detailed knowledge of the physical characteristics of river basins, especially in regions where natural resources are facing increasing pressures. The Lurio River basin is one of the main water sources draining the provinces of Niassa, Cabo Delgado, Nampula and Zambézia, ecologically and economically important regions in Mozambique. Despite its significance, the basin lacks a comprehensive morphometric analysis to support appropriate conservation and management practices. Therefore, this study aims to analyze the morphometry of the Lurio River, contributing to discussions on the challenges of sustainable water resources management in the region. For this purpose, drainage density, form factor, compactness coefficient, maintenance coefficient, circularity index and elongation ratio were evaluated. SRTM and Sentinel-2 images were processed using ArcGIS software. The results show that flat terrain dominates the area (75.66%), with elevations ranging from 467 to 588 m (28.63%). The most representative soils are red Rhodic Ferralsols (ferrallitic soils) with medium texture (39.99%). In terms of land cover, pastures account for 71.55% of the area, followed by other vegetation (26.39%), dominated by sparse vegetation (43.69%) and very sparse vegetation (30.02%). Morphometric results reveal that the basin covers an area of 61,370.50 km², with a drainage density of 0.13 km/km², a compactness coefficient of 1.90 and an elongated shape, indicating low drainage capacity. These findings are essential for sustainable water resources management and territorial planning, providing technical support for public policies and interventions targeting environmental conservation and balanced regional development.

Key words: morphometry; water management; territorial planning

1 Introduction

Although approximately 77% of the Earth's surface is covered by water, the availability and quality of this resource vary greatly, limiting safe access to drinking water and productive activities in many regions worldwide (Tomas et al., 2021; Sjöstrand, 2023). River basins are fundamental units for understanding hydrological processes, as they represent natural areas where precipitation converges towards an outlet, regulating water and sediment transport (Christopher et al., 2010; Rastogi & Sharma, 2022; López-Ramos et al., 2022; Fischer, 2024). Physical characteristics of these basins, such as

geometric shape, drainage network extent, slope and volume, directly affect hydrological dynamics, with implications for water resource management and environmental risk mitigation (Zhang et al., 2024; Li et al., 2024).

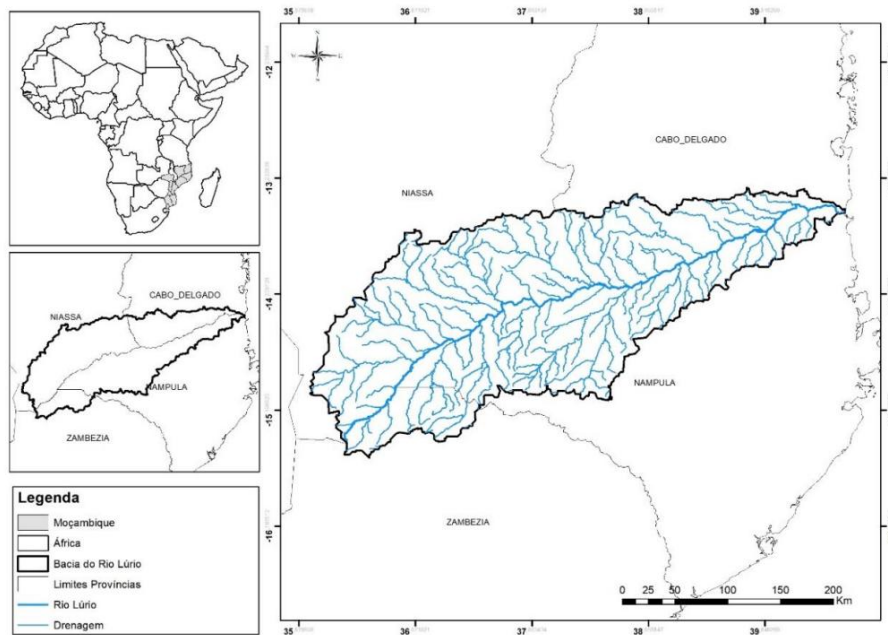
Recently, advances in Geographic Information Systems (GIS) and remote sensing techniques have expanded the capacity for spatial and temporal analysis of river basins, providing tools for detailed monitoring and hydrological modeling (Song et al., 2024; Li et al., 2024). Effective basin management contributes to reducing the impacts of erosion processes, floods and landslides, increasing the environmental and social resilience of affected regions (Meshram et al., 2018; Benzougagh et al., 2022; Wang & Xie, 2024). However, in highly vulnerable areas, particularly in sub-Saharan Africa, there remains a shortage of comprehensive morphometric studies capable of guiding sustainable interventions and the conservation of water ecosystems (Khadse et al., 2015; Meshram et al., 2018; Tang & Adesina, 2022).

In the Mozambican context, the Lúrio River basin, which covers the provinces of Niassa, Cabo Delgado, Nampula and Zambézia, plays a strategic role in regional environmental and socio-economic sustainability. Nevertheless, it faces challenges arising from inappropriate natural resource use, soil erosion and environmental degradation, threatening water security and the quality of life of local populations (Muchanga, 2016; Nhassengo et al., 2021; Martins et al., 2021). Therefore, this study aims to analyse the morphometry and physical characteristics of the basin, providing technical support for environmental and territorial planning to promote integrated and sustainable management of the natural resources of the Lúrio River.

2 Methodology

2.1 Physiographic characterization of the study area

The Lúrio River is located in northeastern Mozambique, within Cabo Delgado Province. It originates in the mountainous region at the centre of the province and flows northwards to empty into the Indian Ocean near Pemba city, the capital of Cabo Delgado Province. The Lúrio River basin has an approximate channel length of 695.82 km, extending from its source at Mount Malema, above 1,000 m altitude, to its mouth near the Lúrio Administrative Post. This basin represents the largest hydrological unit entirely within Mozambican territory, covering an estimated area of approximately 61,370.50 km² (Map 1). Furthermore, the Lúrio River has an important geospatial function, administratively delimiting Zambézia and Nampula Provinces to the south, as well as Niassa and Cabo Delgado Provinces to the north.



Map 1. Location of the Lúrio River in Mozambique (Source: Prepared by the authors (2025))

2.1.1 Geology

The Lúrio River basin lies within a geologically complex region, reflecting the tectonic and lithological diversity of northern Mozambique. The northern part of the country is mainly characterized by Proterozoic formations, whereas the south presents Phanerozoic formations (Vasconcelos, 2010). The study area comprises distinct tectonic blocks formed during the collisions that assembled the Gondwana supercontinent, namely the East, West and South Gondwana blocks, separated by major tectonic structures such as the Lúrio Tectonic Belt and the Sanângoè Shear Zone.

Rocks of the South Gondwana lithospheric block predominate within the basin, with records ranging from the Archean to the Neoproterozoic, including greenstone belts composed of basic to ultrabasic volcanoclastic rocks, metasediments and granitoids (GTK, 2006; Vasconcelos, 2010). Paleoproterozoic formations are associated with pericratonic marine environments and comprise metamorphic complexes consisting of gneisses, quartzites and calc-silicates, affected by multiple tectono-metamorphic events (GTK, 2008). The Phanerozoic sediments covering the coastal plain include the Karoo Supergroup and formations related to the East African Rift System, revealing geodynamic processes linked to Gondwana breakup and the emplacement of the Karoo Large Igneous Province (~190 Ma) (Vasconcelos & Jamal, 2010).

