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Morphometric Characterization of the Lova River Sub-basin in the Perimeter of the Concession of the Catoca Mining Society with Geotechnology for the Definition of Environmental Indicators

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Abstract: The present study of "Morphometric Characterization of the Lova River Sub-basin in the Perimeter of the Concession of the Sociedade Mineira de Catoca with Geotechnology for the Definition of Environmental Indicators", aims to determine the morphometric aspects of the Lova River sub-basin, located in the perimeter of the concession of Sociedade Mineira de Catoca, Lda. From the digital modeling of conditioned hydrological elevation, using the ArcMap/ArcGIS 10.8 software, data were generated that enable the delimitation of the basin and the analysis of critical variables. These morphometric parameters, such as drainage density and slope, serve as essential tools for the definition of environmental indicators and the sustainable planning of mining operations and environmental recovery. The approach integrates remote sensing techniques and geographic information systems, providing a comprehensive view of the hydrological and environmental conditions of the area. The results highlight that the sub-basin has distinct morphometric characteristics, such as a total area of 162 km² and predominantly smooth relief, with significant implications for runoff and erosion dynamics. Parameters such as concentration time and drainage density reveal a moderate hydrological response, being useful to guide local environmental management. The analysis highlights the importance of using geotechnologies in the management of natural resources, contributing to the development of strategies adapted to the particularities of the sub-basin, with the potential to promote sustainable practices and minimize environmental risks.

Keywords: *Morphometric Analysis; Environmental Indicators; Geotechnologies Applied to Environmental Management, Sociedade Mineira De Catoca, Lda.*

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I. INTRODUCTION

Watersheds are fundamental for the sustainable management of natural resources, as they serve as strategic territorial units in integrated environmental planning. Their importance lies in reconciling multiple water uses, ensuring both its quality and quantity. Geomorphological characteristics, such as relief, area, geology, drainage network, soil, and vegetation cover, play an essential role in determining the hydrological behavior of watersheds. These variables influence key processes such as infiltration, surface runoff, and evapotranspiration, making their detailed analysis indispensable for mitigating environmental impacts and promoting sustainable management.

In this context, morphometric characterization stands out as an essential methodology for quantitatively assessing watersheds, using parameters such as drainage density, slope, watercourse length, compactness coefficient, form factor, circularity index, etc. This study focuses on the Lova River sub-basin, located within the concession perimeter of Sociedade Mineira de Catoca, Lda., in Angola. Through geotechnologies, including digital elevation modeling, remote sensing, and geographic information systems, the region's hydrological characteristics are analyzed. These data help identify areas vulnerable to issues such as erosion and contamination, as well as provide a basis for sustainable exploration practices.

The main objective of this study is to generate environmental indicators based on the morphometric

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characterization of the Lova River sub-basin, contributing to the integrated management of water resources and the mitigation of mining-related impacts. The use of advanced technologies enables a detailed understanding of environmental processes, guiding strategies that promote ecological recovery and water resource conservation. Thus, this study aims to foster sustainable mining practices while ensuring environmental preservation and ecological balance in the region.

II. STUDY AREA CHARACTERIZATION

Sociedade Mineira de Catoca is a company dedicated to the prospecting, exploration, processing, and commercialization of diamonds, established at the initiative of the Angolan government to exploit the first kimberlite under mixed capital and Angolan jurisdiction.

Catoca's corporate structure consists of Endiama EP, which represents the Angolan state and holds 59% of the shares, and Alrosa, a Russian publicly traded company, with a 41% stake. Operating under a mining exploration title, Catoca has a concession area of 357 km². This area includes a residential village, industrial infrastructure, and various support facilities for the exploration process, forming an integrated structure for its activities in the diamond sector.

➢ *Geographical Location*

The micro-basin is located within the concession perimeter of Sociedade Mineira de Catoca, Lda., situated in the northeast of the Republic of Angola, in the northwestern region of Lunda-Sul province. Geographically, it is near the city of Saurimo, approximately 35 km away, and about 1,000 km from Luanda, the country's capital

The concession territory is mapped on topographic sheet 121-SG34, at a 1:1,000,000 scale, according to the Angolan state’s topographic register. This area is strategically located on the borders of Lunda-Norte and Lunda-Sul provinces, in a region of economic and environmental significance for the mining sector.

Figu 1 Geographical Location of the Micro-basin in the Catoca Mine. (authors).

➢ *Access Roads*

Access to the region can be made by air or land. By air, large aircraft land at Saurimo Airport, while smaller planes can land at the airport located at the Catoca mine. By land, access is provided by the national highways EN180, which connects Saurimo to Dundo in Lunda Norte, and EN230, which links Malanje to Saurimo in Lunda Sul.

The study site is accessible via a main paved road built by Sociedade Mineira de Catoca, branching off from EN180 at the Muacumbi neighborhood. Within the residential village, several secondary roads are also paved, while roads in production areas have been leveled. All these roads undergo regular maintenance, including water spraying to reduce dust emissions, ensuring better traffic conditions and safety.

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Fig 2 Disembarkation of Workers at the Airfield of Sociedade Mineira de Catoca Facilities (Authors).

➢ *Hydrography*

The region's hydrographic network is oriented northward, draining its waters into the Zaire River through the Kassai River, one of its largest tributaries. The Kassai River is fed by numerous sub-tributaries that cross the region from south to north. Its main tributaries, from west to east, include the Kuango River, Kuilo River, Luangue River, Luxico/Luele River, Lovua River, Chikapa River, Luachimo River, Chihumbe River, and Luembe River.

The hydrography within Catoca's concession area, located in Lunda Sul province, Angola, is part of the Congo River hydrographic system, with the Chicapa River as its main watercourse. The watershed covers an area of 161.64 km² and is subdivided into eight sub-basins, ranging in size from 3.34 km² to 42.1 km². The third-order Chicapa River receives contributions from a network of first- and second-order tributaries, collecting and directing runoff toward the Kassai River, which lies outside the concession boundaries.

The Lova River micro-basin is composed of several tributaries that play essential hydrological roles, influencing surface flow dynamics and maintaining the region's environmental quality.

- The Catoca River, with its clear waters and steady flow, is crucial for stabilizing Lova River levels during the dry season.
- The Luite River, with a high water contribution capacity, particularly during the rainy season, increases flow intensity and sediment transport in the Lova River.
- The Lupuge River, with its densely vegetated banks, serves as a natural filtration system, reducing sediment loads and improving water quality before reaching the Lova River, particularly in sedimentation zones associated with the tailings basin.
- The Camitongo River, with its meandering course and multiple springs, ensures continuous water input, stabilizing runoff regimes.
- The Canguenge River exhibits variable hydrological flow, adding to the micro-basin's hydrodynamic complexity and significantly influencing sediment transport and flow patterns.
- The Calputa River, characterized by its rocky bed and fast flow, plays a key role in water oxygenation, contributing to the ecological health and environmental resilience of the Lova River system.

The region's morphology varies significantly among sub-basins. In the upper areas, steeper slopes promote rapid surface runoff and sediment transport. In contrast, central and lower sub-basins have gentler slopes, facilitating sediment deposition.