2.1.2 Soils

Soils within the Lúrio River basin reflect the local geomorphological and lithological diversity. Rhodic Ferralsols, red clay soils typical of plateau areas, are dominant; their colour ranges from red to orange and yellow depending on topography (Banze, 2016). Leached sandy soils such as Ferralic Arenosols and Haplic Arenosols also occur, especially on coastal dunes and inland sandy covers. Fluvisols with medium to heavy texture prevail in alluvial areas and are subject to periodic flooding. Hydromorphic soils vary from sandy to clayey and are found in depressions ("dambos"), classified as Gleysols and Phaeozems. Upper hillslopes and summits are dominated by red to yellow, well-drained clayey soils typical of higher-elevation areas (GTK, 2008; Banze, 2016).

2.1.3 Climate

The climate of the Lúrio River basin is classified as semi-arid to dry subhumid. The mean annual precipitation is approximately 1,029 mm, ranging from 800 to 1,200 mm across most of the region; locally, rainfall may exceed 1,500 mm, creating rainy subhumid microclimates. Annual potential evapotranspiration ranges from 1,300 to 1,500 mm, indicating a water deficit in some areas (Banze, 2016). Mean annual temperatures fluctuate between 20 °C and 25 °C, with peaks above 25 °C during the agricultural growing season, which directly affects the hydrological regime and productive potential of the basin.

2.1.4 Hydrography

The Lúrio River basin is part of the hydrographic system of northern Mozambique, characterized by rivers with a predominantly pluvial and intermittent regime. The watercourses originate in inland areas and drain towards the Indian Ocean, crossing varied topographic gradients from plateaus to coastal plains (Muchangos, 1999). The Lúrio River is the main watercourse of the basin, supplying local communities and supporting agricultural and fishing activities. The hydrological regime exhibits marked seasonal variations, which constrains the use of water resources and requires planning to guarantee the water security of the population.

2.1.5. Land use and vegetation cover

Land occupation in the Lúrio River basin is dominated by subsistence agriculture. Small family farms mainly grow crops such as banana, maize, sunflower, sesame, sweet potato and pumpkin. Larger areas are allocated to cashew, cotton and tobacco, while irrigated zones support vegetables and other cash crops (Bolfe et al., 2011). Natural vegetation cover is

markedly reduced near major transport routes where agriculture is intensive. In contrast, more remote areas contain dense deciduous forests, evergreen and open forests, together with herbaceous formations and lowland open forests. Soil texture is generally medium to heavy, coupled with moderate to good drainage, which shapes land-use patterns and native vegetation dynamics.

2.2. Economic activities

The Lúrio River basin exhibits sustained economic growth driven by diversified sectors including natural resources, agriculture, livestock farming, fisheries, mining and civil construction (Government of Nampula Province - GPN, 2015). The subsurface of Cabo Delgado is rich in a variety of minerals. The province is world-famous for its high-quality rubies, which are mined mainly in the Montepuez district. In addition to rubies, there are substantial deposits of graphite, gold, marble and heavy minerals (Chichango et al., 2022). Timber exploitation, although economically important, has also become a source of environmental concerns. The productive base is predominantly agricultural, with approximately 8% of the total area under cultivation. Food crops such as maize, rice, cassava, beans and vegetables stand out, alongside cash crops including cashew nuts, cotton, sunflower and tobacco (Banze, 2016).

The growth of the agricultural and livestock sector was the most remarkable, reaching 12.8% between 2013 and 2014, followed by fisheries (12.3%) and construction (11.6%), yielding an overall economic growth rate of 11.7% for the period (GPN, 2015). Livestock production expanded, with emphasis on cattle, pig and small ruminant rearing.

In the fisheries sector, total production reached 56,584 tonnes in 2014, with 99% coming from artisanal fishing. This output represents a 97.9% increase compared with the previous year, reflecting the socio-economic importance of the sector.

Mineral resources, including gold, phosphates, heavy minerals and gemstones, are mainly exploited through artisanal mining. Although mineral extraction is vital for local subsistence, it relies on rudimentary techniques, leading to water resource waste and environmental degradation.

Although the current water resource utilization accounts for less than 1% of the estimated available volume of 189 million m³ per year, the Lúrio River has high potential for sustainable development, with room for expansion in the agricultural, industrial and energy sectors (Nascimento, 2018).

2.3 Morphometric analysis

Vector files (shapefiles) of administrative boundaries provided by the National Center for Cartography and Remote Sensing (CENACARTA, 2016) were used. These served as the basis for delineating the study area and preparing the basin location map. For topographic analysis, Digital Elevation Models (DEM) from the Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 30 meters were employed, accessed via the TOPODATA platform (TOPODATA, 2023). These data were essential for deriving altimetric products such as contour lines, slope models and hypsometry.

Multispectral images from the Sentinel-2 satellite, provided by the European Space Agency (ESA), were used to assess land use and land cover, as well as for vegetation analysis by calculating the Normalized Difference Vegetation Index (NDVI). For this purpose, bands 4 (red) and 8 (near infrared), both with a spatial resolution of 10 m, were used, ensuring sufficient spectral accuracy for detecting vegetation patterns and phenological variations (ESA, 2023).

The extraction, classification and interpretation of spectral data were carried out using the Esri Landscape Monitoring System platform (Esri, 2022). It delivers periodic, corrected Sentinel-2 image mosaics optimized for thematic analysis of vegetation cover and land use. The data were processed and integrated into a geospatial database built within ArcGIS software, which enabled vector and raster manipulation, as well as the production of high-precision thematic maps.

The morphometric analysis of the basin was performed using parameters derived from the DEM, hydrographic

network vector files and basin boundaries, processed within the GIS environment. As shown in Table 1, the Field Calculator tool in ArcGIS® was used to compute metrics including area, perimeter, compactness index, form factor, drainage density and circularity index (Christofaletti, 1974; Chorley et al., 1985). These parameters are essential for understanding the hydrological behaviour of the basin and help identify priority areas for conservation and the sustainable use of natural resources.

Table 1. Morphometric characteristics of hydrographic basins

Index	Equation	Variables
Drainage Density (Dd)	$Dd=Lt/A$	Lt is the total length of the watercourse; A is the area of the hydrographic basin.
Form Factor (Kf)	$Kf=A/Lx^2$	A is the basin area (km ²); Lx is the length of the main river (km).
Compactness Coefficient (Kc)	$Kc=0.282P/\sqrt{A}$	Kc = compactness coefficient, dimensionless; P = basin perimeter (km); A = drainage area (km ²).
Maintenance Coefficient (Cm)	$Cm=(1/Dd) \cdot 100$	Cm = maintenance coefficient, m ² ·m ⁻¹
Circularity Index (Ic)	$Ic=A/Ac$	Ic = circularity index; Ac = area of a circle with the same perimeter as the basin (km ²).
Elongation Ratio (Re)	$Re=1.1284\sqrt{A}/Lx$	A is the basin area (km ²); Lx is the length of the main river (km).

Source: Villela & Mattos, 1975; Pallard et al., 2009; Nardini et al., 2013; Silva & Tonello, 2014; Melo Neto & Mello, 2015

The adopted methodology complies with established practices of environmental analysis and territorial planning supported by geotechnologies (Silva et al., 2023; Lopes et al., 2022), ensuring the reproducibility of the procedures and the reliability of the obtained results.

3 Literature review

The morphometry of hydrographic basins constitutes an essential tool for understanding the hydrological, geomorphological and environmental processes occurring in a given region. The systematic study of the physical characteristics of basins allows inferring the hydrodynamic behaviour of watercourses, susceptibility to extreme events such as floods, and the conditions of land use and land occupation.

According to Villela and Mattos (1975), morphometric parameters such as drainage density, form factor, circularity index and elongation ratio provide objective support for the classification and comparison of different basins. The authors highlight the importance of drainage density as an indicator of surface runoff capacity and the degree of relief dissection.

The morphometric approach has evolved over time, incorporating modern techniques and geotechnologies. Pallard et al. (2009) emphasize that morphometric parameters, when integrated with geographic information systems (GIS), deliver more accurate and spatially explicit analyses, which are essential for environmental planning and water resource management.

Studies such as that of Nardini et al. (2013) demonstrate the application of morphometric indices in identifying risk areas and delineating priority conservation zones. Similarly, Silva and Tonello (2014) argue that morphometry allows the inference of the basin's hydrological stability and, consequently, its resilience to climate change and anthropogenic activity.

Morphometric analysis is also discussed by Melo Neto and Mello (2015), who emphasize the importance of considering geological and pedological contexts when interpreting the indices. According to the authors, the variability of morphometric parameters is directly related to the physical and climatic characteristics of the study area.

More recently, the use of geotechnologies has become established as the methodological foundation for morphometric studies. Silva et al. (2023) and Lopes et al. (2022) point out that the use of digital tools and standardized methods ensures the reproducibility of analyses and improves the reliability of results. These practices are widely recognized as essential to support territorial planning and the sustainable management of water resources.

4 Results and discussion

In general, the basin has a total area of 61,370.50 km², bounded by a perimeter of 1,682.90 km. Its main channel extends for 695.82 km, while the total length of all channels amounts to 7,707.93 km. Morphometric analysis of the basin reveals fundamental hydrological characteristics for understanding its hydrodynamic behaviour and water availability. These variables are essential for territorial planning and management. According to Buffington & Montgomery (2021), basin morphometry is a direct indicator of its hydrological potential and its responses to extreme events such as floods and droughts.

One of the parameters analyzed was the drainage density (Dd), whose calculated value was 0.13 km/km², indicating a poorly developed hydrographic network. This value suggests low subdivision of the drainage network, generally associated with more permeable terrain and/or areas with a lower rate of concentrated surface precipitation. According to the criteria established by Villela and Mattos (1975) and updated by Santos et al. (2022), Dd values below 0.5 km/km² characterize basins with poor drainage or highly infiltrative soils, which is consistent with dry tropical regions or areas with dense vegetation cover.

The basin form factor (Ff), calculated at 0.13, indicates an extremely elongated morphology, which implies a longer concentration time, i.e., a greater interval between the start of a rainfall event and the peak river discharge. This characteristic reduces susceptibility to flash floods, as runoff is distributed over time. In addition, the compactness coefficient (Kc) was determined to be 1.90, suggesting that the basin deviates significantly from a circular shape, reinforcing its tendency toward slower hydrological responses (Júnior, 2022).

The index of circularity (Ic) was calculated as 0.27, a value that also confirms the elongated nature of the basin. As observed by Pereira et al. (2019), lower Ic values indicate greater elongation, which positively influences the rainwater absorption capacity and reduces the risk of flash floods.

Another relevant index is the maintenance coefficient (Cm), with a value of 7,961.99, representing the area required to sustain 1 km of watercourse. High Cm values, such as in this case, are generally associated with soils having high infiltration capacity or low surface flow density (Christofolletti, 1974; Junior & Andreoli, 2015).

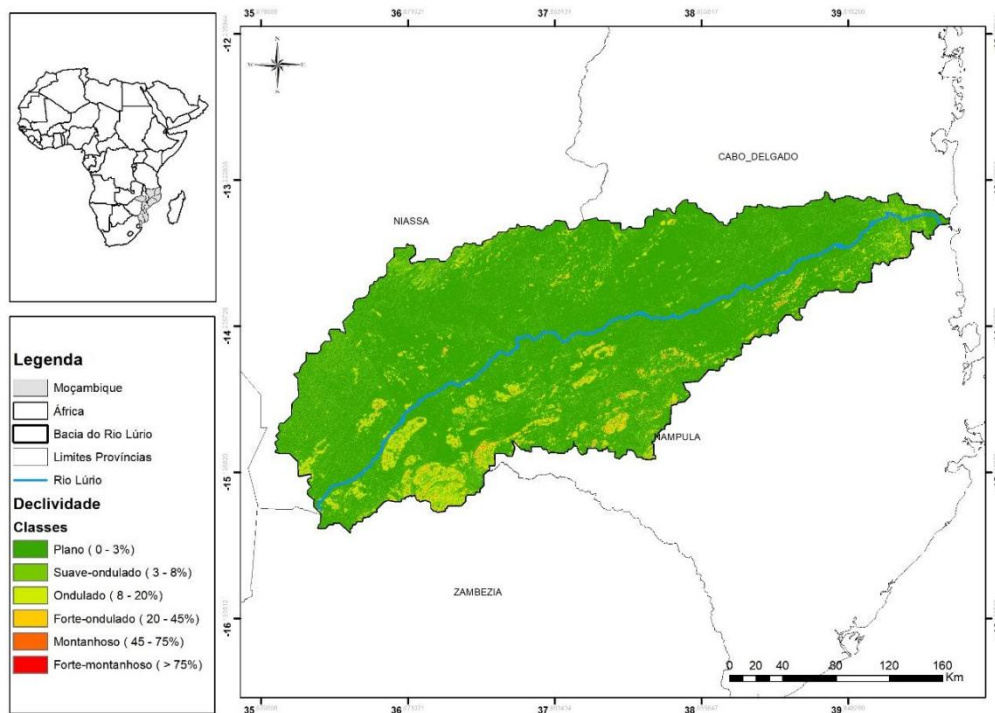
The elongation ratio (Re) was calculated as 0.40, reinforcing the basin's elongated shape, which is directly correlated with a lower potential for rapid response to extreme events. Finally, the ratio between the total basin length and its area (L/A) yielded 2.16, a typical value for basins of elongated form with longer hydrological response times and, therefore, a lower risk of severe flash floods.