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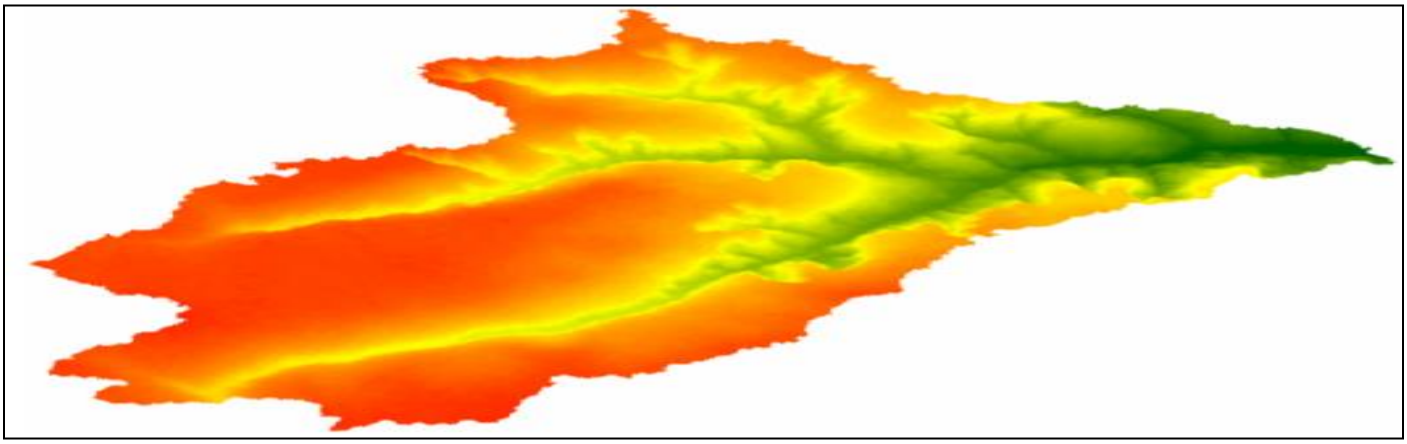

Fig 3 Three-Dimensional Visualization of the DEM of the Lova River Micro-Basin (Authors).

➢ *The Climate*

The region has a tropical climate, which supports activities such as agriculture, livestock farming, and fishing. The year is divided into two main seasons: the rainy season, which lasts from August 15 to May 15, and the dry season, locally known as *cacimbo*, which lasts 90 days, from May 15 to August 15. According to the meteorological control center at Catoca Airport, the rainiest period occurs between November and March, with an average annual precipitation of 1,366 mm.

Temperatures vary throughout the year, ranging from a minimum of 12℃ to a maximum of 34℃. The average annual relative humidity is 63%, providing favorable conditions for vegetation growth and other natural resource-related activities.

The prevailing winds change throughout the year, with recorded directions ranging from north to northeast and south to southwest, influencing local climate patterns and impacting economic and environmental activities in the region.

III. METHODOLOGY

The methodology adopted for this study focused on analyzing the morphometric characteristics of the Lova River sub-basin, using advanced hydrological modeling techniques and geotechnologies. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 30 meters, accessed through the Earth Explorer platform (https://earthexplorer.usgs.gov). These data were processed using ArcGIS 10.8 software, integrated with the Spatial Analyst (Hydrology) extension, allowing for detailed analysis of hydrological variables.

The methodological process emphasized hydrological modeling to delineate the sub-basin and extract essential information such as drainage networks, watershed boundaries, and contributing areas. Additionally, the morphometric characteristics of the basin were determined, including parameters such as drainage density, slope, form coefficients, and other relevant indicators. These analyses aimed not only to characterize the hydrological dynamics of the sub-basin but also to support the development of sustainable water resource management strategies in the study area.

➢ *Hydrological Modeling*

The hydrological modeling process consisted of:

- Correction of the Digital Elevation Model (DEM);
- Creation of the flow direction map;
- Creation of the flow accumulation map;
- Generation of the drainage network map;
- Production of the stream order map;
- Conversion of raster maps to vector format.

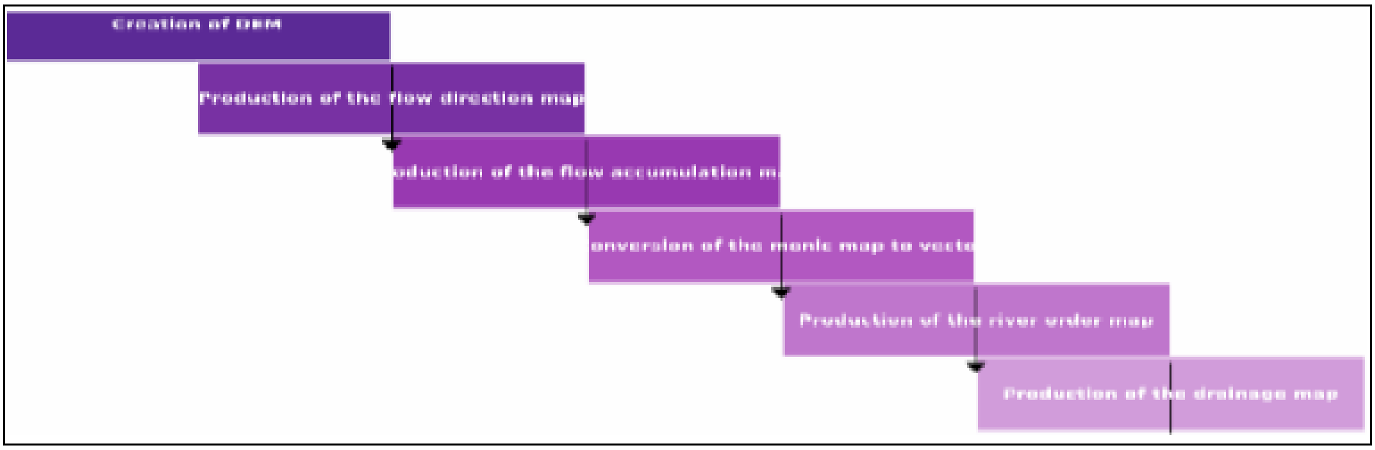

Fig 4 Hydrological Modeling

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For the morphometric analysis of the Lova River sub-basin, procedures were applied using ArcGIS 10.8 software, prioritizing data consistency and hydrological accuracy. Initially, the "Fill" command was used to correct the Digital Elevation Model (DEM), eliminating spurious depressions that could cause disruptions in surface runoff along the drainage network (BAENA et al., 2004). Then, the flow direction was generated using the "Flow Direction" command, identifying eight possible directions (1, 2, 4, 8, 16, 32, 64, and 128).

Based on the flow direction, flow accumulation was calculated using the "Flow Accumulation" command, allowing for the determination of the water contribution of each cell in the study area. The numeric hydrography was extracted using the "Raster Calculator" tool and converted to vector format (shapefile) using the "Stream to Feature" command. Finally, to delineate the sub-basin drainage area, a point was created at the river mouth, and with the "Watershed" command, the drainage area associated with the Lova River sub-basin was obtained. This sequence of steps enabled the detailed definition and characterization of the hydrography and runoff dynamics of the studied region.