Table 2. Physical characteristics of the Lúrio River Basin, Mozambique

Parameters and units	Results
Area (km ²)	61,370.50
Perimeter (km)	1,682.90
Main channel length (km)	695.82
Total length of channels (km)	7,707.93
Drainage density (km/km ²)	0.13
Form factor (Kf)	0.13
Compactness coefficient (Kc)	1.90
Maintenance coefficient (Cm)	7,961.99
Circularity index	0.27
Elongation ratio	0.40
Basin length-area ratio	2.16

Source: Prepared by the authors (2025)

75.66% of the basin area (46,413.78 km²) consists of flat terrain with slopes ranging from 0 to 3% (Table 3 and Map 2). Areas with gently undulating slopes (3–8%) account for 18.38%, corresponding to 11,273.41 km²; undulating terrain (8–20%) covers 4.25% (2,610.17 km²), while strongly undulating slopes (20–45%) represent 1.38% (849.04 km²). There are also mountainous areas with slopes between 45 and 75%, occupying 0.27% (165.45 km²), and terrain classified as steeply mountainous with slopes greater than 75%, which makes up only 0.06% (34.02 km²). The predominance of flat areas indicates low erosive potential and high agricultural suitability. However, steeper zones require conservation management to prevent environmental degradation and soil loss (Ross, 2012; Embrapa, 2021).



Map 2. Slope classes of the Lúrio River Basin, Mozambique (Source: Elaborated by the authors (2025))

Approximately 18.38% of the area corresponds to gently undulating terrain (slope of 3–8%), used for subsistence agriculture with cultivation of beans, cassava and maize. Nevertheless, these land uses require adequate erosion control and drainage management strategies to maintain productivity and soil conservation (Ross, 2012).

Terrain with slopes greater than 8% occupies only 5.9% of the basin and is more susceptible to erosion and degradation. Nevertheless, these areas remain important for the conservation of native vegetation and sensitive ecosystems. Mountainous areas (slope >45%) account for merely 0.33%, which greatly restricts human settlement and productive expansion.

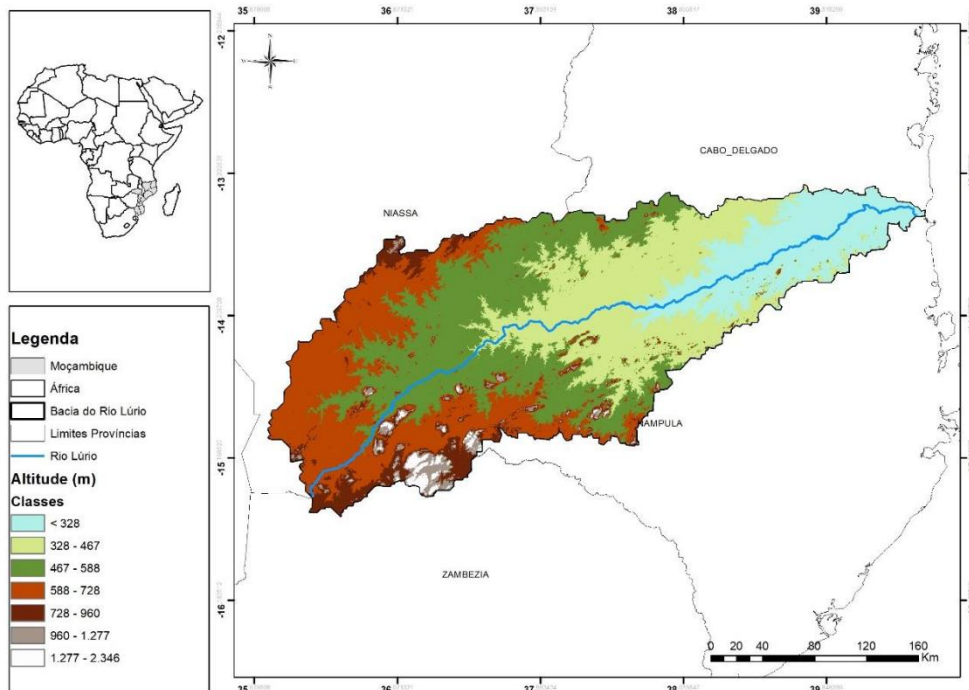
In general, the basin relief is largely favourable for agricultural use and the installation of rural infrastructure, provided that sustainable management practices are adopted, especially in steep-slope areas (Santos et al., 2021).

Table 3. Area occupied by slope classes of the Lúrio River Basin

Slope class	Occupied area	
	(km ²)	%
Flat (0 - 3%)	46,413.78	75.66%
Gently undulating	11,273.41	18.38%
Undulating (8 - 20%)	2,610.17	4.25%
Strongly undulating (20 - 45%)	849.04	1.38%
Mountainous (45 - 75%)	165.45	0.27%
Steeply mountainous (> 75%)	34.02	0.06%
Total	61,345.86	100.00%

Source: Elaborated by the authors (2025)

The Lúrio River Basin is dominated by moderate elevations (Map 3 and Table 4). The elevation band of 467–588 m accounts for 28.63% of the basin area (17,564.37 km²), representing the dominant altitudinal range (Map 3). Elevations between 328 and 467 m occupy 24.46% of the basin (15,006.63 km²), while terrain ranging from 588 to 728 m comprises 23.50% (14,416.90 km²). The highest areas, with elevations of 728–960 m, are less representative, covering only 5.57% of the total surface area (3,414.05 km²).



Map 3. Elevation classes of the Lúrio River Basin (Source: Elaborated by the authors (2025))

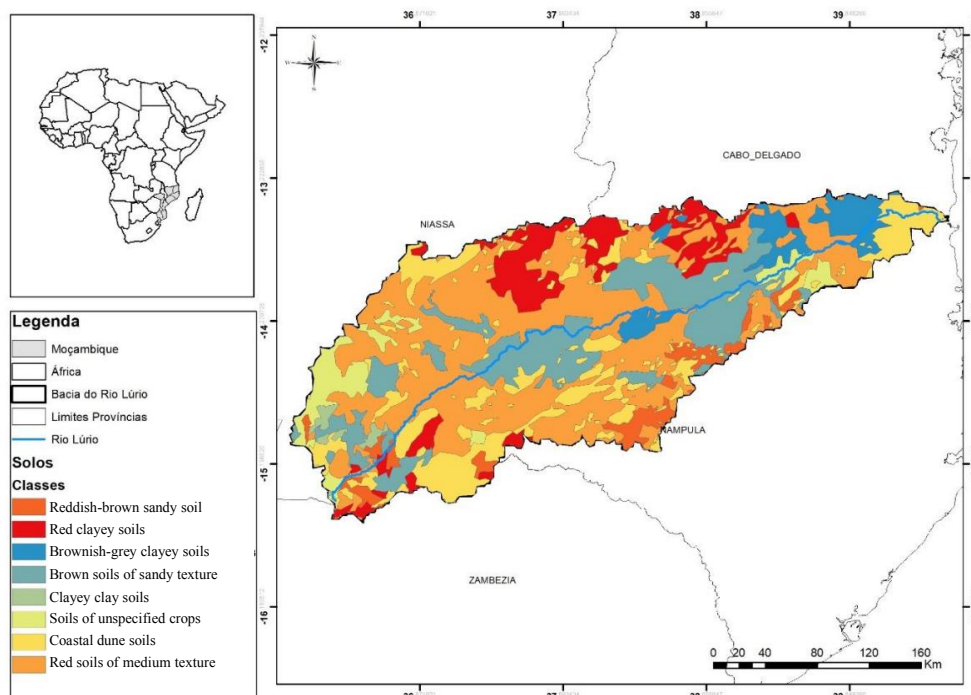
This altitudinal distribution reflects a gently undulating to moderate relief, which favours agricultural occupation and surface runoff. It is also determinant for the hydrological behaviour and erosive potential of the basin (Werneck, 2023).

Table 4. Area occupied by elevation classes of the Lúrio River Basin

Elevation	Occupied area (km ²)	%
< 328	9,114.68	14.86%
328 - 467	15,006.63	24.46%
467 - 588	17,564.37	28.63%
588 - 728	14,416.90	23.50%
728 - 960	3,414.05	5.57%
960 - 1,277	1,238.85	2.02%
1,277 - 2,346	590.37	0.96
Total	61,345.86	100.00%

Source: Elaborated by the authors (2025)

The Lúrio River hydrographic basin exhibits considerable diversity in soil types. Their spatial distribution exerts a direct influence on land use, agricultural productivity, environmental management, and conservation of natural resources in the region. Soil characterization was carried out based on detailed pedological surveys, allowing identification of the main edaphic groups and their territorial extent (Table 1).



Map 4. Soil class maps of the Lúrio River basin (Source: Elaborated by the authors (2025))

Soil classes and their corresponding areas were obtained for the Lúrio River hydrographic basin (Table 5). The Lúrio River Basin is dominated by red soils of medium texture (Argissolos/Latossolos), which occupy approximately 40% of the total area (24,533 km²). These soils are characterized by good depth and moderate water retention capacity, favouring sustainable agriculture (Cunha, 22; Santos, 2024). Sandy soils (Neossolos Quartzarênicos), covering around 34% of the basin, have low fertility and require careful management to avoid degradation (Lopes et al., 2017).

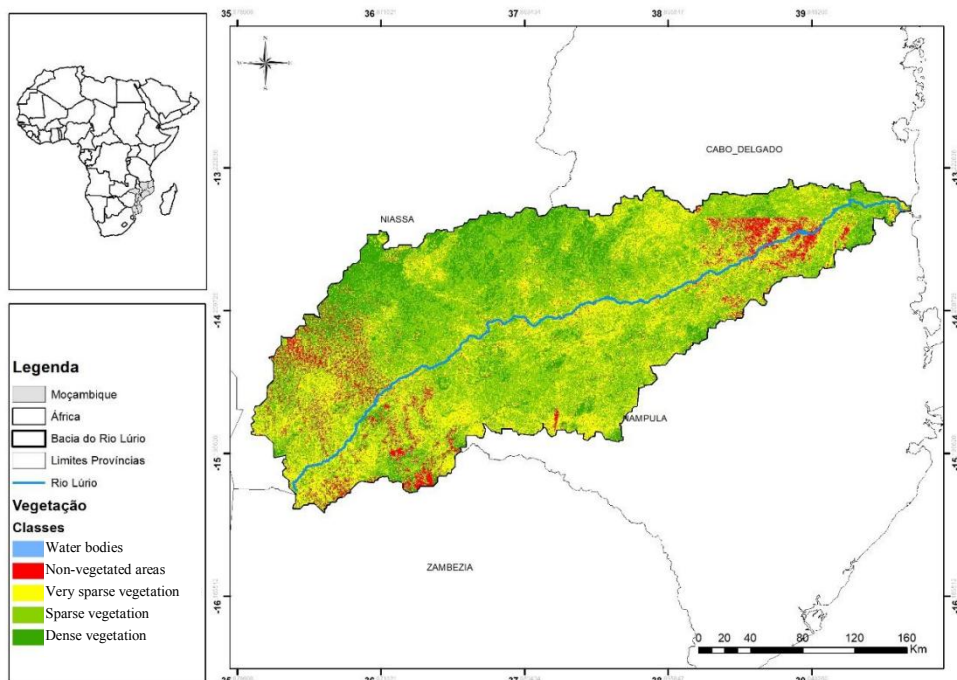
Other important soils include clayey Latossolos/Nitossolos (10%) and Cambissolos (5%), with higher agricultural potential due to greater fertility (Madari et al., 2009). Small areas are covered by alluvial and regolithic soils, which are essential for local hydrological dynamics. This pedological diversity demands site-specific practices to ensure the sustainable use of natural resources in the region (Francisco et al., 2022).

Table 5. Area occupied by soil classes of the Lúrio River Basin

Soil		Occupied area	
		Area (km ²)	%
Reddish-brown sandy soils	Argissolo/Latossolo	2,617.75	4.27%
Red clayey soils	Latossolo/Nitossolo	6,141.50	10.01%
Greyish-brown clayey soils	Cambissolo Háplico	3,312.82	5.40%
Brown sandy-textured soils	Neossolo Quartzarênico	10,943.29	17.84%
Clayey alluvial soils	Gleissolo Háplico	507.21	0.83%
Undifferentiated colluvial soils	Neossolo Regolítico	3,153.06	5.14%
Coastal dune soils	Neossolo Quartzarênico	10,137.61	16.53%
Medium-textured red soils	Argissolo/ Latossolo	24,532.62	39.99%
Total		61,345.86	100.00%

Source: Elaborated by the authors (2025)

According to Map 5 and Table 5, areas devoid of vegetation total 3,920.03 km², representing 6.39% of the total area. Sparse vegetation is divided into two classes: very scattered flora, covering 18,414.26 km² (30.02%), and scattered flora, occupying 26,804.27 km² (43.69%). Regions with dense vegetation cover 11,751.34 km², corresponding to 19.16% of the total area. Water bodies within the basin occupy 455.95 km², equivalent to 0.74% of the total area. This spatial distribution of vegetation cover is essential for analyzing ecological and hydrological processes as well as land use management in the region.