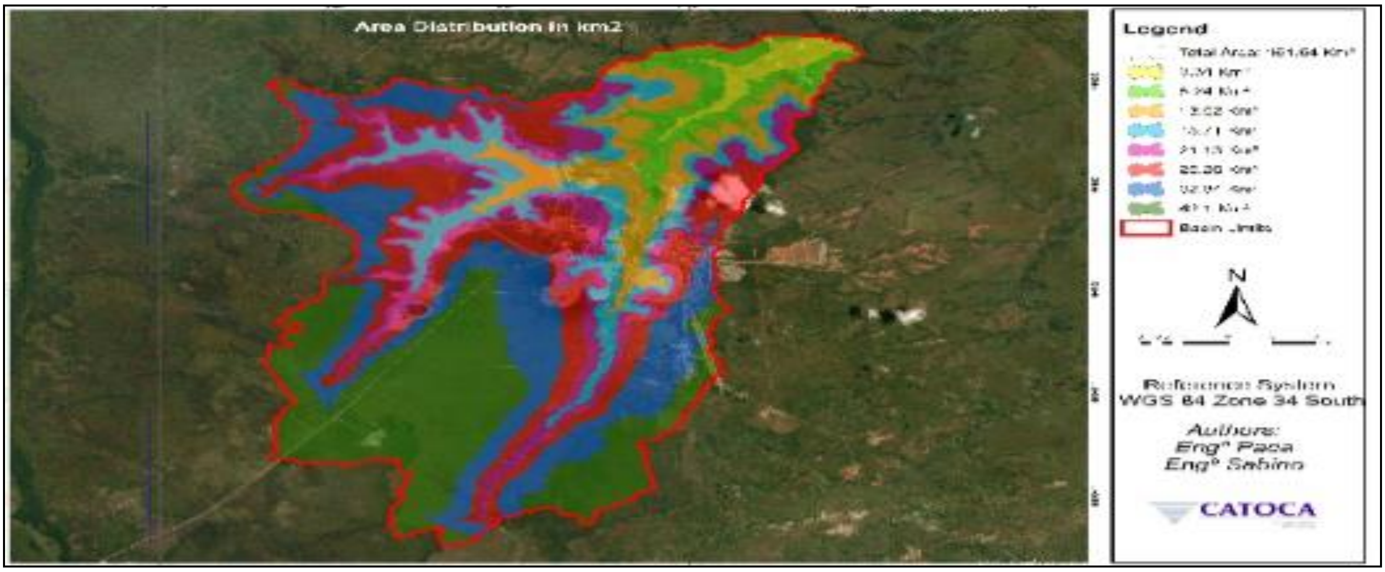

Fig 5 Distribution of Areas in km² (Authors).

- *Determination of Morphometric Characteristics*

The morphometric characteristics of the Lova River sub-basin were obtained from information extracted from the Corrected Digital Elevation Model (MDEHC), as described below:

- *Drainage Area*

The drainage area of a watershed corresponds to the horizontal projection delimited by its topographic divides, representing a key parameter for hydrological studies (VILLELA & MATTOS, 1975). This information serves as the basis for calculating other physiographic characteristics of the basin.

Once the basin perimeter is defined, the area can be accurately calculated using digital techniques and specialized applications (CHRISTOFOLETTI, 1980). In other words, it can be determined using the following basic formula: A = Sum of Digital Elevation Model (MDE) Cell Areas × Cell Resolution

The drainage area, represented by the letter "A", is expressed in square kilometers (km²) or hectares (ha). The basin area is fundamental for determining its water potential. By multiplying the area value by the precipitation depth, the total volume of water received by the basin is obtained—crucial information for analyzing water availability and natural resource planning (TUCCI, 2001).

This parameter is essential for assessing the basin's hydric potential and its capacity to respond to rainfall events. In this study, the drainage area was delineated using geoprocessing techniques in ArcGIS 10.8 software, applying the "Watershed" command, which identified all contributing cells to the Lova River sub-basin outlet point.

- *Relay Factor*

The hypsometric curve is a crucial tool for the analysis of the relief of a river basin, as it allows visualizing the distribution of the basin area at different altitudes, in relation to the mean sea level. This curve represents the variation in the altitude of the basin terrain, showing the area (A) of the basin above each altitude (Z). The formula for this relationship is expressed as A = f(Z), where A is the area of the basin and Z is the altitude.

The hypsometric curve provides a clear view of the altimetric distribution and is fundamental for understanding the dynamics of the basin in relation to rainwater runoff and infiltration.

The calculation of the median altitude consists of the intersection of the hypsometric curves, where the area above this altitude is equal to the area below it. This value is particularly relevant, as it offers a representative measure of the altimetric distribution of the sub-basin, allowing us to

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understand whether most of the basin is located at higher or lower altitudes.

Median altitude is a key indicator for relief analysis and for predicting hydrological behaviors, such as surface runoff and infiltration.

The weighted average altitude is a measure that takes into account the contribution of different altitudes in the basin area. The calculation is performed using the following formula:

$$H \square \frac{\square\square\ a_i c_i \square}{A} \qquad c_i = \frac{(c_i + c_{i-1})}{2}$$

- *Where:*

- ✓ *ai = Partial area of land between contour lines;*
- ✓ *Ci = Average altitude of each partial area between two contour lines;*
- ✓ *A = Area of the micro basin*

The value provides an average of altitudes, weighted by the area corresponding to each elevation range, and is used to better understand the spatial distribution of altitudes within the basin, directly influencing the hydrological characteristics and environmental planning of the region.

The simple average altitude is calculated by the arithmetic average of the altitudes of all points or cells in a watershed, which is done by the following formula:

$$H_{ms} = \frac{(c_M + c_m)}{2}$$

- *Where*:

- ✓ *Cm = Highest level or altitude of the basin;*
- ✓ *Cm = Lowest level or altitude of the basin*

The calculation provides a general estimate of the average altitude of the entire basin area, and is useful for an initial analysis of the relief and for comparison with other altimetric measurements, such as the median altitude or the weighted average altitude. The measurement is simple, but important to understand the general variation of elevation in the study region.

The calculation of the frequency polygon of partial areas provided a detailed understanding of the spatial distribution of the areas within the sub-basin. This procedure involves the graphical representation of the areas that are associated with different altitude ranges, showing how these areas are distributed along the relief of the basin. Through the construction of a frequency graph, it will be possible to visualize in an orderly and cumulative way the contributions of these areas to the whole.

The frequency polygon allows to clearly identify how the sub-basin area is distributed in relation to the variation of altitudes, facilitating the analysis of aspects such as the topography and hydrography of the region.

➢ *Shape Parameters*

The compactness coefficient, also known as the Gravelius index (K), is a measure that relates the shape of a watershed to the ideal shape of a circle. It is calculated from the comparison between the actual perimeter of the basin (P) and the perimeter of a circle (P') that has the same area (A) as the basin. The formula used to calculate the compactness coefficient is:

$$K = 0.28 * \frac{P}{\sqrt{A}}$$

- *Where:*

- ✓ *P = Perimeter of the basin in km*
- ✓ *A = Area of the basin in km²*

The index ranges from 1 to larger values, where a value of K = 1 indicates a perfectly circular (more compact) shape, while values greater than 1 indicate more elongated and less compact shapes. The compactness coefficient is useful to analyze the efficiency of the flow and the vulnerability to processes such as erosion and infiltration, because more compact basins tend to have a faster and more concentrated flow.

The concept of equivalent rectangle, introduced by French hydrologists, aims to provide a better understanding of the influence of the geomorphological characteristics of the hydrographic basin on the flow (Vilela and Matos, 1975). The method seeks to approximate the basin to a rectangle, so that the length (L) and width (l) of the rectangle have the same perimeter (P), area (A) and hypsometric characteristics of the basin, such that:

$$\text{Bigger side} = \quad L = \frac{K\sqrt{A}}{1.12}\left(1 + \sqrt{1 - \left(\frac{1.12}{K}\right)^2}\right)$$

$$\text{Minor side} = \quad l = \frac{K\sqrt{A}}{1.12}\left(1 - \sqrt{1 - \left(\frac{1.12}{K}\right)^2}\right)$$

- *Where:*

- ✓ *K= Compactness coefficient or Gravelious index*
- ✓ *A = Basin area in km²*

The equivalent rectangle is used to facilitate comparison between basins of different shapes, offering a simplified way to understand the relationship between basin shape and hydrological behavior.