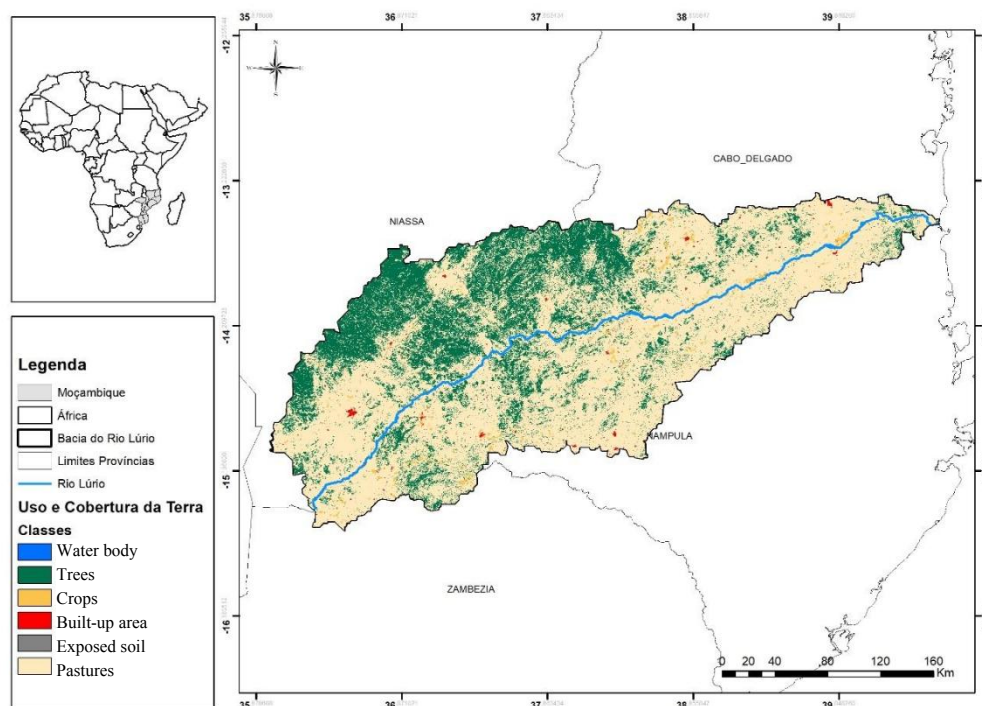
Map 5. Vegetation classes map of the Lúrio River hydrographic basin (Source: Elaborated by the authors (2025))

Table 6. Area occupied by vegetation classes in the Lúrio River Basin

Vegetation type	Occupied Area	%
	(km ²)	
Water bodies	455.95	0.74%
Non-vegetated areas	3,920.03	6.39%
Very sparse vegetation	18,414.26	30.02%
Sparse vegetation	26,804.27	43.69%
Dense vegetation	11,751.34	19.16%
Total	61,345.86	100.00%

Source: Prepared by the authors (2025)

Analysis of land use and land occupation in the Lúrio River Basin, based on Map 6 and Table 7, shows that most of the area is covered by pastures, accounting for 71.55% (43 894.35 km²) of the total. Tree-covered areas account for 26.39% of the area, equivalent to 16 190.05 km². Areas for agricultural crops represent only 1.47% (899.41 km²). Urbanized areas occupy 0.36% (222.11 km²), water bodies account for 0.13% (81.79 km²), and exposed land surfaces constitute the smallest proportion, at 0.09% (58.14 km²) of the basin.



Map 6. Land-use and land-occupation classes of the Lúrio River Hydrographic
(Basin Source: Prepared by the authors (2025))

Table 7. Area occupied by land- use and land- occupation classes in the Lúrio River Basin

Land use and land cover	Occupied Area (km ²)	%
Water body	81.79	0.13%
Tree cover	16,190.05	26.39%
Cropland	899.41	1.47%
Built-up area	222.11	0.36%
Exposed land	58.14	0.09%
Pastures	43,894.35	71.55%
Total	61,345.86	100.00%

Source: Prepared by the authors (2025)

5 Conclusion

Data obtained for the Lúrio River hydrographic basin indicate that most of the area consists of flat lands with soils suitable for agriculture, which reveals a substantial potential for sustainable agricultural development in the region. This information can guide decisions regarding agricultural expansion and the implementation of irrigation systems, prioritizing low-slope areas to minimize environmental risks.

Low drainage density and the elongated shape of the basin suggest a lower risk of severe flooding, which allows rural infrastructure to be planned with less concern about extreme hydrological events. This evidence should be considered in territorial planning and risk management. Considering the diversity of soil types and vegetation distribution, the adoption of agricultural practices that account for the conservation of soil and native vegetation is recommended, especially in the steeper and more sensitive areas, to avoid erosion and environmental degradation.

The data also point to the need for continuous monitoring of land use and vegetation cover using remote-sensing techniques, to ensure that economic activities are compatible with the basin's environmental sustainability. As new approaches, it is suggested to develop agro-ecological zoning and implement integrated natural-resource management programmes, which shall use the information obtained to promote rational land use, water conservation and improvement of agricultural productivity.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] BANZE, A. G. Caracterização geoquímica de sedimentos e águas da bacia hidrográfica do Rio Monapo (Nampula, Moçambique). 2016. Dissertação (Mestrado em Engenharia Geológica)—Universidade de Aveiro, Departamento de Geociências, Portugal, 2016. Disponível em: <https://files.core.ac.uk/download/pdf/78556953.pdf>. Acesso em: 28 nov. 2024.
- [2] BARBOSA JUNIOR, A. R. Elementos de hidrologia aplicada. São Paulo: Editora Blucher, 2022.
- [3] BENZOUGAGH, B. et al. Identification of critical watershed at risk of soil erosion using morphometric and geographic information system analysis. Applied Water Science, Heidelberg, v. 12, n. 8, p. 1-20, 2022. Disponível em: <https://link.springer.com/article/10.1007/s13201-021-01532-z>. Acesso em: 03 dez. 2024.
- [4] BOLFE, E. L. et al. Base de dados geográficos do "Corredor de Nacala". In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 15., 2011, Curitiba. Anais... Curitiba: INPE, 2011. Disponível em: <https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/902393/1/BolfeSBSR.pdf>. Acesso em: 07 dez. 2024.