The shape factor is an important geometric feature for watershed analysis, as it relates the shape of the basin to an idealized rectangle. This factor is used to understand how the geometry of the basin can influence surface runoff and hydrological response time.

- The formula for calculating the form factor is given by the equation:

$$F_f = \frac{l}{L} = \frac{A}{L^2}$$

- *Where*:

- ✓ *l = Short side of the equivalent rectangle or is the average width of the basin, defined as the average of the transverse distances perpendicular to the main axis of the basin, usually obtained from a digital elevation model (DEM);*
- ✓ *L = Longest side of the equivalent rectangle or is the length of the basin, which corresponds to the distance between the point of greatest elevation of the basin (or highest point of the watershed) to the mouth of the basin.*
- ✓ *A = Area of the basin.*
- ✓

A lower value for the form factor indicates a more elongated basin and therefore a shorter concentration time, which means that rainwater reaches the mouth more quickly. In contrast, a basin with a larger form factor (indicating a more compact or rounded shape) will have a longer response time, meaning that surface runoff will be spread out over a longer period.

According to Taylor and Schwarz (1969), the main slope of the river is one of the morphometric characteristics that describes the average slope of the hydrographic basin. It can be calculated using the ratio between the difference in elevation between the highest and lowest points of the basin and the length of the main watercourse.

$$S = \left[\frac{n}{\frac{1}{\sqrt{S_1}} + \frac{1}{\sqrt{S_2}} + \ldots\ldots \frac{1}{\sqrt{S_n}}} \right]^2$$

This measurement is important to understand the behavior of runoff in the basin, since basins with high slope tend to have faster runoffs, which can affect water storage capacity and flood intensity.

➢ *Parameters Related to the Hydrographic Network*

The drainage density index (Dd) is an important metric to assess the degree of development of the drainage system of a watershed. It reflects the distribution and intensity of the drainage network within the basin, and can provide information on soil type, land use, and basin morphology. It is expressed by the ratio between the total length of the watercourses of a basin and its total area (VILLELA; MATTOS, 1975).

$$D_d = \frac{L_i}{A}$$

- *Where*:

- ✓ Li = Total longitude of rivers or can be treated as the total length of watercourses within the basin (in Km or m);
- ✓ A = Area of the total basin (in km² or m²).

➢ *Drainage Density is Important Because:*

- High drainage density may indicate a basin with more permeable soils or with dense vegetation, favoring the formation of many watercourses;
- Low drainage density may indicate a basin with more impermeable soils, low precipitation or with geological characteristics that hinder the formation of drainage.

The river frequency index is related to the capacity of a watershed to generate a greater volume of water, considering the number of watercourses present in a given area.

This index is a measure of the distribution and density of rivers within the basin, allowing an evaluation of the drainage capacity and the contribution of the basin to surface runoff. The formula for calculating the frequency of rivers is as follows:

$$F_r = \frac{N}{A}$$

- *Where:*

- ✓ Fr = is the frequency index of rivers (in units such as rivers/km² or rivers/m²);
- ✓ N = is the number of channels or watercourses within the basin.
- ✓ A = is the total area *of the basin (in km² or m²).*

However, it is important for the analysis of the basin's water production, as it indicates the number of watercourses that contribute to the flow in the region. Basins with a higher frequency of rivers tend to have a greater drainage capacity and can generate a greater volume of water during periods of precipitation.

Mean runoff extent (Es), also known as mean runoff length, refers to the average distance that water travels from the point of precipitation to the main watercourse of a watershed. It is an important measure to understand the trajectory of water along the basin and the behavior of surface runoff.

- According to Vilela and Matos (1975), the formula to calculate the average extent of surface runoff (Es) is:

$$E_s = \frac{A}{P}$$

- *Where:*

- ✓ Es = is the average extent of surface runoff (in meters or kilometers).
- ✓ A = is the area of the basin (in km² or m²).

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- P = is the perimeter of the basin (in km or m).

The formula considers the total area of the basin and its perimeter, providing an estimate of the average path that the water takes to reach the main water body. The average extent of runoff is useful for evaluating the dynamics of surface runoff, indicating the drainage capacity of the basin and its relationship with the shape and size of the drainage area.

The concentration time (Tc) is the time required for the precipitated water at any point in the watershed to reach the outlet point of the basin, that is, the point of measurement of the runoff. This parameter is important for determining the hydrological response of the basin to a precipitation, influencing the calculation of flows and the behavior of the flow.

Kirpich's (1940) formula, one of the most widely used to calculate the concentration time in small basins and with poorly defined channels, is given by:

$$Tc = \left(\frac{0.87 L^3}{H} \right)^{0.385}$$

- *Where***:**

- Tc = is the time of concentration (in hours),
- L = is the length of the main watercourse to the point of exit of the basin (in meters or kilometers),
- H= is the height of precipitation (in meters or millimeters).

The Kirpich equation is useful for quickly estimating concentration time and understanding the basin's response to precipitation events, especially when more detailed data are not available. It is useful, to quickly estimate the concentration time and understand the response of the basin to precipitation events, especially when more detailed data is not available.

- *Other Parameters*

The slope index of a watershed (Ip) is a measure that represents the average slope of the land, providing information about the topography of the area and its influence on surface runoff. It is calculated by the ratio between the variation in altitude and the extent of the basin, according to the following formula:

$$I_p = \frac{\Delta H}{L}$$

- *Where:*

- Ip = Slope index (in % or degrees);
- ΔH = Difference in altitude between the highest and lowest point of the basin (in meters);
- L = Length of the main watercourse or total distance from the basin (in meters or kilometers).

Calculating the average slope of a watershed is critical to understanding its capacity for runoff, erosion, and response to hydrological events. The slope, expressed as a percentage, represents the average slope of the channels and directly influences the speed of surface runoff and the capacity to drain floods. The formula used is:

$$I_b = \frac{(H_{max} - H_{min})}{L_c} \times 100$$

- *Where:*
- Ib = Average slope of the basin (%);
- Hmax = Maximum altitude (m);
- Hmin = Altitude mínima (m);
- Lc = Length of the main watercourse (km).

This metric synthesizes the interaction between the topography and hydrology of the basin, being fundamental for the management of water resources and the prevention of extreme events.

IV. RESULTADOS E DISCUSSÃO

- *Basin Area*

The results obtained in the morphometric characterization of the Lova River sub-basin, as presented in Figure 6, indicate that the sub-basin has a total area of 162.00 km² and a perimeter of 77.33 km. These values reflect the physical dimensions of the basin, which are fundamental to understand its hydrological dynamics and plan environmental interventions.

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Total Basin Area	162.00	Km2
Basin Perimeter	77.33	Km

1.2.- TABLE OF PARTIAL AND ACCUMULATED AREAS ACCORDING TO ALTITUDE

With the ArcGIS 10.8 software, we obtain the area between contour lines/elevations, as well as the partial areas

Graph No. 01: Partial and accumulated areas for the development of the Hypsometric Curve

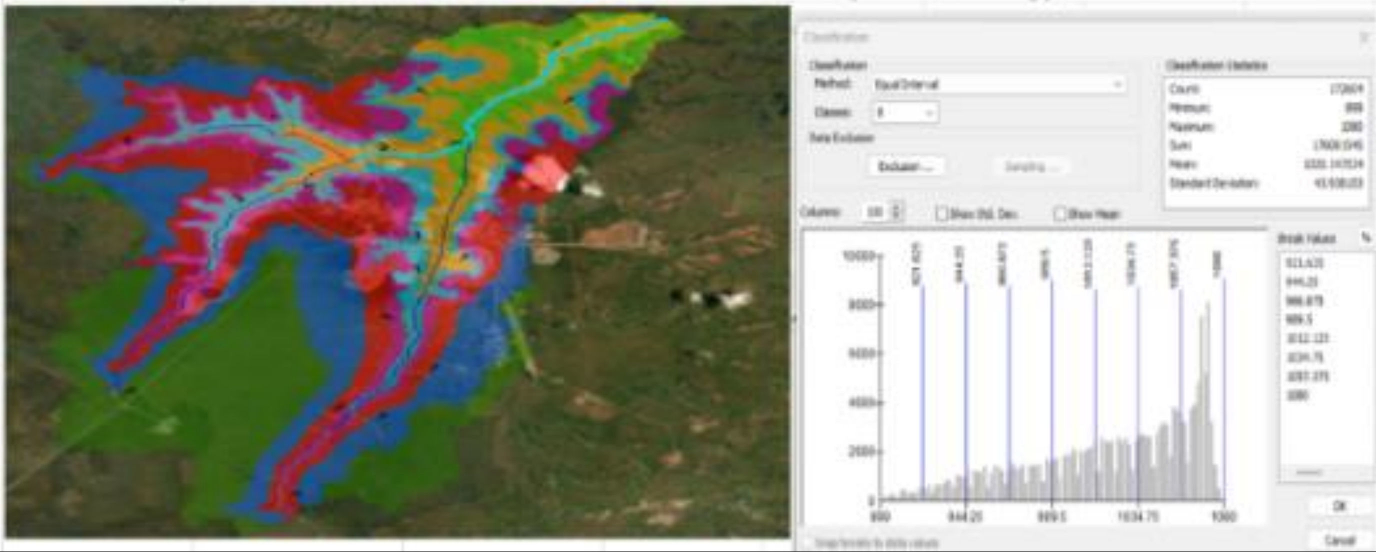

Fig 6 Graph of Partial Areas for Hyposometry

As shown in table 1, the distribution of partial and accumulated areas clearly reflects the topography of the sub-basin. The significant concentration of area at higher altitudes, especially around 1080 m, evidences the presence of extensive terrains in these regions. These higher areas have greater potential to act as sources of erosion, contributing to the transport of sediments to lower altitudes. The detailed analysis of partial areas is, therefore, an essential tool to identify critical zones that require specific interventions in erosion management and control.

Table 1 Partial and Accumulated Areas

ALTITUDE	PARTIAL AREAS		ACCUMULATED AREAS			
			BELOW		ABOVE	
m.s.n.m.	Km2	(%)	(KM2)	(%)	KM2	(%)
Lowest point						
899	0.00	0.00	0.00	0.00	161.64	100.00
922	3.34	2.07	3.34	2.07	158.30	97.93
945	8.24	5.10	11.58	7.16	150.06	92.84
967	13.02	8.05	24.60	15.22	137.04	84.78
990	15.71	9.72	40.31	24.94	121.33	75.06
1013	21.13	13.07	61.44	38.01	100.20	61.99
1035	25.26	15.63	86.70	53.64	74.94	46.36
1058	32.84	20.32	119.54	73.95	42.10	26.05
1080	42.1	26.05	161.64	100.00	0.00	0.00
Highest point						
TOTAL	161.64	100.00				

➢ *Relay Factor*

- *Hypsometric Curve*

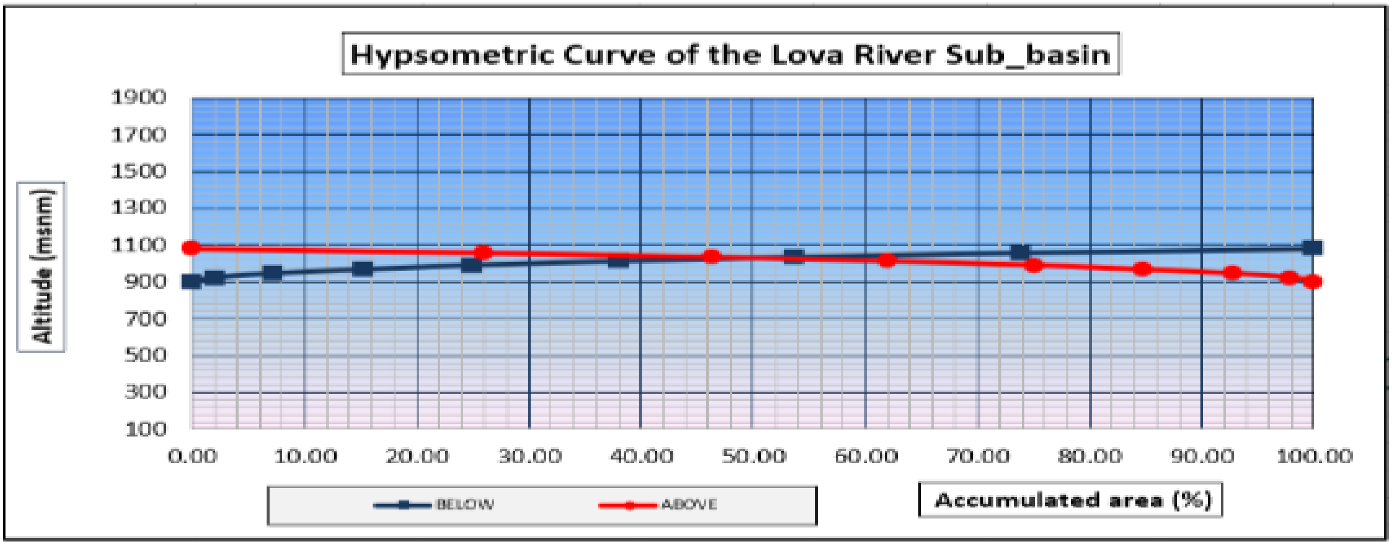

Fig 7 Hypsometric curve

Figure 7 shows the relationship between the accumulated percentage of sub-basin area and altitudes, offering a clear analysis of the topography of the region. On the horizontal axis (x), the accumulated percentage of the sub-basin area is observed, while the vertical axis (y) represents the altitudes, ranging from approximately 700 m to 1100 m above sea level.

The blue curve, which reflects the accumulated elevation over the area, exhibits a relatively constant profile, indicating little significant variation in elevation. The red curve, in turn, represents the average elevation accumulated over the area, reinforcing the altimetric uniformity of the sub-basin.

This predominant and horizontal shape of the curves reveals that the Lova River sub-basin has a relatively flat or gently sloping topography. This pattern implies a slower water runoff, which can influence the speed of response to precipitation events, increasing the susceptibility to flooding in heavy rainfall. On the other hand, areas with less altitude variation generally have a lower risk of erosion compared to more inclined terrain, contributing to soil stability.

The topographic uniformity highlighted in the analysis reinforces the importance of adequate water resources management measures, such as runoff monitoring and the implementation of effective drainage systems, to minimize flood risks and maximize the water efficiency of the sub-basin.

- *Altitude Median*

The median altitude of **1035 masl**, determined by the intersection of the hypsometric curves, represents a central value in the altimetric distribution of the Lova River sub-basin. This data reflects a balanced topography, being crucial for environmental planning, efficient management of water resources and the mitigation of natural hazards, such as erosion and flooding. Understanding the median altitude makes it possible to inform informed decisions about sustainable land use, the conservation of natural resources, and the development of strategies adapted to the specific characteristics of the sub-basin.