- [5] BUFFINGTON, J. M.; MONTGOMERY, D. R. Geomorphic classification of rivers: an updated review. Academic Press, New York, 2021, p. 1143-1190.
- Disponível em: <https://research.fs.usda.gov/treesearch/63526>. Acesso em: 04 jan. 2025.
- [6] CENTRO NACIONAL DE CARTOGRAFIA E TELEDETECÇÃO - CENACARTA. Base de Dados Cartográfica Nacional. Maputo, 2016.
- [7] CHICHANGO, D. B. et al. Caracterização e sustentabilidade dos recursos naturais da província de Cabo Delgado. Revista Ibero-Americana de Humanidades, Ciências e Educação, São Paulo, v. 8, n. 8, p. 32- 49, 2022. Disponível em: <https://periodicorease.pro.br/rease/article/view/6558>. Acesso em: 02 dez. 2024.
- [8] CHORLEY, R. J.; SCHUMM, S. A. ; SUGDEN. Geomorphology. Londres: [S.n.], 1984.
- [9] CRISTOFOLETTI, A. Geomorfologia. São Paulo: Ed. Blucher, 1974.
- [10] CHRISTOPHER, O.; ADETIMIRIN, O. I. ABODERIN, O. Hydrological analysis of onitsha north east drainage Basin using geoinformatic techniques. World Applied Sciences Journal, Faisalabad, v. 11, n. 10, p. 1297-1302, 2010. Disponível em: https://www.researchgate.net/publication/267848442_Hydrological_Analysis_of_Onitsha_North_East_Drainage_Basin_Using_Geoinformatic_Techniques. Acesso em: 21 fev. 2025.
- [11] CUNHA, R. R. Inter-relações dos atributos físico-hídricos e estruturais do solo em classes e aptidão agrícola das terras no Semiárido Potiguar. 2022. 112 f. Tese (Doutorado em Manejo de Solo e Água) — Universidade Federal Rural do Semi-Árido, Mossoró, 2022.
- Disponível em: <https://repositorio.ufersa.edu.br/items/acdedd3e-3356-49c1-85c0-ebfa03f73333/full>. Acesso em: 15 abr. 2025.
- [12] EUROPEAN SPACE AGENCY (ESA). Copernicus Sentinel-2 User Guide. 2023.
- Disponível em: <https://sentinel.esa.int>. Acesso em: 13 mar. 2025.
- [13] LOPES, J. R. A. E et al. Caracterização morfométrica da microbacia hidrográfica do Açude Grande no semiárido do Rio Grande do Norte. Revista Brasileira de Geografia Física, Recife, v. 15, n. 01, p. 429-442, 2022.
- [14] FISCHER, A. Geomorphology, sedimentology, and depositional chronology of the christmas dunes and their implications for proglacial lake drainage in the lake superior basin. 2024. Dissertação (Mestrado) — Minnesota State University, Mankato, 2024. Disponível em: <https://cornerstone.lib.mnsu.edu/etds/1447/>. Acesso em: 07 fev. 2025.
- [15] FRANCISCO, P. R. M et al. Potencial de incerteza das terras da região do médio curso do Rio Paraíba utilizando geotecnologias, 2022. Disponível em: <https://dspace.sti.ufcg.edu.br/jspui/bitstream/riufcg/37428/1/POTENCIAL%20DE%20IRRIGA%C3%87%C3%83O%20DAS%20TERRAS%20DA%20REGI%C3%83O%20DO%20M%C3%89DIO%20CURSO%20DO%20RIO%20PARA%C3%84%20E2%80%93%20AR%20TIGO%20DE%20PERI%C3%93DICO%20CDSA%202022.pdf>. Acesso em: 12 dez. 2024.
- [16] NAMPULA. GOVERNO DA PROVÍNCIA (GPN). Plano Económico e Social e Orçamento do Estado Provincial (PESOP) para o ano de 2014. Nampula, 2015. Disponível em: <https://www.mef.gov.mz/index.php/todas-publicacoes/instrumentos-de-gestao-economica-e-social/plano-economico-e-social-e-orcamento-do-estado-pesoe/pesoe-2023/mapas-integrantes-da-lei-pesoe-ar/mapa-f-provincia/1727-mapa-i-03-nampula/file?force-download=1>. Acesso em: 10 jan. 2025.
- [17] JÚNIOR, J. J.; ANDREOLI, C. V. Uso de dados climáticos e hidrológicos como subsídio na determinação do regime de fluxo de canais de drenagem. Revista Brasileira de Geomorfologia, São Paulo, v. 1, n. 1, 2015. Disponível em:

<https://rbgeomorfologia.org.br/rbg/article/view/422>. Acesso em: 15 dez. 2024.

[18] KHADSE, G. K. ; VIJAY, R.; LABHASETWAR, P. K. Priorização de bacias hidrográficas com base na erosão do solo usando sensoriamento remoto e SIG. *Monitoramento e Avaliação Ambiental*, Brasília, v. 187, p. 1-11, 2015.

[19] LI, S. et al. Variação da vazão sob condições climáticas com base em um modelo de ferramenta de avaliação de solo e água: um estudo de caso da Bacia do Rio Bailong. *Sustainability*, Basel, v. 16, n. 10, p. 3901, 2024.

[20] LOPES, AS; GUILHERME, L. R. G Fertilidade do solo e produtividade agrícola. In: *Fertilidade do solo*. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2007. p. 1-64.

[21] LÓPEZ-RAMOS, A. et al. Assessment of morphometric parameters as the basis for hydrological inferences in water resource management: a case study from the sinú river basin in Colombia. *ISPRS International Journal of Geo-Information*, Basel, v. 11, n. 9, p. 459, 2022. DOI:10.3390/ijgi11090459. Disponível em:

<https://www.semanticscholar.org/paper/Assessment-of-Morphometric-Parameters-as-the-Basis-L%C3%B3pez-Ramos-Medrano-Barboza/08b77f44f344baac7c70fbab89f39cb181a1de12>. Acesso em: 14 jan. 2025.

[22] MADARI, B. E. et al. Matéria orgânica dos solos antrópicos da Amazônia (Terra Preta de Índio): suas características e papel na sustentabilidade da fertilidade do solo. In: TEIXEIRA, W. G. et al. *As Terras Pretas de Índio da Amazônia: sua caracterização e uso deste conhecimento na criação de novas áreas*. Manaus: Embrapa Amazônia Ocidental, 2009. p. 172-189.

[23] MARTINS, A. P.; BATISTA, D. F.; CABRAL, J. B. P. Análise fisiográfica da bacia do rio Monapo—provincia de Nampula—Moçambique. *Geografia*, Niterói, v. 50, 2021. Disponível em:

https://www.researchgate.net/publication/350533734_ANALISE_FISIOGRAFICA_DA_BACIA_DO_RIO_MONAPO_-_PROVINCIA_DE_NAMPULA_-_MOCAMBIQUE. Acesso em: 02 mar. 2025.

[24] MELO NETO, J. ; MELLO, C. R. de. Levantamento das propriedades morfométricas da bacia hidrográfica do ribeirão vermelho com o uso de geoprocessamento. *Global Science & Technology*, Rio Verde, v. 8, n. 2, 2015.

[25] MESHRAM, S. G. ; POWAR, P. L.; MESHRAM, C. Comparison of cubic, quadratic, and quintic splines for soil erosion modeling. *Applied Water Science*, Heidelberg, v.8, n.173, p.1-7, 2018.

Disponível em: <https://link.springer.com/article/10.1007/s13201-018-0807-6>. Acesso em: 05 fev. 2025.

[26] MUCHANGA, E. Assessment of the impact of landuse changes on the water quality of Incomati River, Southern Mozambique. 2016. Disponível em: <https://ir.uz.ac.zw/xmlui/handle/10646/3399>. Acesso em: 09 fev. 2025.

[27] MUCANGOS, A. dos. Moçambique, paisagens e regiões naturais. 1999.

Disponível em: <https://biblioteca.uniscied.edu.mz/handle/123456789/1534>. Acesso em: 13 abr. 2025.

[28] NARDINI, R. C. et al. Análise morfométrica e simulação das áreas de preservação permanente de uma microbacia hidrográfica. *Irriga*, Viçosa, v. 18, n. 4, p. 687-699, 2013.