- *Weighted Average Altitude*

Table 2 Partial areas between contour lines

	ai	ci(average altitude)	ai*ci
	3.34	910.5	3041.07
	8.24	933.5	7692.04
	13.02	956.0	12447.12
	15.71	978.5	15372.24
	21.13	1001.5	21161.70
	25.26	1024.0	25866.24
	32.84	1046.5	34367.06
	42.10	1069.0	45004.90
Σ	161.64	Σ	164952.36
	H =	1 020.49	msnm

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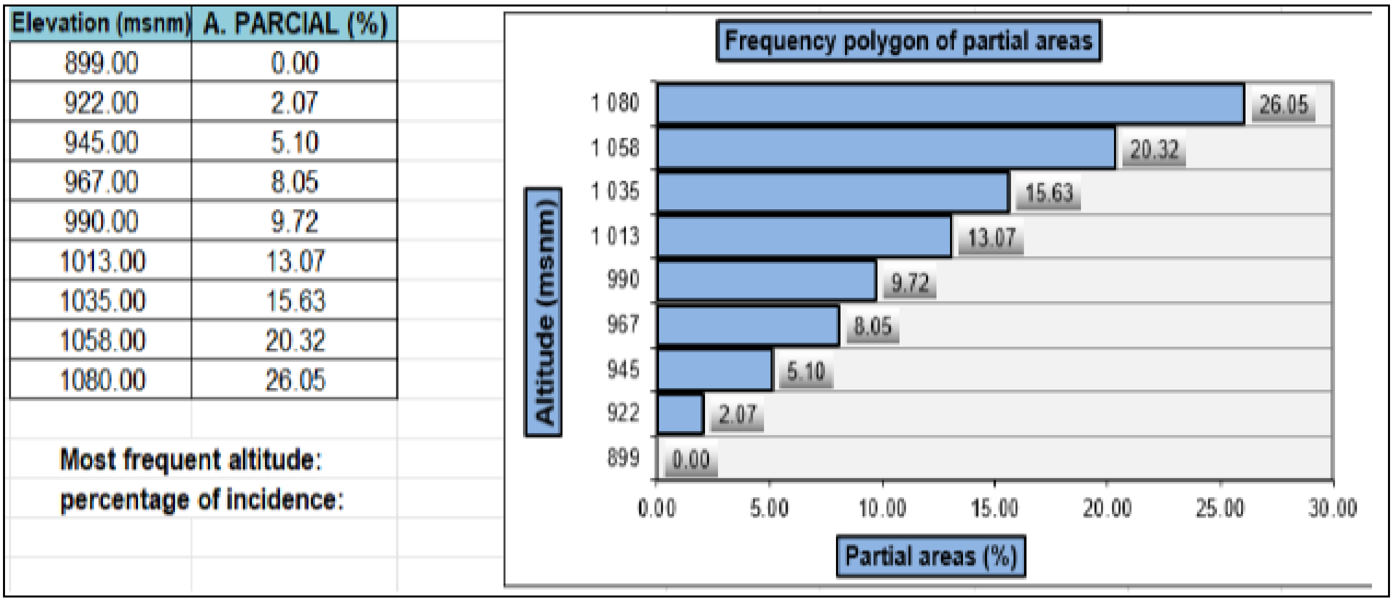
The average altitude of 1020.49 masl complements the median altitude by offering a comprehensive view of the altimetric distribution of the Lova River sub-basin. Together, these metrics provide a solid foundation for environmental planning and integrated water resources management. In addition, they are important to guide the sustainable use of the soil and the implementation of effective strategies to mitigate natural hazards, such as erosion and flooding. The detailed analysis of these data enables an informed and balanced approach, promoting sustainable development and the conservation of the sub-basin.

- *Medium Single Altitude*

The simple average altitude of 989.50 m, calculated mathematically, is lower than the median altitude of 1035.00 m, which indicates an asymmetric distribution of elevations in the Lova River sub-basin. This pattern reflects a greater concentration of areas at lower elevations, evidencing a slightly sloping topography. This asymmetry is relevant to understand runoff dynamics, erosion patterns, and priority areas for environmental management and soil conservation.

- *Partial Area Frequency Polygon.*



Elevation (msnm)	A. PARCIAL (%)
899.00	0.00
922.00	2.07
945.00	5.10
967.00	8.05
990.00	9.72
1013.00	13.07
1035.00	15.63
1058.00	20.32
1080.00	26.05

Fig 8 Frequency Polygon of Partial Areas

Figure 8 presents a frequency polygon that relates the partial areas of the sub-basin with different elevations, highlighting the most frequent altitudes. Figure 8 reveals that most of the basin area is concentrated at higher altitudes, and the elevation of 1080 masl corresponds to 26.05% of the total area. As altitudes decrease, a reduction in the percentage of partial area is observed, with the lowest incidence recorded at the elevation of 899 masl (0%).

The combined analysis of the simple mean (989.50 m), median (1035.00 m) and weighted mean (1020.49 m) measurements allows a detailed understanding of the topography of the basin. While the simple mean provides an initial view, the median and weighted average offer a more accurate perspective, especially in cases of uneven altimetric distribution.

➢ *Shape Parameters*

- *Indice de Gravelious (K)*

With a perimeter of 77.33 km and a basin area of 162 km², using the appropriate mathematical formulas, a value of K = 1.7140 was obtained, which indicates that the analyzed basin is less compact than a perfectly circular basin, whose K value is equal to 1. The result suggests that the basin has a more elongated or irregular shape, characterized by a distended morphology, in contrast to the symmetry observed in circular basins.

Basins with this configuration tend to have longer water concentration times, as the water travels longer distances due to the elongated or complex geometry of the basin.

This behavior results in a more gradual runoff, directly impacting the hydrological dynamics. The response of the basin to precipitation events is therefore slower, with delayed surface runoff. This characteristic must be considered in the management of water resources, requiring rigorous planning for drainage control and flood prevention.

- *Rectangle Equivalent*

The calculation of the equivalent rectangle, with dimensions L = 34.15 km and l = 4.734 km, simplifies the watershed, making it more suitable for various environmental analyses. This approach can be applied in flood forecasting studies, soil conservation, green infrastructure planning, pollution control, and ecological restoration, facilitating the implementation of more efficient and targeted management strategies.

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L = 34.224
l = 4.734

Equivalent rectangle

Elev (msnm)	Partial Areas ai (Km2)	Width, ci (Km)
899.00	0.00	0.00
922.00	3.34	0.71
945.00	8.24	1.74
967.00	13.02	2.75
990.00	15.71	3.32
1013.00	21.13	4.46
1035.00	25.26	5.34
1058.00	32.84	6.94
1080.00	42.10	8.89
	Sum ci= L=	34.15

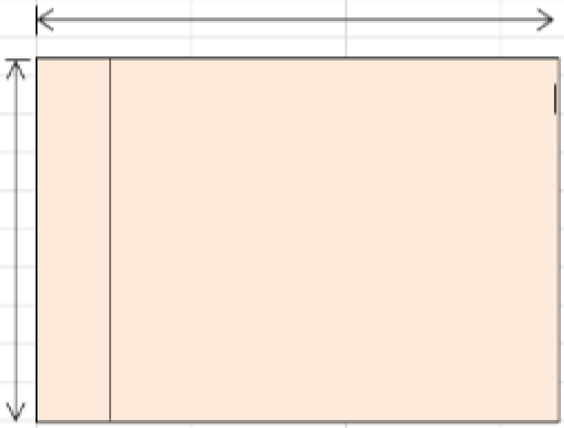

Fig 9 Equivelent Rectangle of the Lova River Sub-Basin

- *Form Factor*

With the dimensions of the longer side (L = 34.15 km) and the short side (l = 4.734 km), it was possible to calculate the shape factor (Ff) of 0.1383, which indicates that the Lova River sub-basin has an elongated morphology. This configuration has direct implications for surface runoff, concentration time, and water resource management. A basin with this form factor tends to have a slower hydrological response during precipitation events, which delays peak flooding.

Rainwater that reaches the farthest parts of the basin takes longer to reach the exit point, which contributes to flow dispersion and can reduce the risk of sudden flooding.

- *Main Slope of River*

The analysis of figures 10 and 11 reveals that the longitudinal profile of the main river presents an average slope of 8.51%, indicating a steep topography with direct implications for water dynamics. This topographic variation significantly influences water flow velocity, erosion, sediment transport, and flood risks.

To mitigate the negative environmental impacts of this pending rise, it is crucial to adopt sustainable land use practices and implement management measures that ensure the preservation of the river ecosystem, the protection of adjacent communities, and the health of aquatic ecosystems.

	Progresssive	Long. (m)	Long Accum (m)	Elevation	Slope	S	1/(S)^0.5
0	0+000	0.00	0.00	900.00			
1	1+500	1500.00	1500.00	910.00	10.00	0.0110	9.5394
2	3+000	1500.00	3000.00	926.00	16.00	0.0173	7.6076
3	4+000	1000.00	4000.00	930.00	4.00	0.0043	15.2480
4	6+000	2000.00	6000.00	934.00	4.00	0.0043	15.2807
5	7+500	1500.00	7500.00	940.00	6.00	0.0064	12.5167
6	8+000	500.00	8000.00	944.00	4.00	0.0042	15.3623
7	9+000	1000.00	9000.00	946.00	2.00	0.0021	21.7486
8	10+000	1000.00	10000.00	948.00	2.00	0.0021	21.7715
							119.0747

$$S = \left[\frac{n}{\frac{1}{\sqrt{S_1}} + \frac{1}{\sqrt{S_2}} + \ldots\ldots + \frac{1}{\sqrt{S_n}}} \right]^2$$

S = 0.0045
S = 0.45 %
(According Taylor y Schwarz)
river Slope (%)= 8.51 %

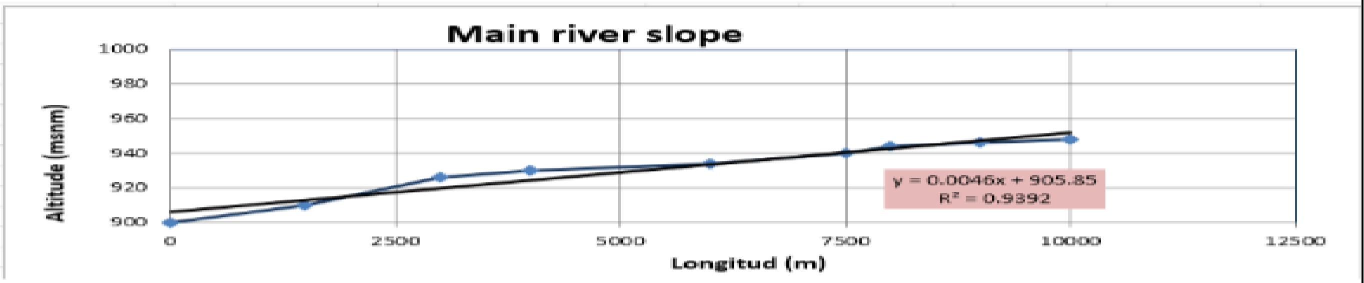

Fig10 Main River Slope

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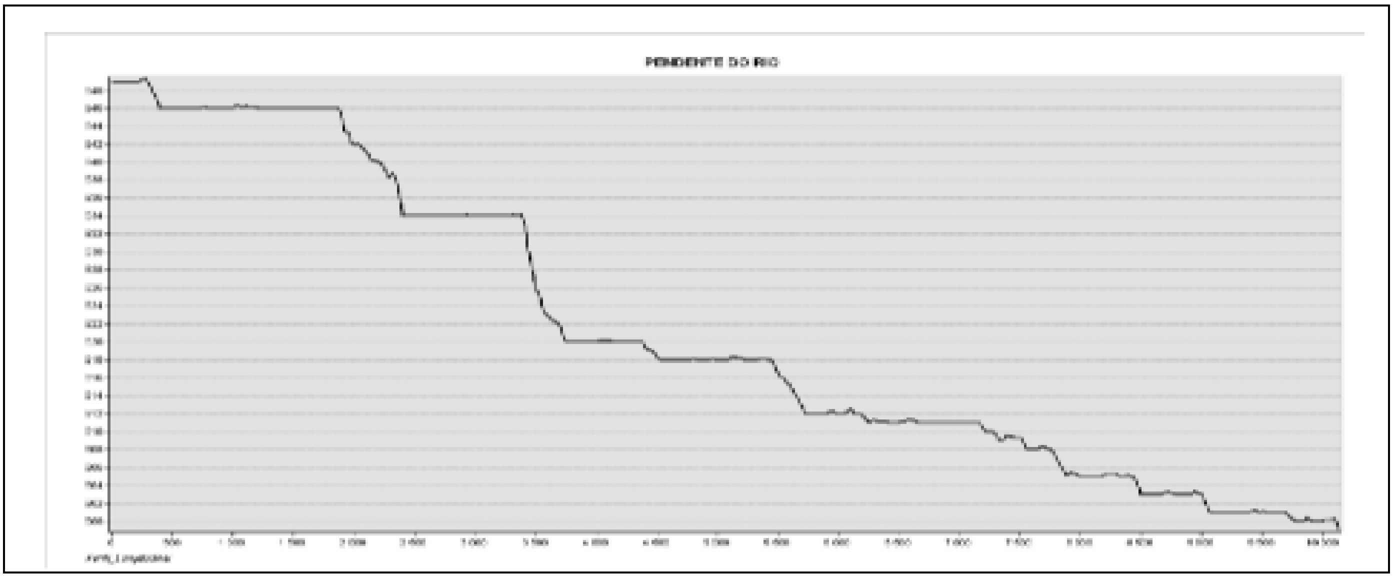

Fig 11 Longitudinal Profile

➢ *Hydrographic Network*

- *Drainage Density*

Based on the obtained values, main channel longitude 10.18 km, contributors' channel longitude 55.61 km and basin area 162 km2, the drainage density of the Lova river sub-basin was calculated as 0.41 km/km² using the corresponding mathematical equation. This value can be considered relatively low, which indicates that the sub-basin has a less dense hydrographic network. As a consequence, rainwater has fewer channels to travel through to the exit point, resulting in a longer concentration time. This factor can influence the hydrological response of the basin, delaying the arrival of the flood peak at the exit points of the basin.

- *Frequence of the River*

The value obtained of 0.210 channels/km² indicates that the sub-basin has a relatively low frequency of channels, which means that there are few channels per unit area. This feature has important implications for the hydrology of the basin, including a longer concentration time, since rainwater has fewer channels to travel through to reach the exit point.

The low density of channels can affect the distribution of water flow, potentially resulting in less efficient drainage and negatively influencing water quality, since water can remain longer in areas of reduced drainage, favoring sedimentation and the accumulation of pollutants.

- *Average Surface Runoff Extent*

The average runoff extension of 0.616 km, obtained by the ratio between the area and the perimeter of the basin, indicates that rainwater travels a relatively short average distance before being captured by the drainage channels. This suggests that the sub-basin has a reasonably efficient drainage network, which can result in a faster concentration time, facilitating the evacuation of rainwater and reducing the risk of flooding.