[29] NASCIMENTO, A. B. F. C do. Simulação da exploração de uma albufeira de armazenamento para fins múltiplos e em cascata com um aproveitamento hidroelétrico a fio de água puro: caso de estudo da bacia hidrográfica do rio Lúrio em Moçambique, 2018. Dissertação (Mestrado em Engenharia Civil) — Técnico Lisboa, 2018. Disponível em:

<https://fenix.tecnico.ulisboa.pt/cursos/mec/dissertacao/1972678479054546>. Acesso em: 18 jan. 2025.

[30] NHASSENGO, O.S. Z; SOMURA, H.; WOLFE III, J. Environmental flow sustainability in the Lower Limpopo River Basin, Mozambique. *Journal of Hydrology: Regional Studies*, Amsterdam, v.36, p.100843, 2021.

DOI:<https://doi.org/10.1016/j.ejrh.2021.100843>.

Disponível em: <https://www.sciencedirect.com/science/article/pii/S2214581821000720>. Acesso em: 24 abr. 2025.

[31] PALLARD, B.; CASTELLARIN, A.; MONTANARI, A. A look at the links between drainage density and flood

statistics. Hydrology and Earth System Sciences, Katlenburg- Lindau v. 13, n. 7, p. 1019-1029, 2009.

[32] PEKKALA, Y.; LEHTO, T.; MÄKITIE, H. GTK consortium geological surveys in Mozambique 2002-2007. Geological Survey of Finland, Finland, v.48, 2008.

Disponível em: <https://search.library.wisc.edu/catalog/9910061940102121>. Acesso em: 05 abr. 2025.

[33] PEREIRA, J. D. S et al. Geoprocessamento como ferramenta de caracterização morfométrica da bacia hidrográfica do rio Parauapebas, PA. Revista Geonorte, Manaus, v.34, n.10, p.168-182, 2019. DOI:10.21170/geonorte.2019.V.10.N.34.168.182.

Disponível em:

https://www.researchgate.net/publication/334287548_GEOPROCESSAMENTO_COMO_FERRAMENTA_DE_CARACTERIZACAO_MORFOMETRICA_DA_BACIA_HIDROGRAFICA_DO_RIO_PARAUAPEBAS_PA. Acesso em: 16 jan. 2025.

[34] RASTOGI, R. A.; SHARMA, T. Análise quantitativa das características da bacia de drenagem. [S.l.; s.n.]: 2022.

[35] ROSS, J. L. S. Landforms and environmental planning: potentialities and fragilities. Revista do Departamento de Geografia, São Paulo, 2012. Disponível em: <https://repositorio.usp.br/item/002395561>. Acesso em: 16 jan. 2025.

[36] SANTOS, A. P. D. Integração de parâmetros ambientais e machine learning na modelagem do solo para agricultura sustentável. [S.l.; s.n.]: 2024.

[37] SANTOS, H. et al. Sistema Brasileiro de Classificação de Solos. Brasília, DF: Ministério da Agricultura, Pecuária e Abastecimento; Embrapa Solos, 2021.

[38] SILVA, J. L.; TONELLO, K. C. Morfometria da bacia hidrográfica do Ribeirão dos Pinheirinhos, Brotas-SP. Irriga, Viçosa, v. 19, n. 1, p. 103-114, 2014.

[39] SILVA ARAÚJO, J. W. et al. Características fisiográficas de sub-bacias do Alto Teles Pires por meio de diferentes modelos digitais de elevação. Nativa, Florianópolis, v. 12, n. 2, 2023.

[40] SJÖSTRAND, K. Water for sustainable development. Nature Water, London, v.1, n.7, p.568-572, jul. 2023. DOI:10.1038/s44221-023-00108-2. Disponível em:

https://www.researchgate.net/publication/372266785_Water_for_sustainable_development. Acesso em: 20 dez. 2024.

[41] SONG, Q. et al. Assessing groundwater artificial recharge suitability in the Mi River basin using GIS, RS, and FAHP: a comprehensive analysis with seasonal variations. Applied Water Science, Heidelberg, v.15, n.39, p.1-21, 2025. Disponível: <https://link.springer.com/article/10.1007/s13201-025-02362-z>. Acesso em: 18 mai. 2025.

[42] TANG, X.; ADESINA, J. A Integrated watershed management framework and groundwater resources in Africa - a review of west Africa sub-region. Water, Basel, v.14, n.3, p.288, 2022.

Disponível em: <https://www.mdpi.com/2073-4441/14/3/288>. Acesso em: 18 mai. 2025.

[43] TOMAS, W. M. et al. Challenges in the conservation and management of legal reserve areas in Brazilian grassland and savanna ecosystems in the face of global climate change. Pesquisa Agropecuária Brasileira, Brasília, v.59, 2024. DOI: 10.1590/S1678-3921.pab2024.v59.03491p. Disponível em:

<https://www.scielo.br/j/pab/a/xLMdy99ykqWTw5BTD8wg3tm/?format=pdf&lang=pt>. Acesso em: 17 abr. 2025.

[44] TOPODATA. Banco de dados de Modelos Digitais de Elevação – Versão atualizada. Instituto Nacional de Pesquisas Espaciais (INPE), 2023.

Disponível em: <https://portal.opentopography.org/raster?opentopoID=OTSDEM.032021.4326.3>. Acesso em: 17 abr. 2025.

[45] VASCONCELOS, L.; JAMAL, D. A nova geologia de Moçambique. In: CONGRESSO DE GEOQUÍMICA

DOS PAÍSES DE LÍNGUA PORTUGUESA, 10., 2010, Porto, Portugal. Resumo dos trabalhos apresentados [...], Porto, Portugal: Universidade do Porto, 2010. p. 53-66.

[46] VILLELA, S.M.; MATTOS, A. Hidrologia aplicada. São Paulo: McGraw-Hill do Brasil, 1975.

[47] WANG, X. W.; XIE, H. A review on applications of remote sensing and geographic information systems (GIS) in water resources and flood risk management. *Water*, Basileia, Suíça, v.10, n.5, 2018.

DOI:<https://doi.org/10.3390/w10050608>. Disponível em: <https://www.mdpi.com/2073-4441/10/5/608>. Acesso em: 08 jan. 2025.

[48] WERNECK, P. R Utilização de geotecnologia para avaliação da piscicultura na sub-bacia hidrográfica do Arroio Guaçu, na bacia hidrográfica do Paraná 3, região oeste do Paraná . 2023. 46 f. Dissertação (Mestrado em Recursos Pesqueiros e Engenharia de Pesca)—Universidade Estadual do Oeste do Paraná, Toledo, 2023. Disponível em: <https://tede.unioeste.br/handle/tede/7015>. Acesso em: 02 abr. 2025.

[49] ZHANG, N. et al. Quantification and analysis study for the morphological characteristics of urban waterbodies: evidences from 42 cases in China. *Ecological Indicators*, Amsterdam, v.166, p.112458, sept. 2024. DOI:<https://doi.org/10.1016/j.ecolond.2024.112458>.

Disponível em: <https://www.sciencedirect.com/science/article/pii/S1470160X24009154>. Acesso em: 11 mai. 2025.