- *Concentration Time (Tc), According to Kirpich*

From the length of the main watercourse to the outlet point of the basin and the height of precipitation, it was possible to calculate a concentration time of 7,580 hours, which indicates that the sub-basin of the Lova River, in the concession perimeter of Sociedade Mineira de Catoca, Lda., has a longer response time to intense rainfall events. The concentration time represents the period necessary for the water to travel the distance from the farthest point of the basin to its exit.

This morphometric characteristic has direct implications on the hydrological dynamics of the basin, as water can accumulate for longer, which, in some circumstances, can help reduce flood peaks. However, it also implies that the basin has a greater water retention capacity, which can favor the infiltration and recharge of aquifers. Accurate determination of concentration time is essential for planning drainage infrastructure, such as reservoirs and runoff systems, minimizing the impact of heavy rainfall and preventing potential damage to communities and the environment.

➢ *Other Parameters*

- *Slope Index*

The slope index of 2.17809, calculated as shown in Table 3, indicates significant variations in slope along the sub-basin. The sharp variation is an important factor in the environmental dynamics of the region, as areas with higher slopes tend to present a high erosion potential, especially during events of intense precipitation.

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Table 3 Slope Index

Ai 1	Bi = Ai/At 2	ai - ai-1 3	Bi* (ai -Ai-1) 4	Raiz (4) 5	5 * 1/(L)^0.5 6
0.00	0.00	0	0.00	0.00	0.00
3.34	0.02	23.00	0.48	0.69	0.12
8.24	0.05	23.00	1.17	1.08	0.19
13.02	0.08	22.00	1.77	1.33	0.23
15.71	0.10	23.00	2.24	1.50	0.26
21.13	0.13	23.00	3.01	1.73	0.30
25.26	0.16	22.00	3.44	1.85	0.32
32.84	0.20	23.00	4.67	2.16	0.37
42.10	0.26	22.00	5.73	2.39	0.41
161.64				*Ip* =	**2.17809**

Understanding these topographic variations is essential to implement effective interventions, such as sustainable soil management techniques, construction of terraces or vegetative barriers, aiming to reduce negative impacts and promote the environmental preservation of the sub-basin.

- *Basin Slope*

Accordingly, the calculations of 0.523% for the slope of the basin reflect a very smooth terrain. This characteristic is associated with slow surface runoff and low erosion potential, which is beneficial for soil conservation as it reduces sediment loss during precipitation events.

However, this low slope also implies challenges, such as a higher risk of localized flooding due to water accumulation in flat areas. In which, it highlights the need for careful drainage planning, focusing on strategies that promote the dispersion and efficient drainage of rainwater. These measures are essential to minimise the impact of flooding and ensure the environmental sustainability of the basin.

- *Average Slope of the Watershed*

In Table 2, the average slope of 9.795% reflects a moderately sloping topography, composed of flat and sloping areas. This topographic variation has relevant implications for the hydrology of the basin, impacting surface runoff, water flow velocity, and sediment transport. Sloping areas have greater erosion potential, while flatter areas favor water infiltration and sediment accumulation.

Diversity requires careful and balanced planning of land use and management, with the implementation of specific strategies to mitigate erosion in the steepest areas and prevent water saturation problems in flat areas. The measures are essential to ensure the environmental sustainability of the basin and the protection of its water resources.

Table 4 Average Slope of the Basin

Nº	Slope range		Average	Number of Occurrences	AVERAGE x OCCURRENCES	
	Lower	Upper				
1	0	5	2.5	61060	152650	
2	5	12	8.5	63993	543940.5	
3	12	18	15.0	22348	335220	
4	18	24	21.0	10850	227850	
5	24	32	28.0	7659	214452	
6	32	44	38.0	3484	132392	
7	44	100	72.0	846	60912	
				170240	1667416.5	
	Average basin slope:				9.795	%

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- *Slope map*

Figure 12, which shows the slope map of the Lova River sub-basin in the concession perimeter of Sociedade Mineira de Catoca, Lda., the different slope classes highlight important aspects:

- ✓ Flat Areas (<5%): These are essential for water recharge, as they favor water infiltration and minimize surface runoff. They also function as sediment retention zones, contributing to the reduction of erosion and maintenance of water quality.
- ✓ Undulating and Escarped Areas (5-32%): These represent regions vulnerable to erosion due to accelerated runoff. Identifying these areas allows planning soil conservation practices, such as vegetative barriers or terracing, protecting soil productivity and reducing sediment transport to water bodies.
- ✓ Mountainous Terrains (>44%): Require specific interventions to stabilize the soil, control drainage, and prevent landslides. These areas are critical for mitigating environmental risks and protecting nearby infrastructure.

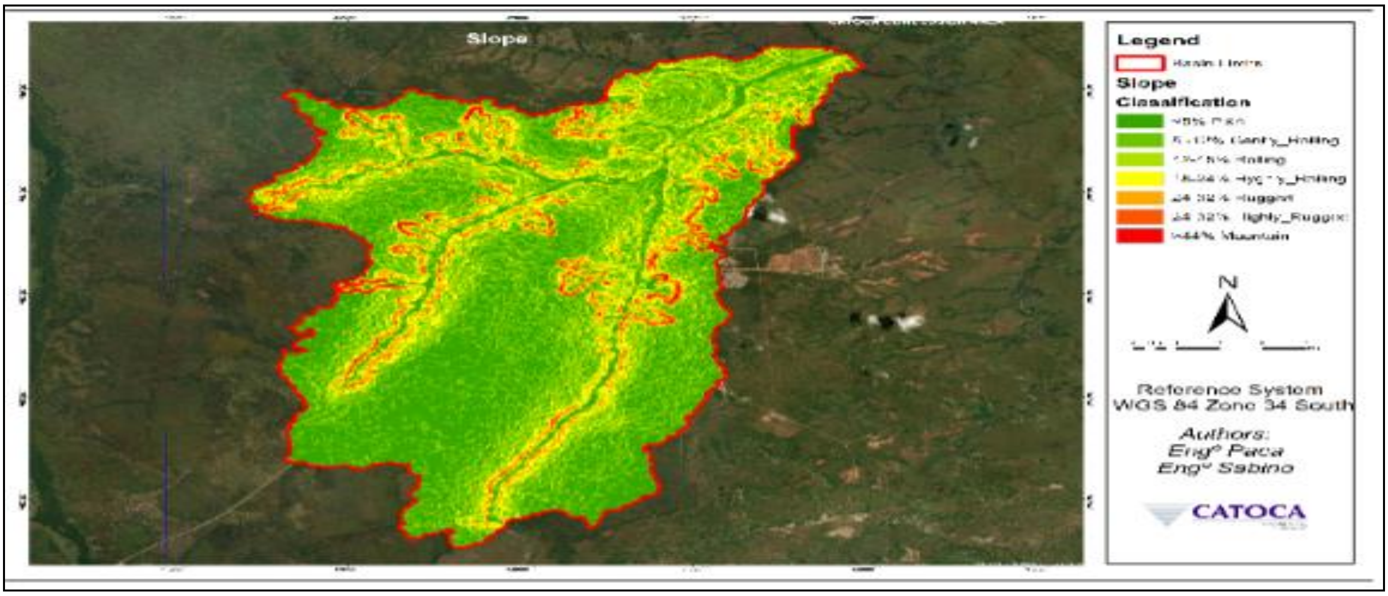

Fig 12 Slope Map

V. Conclusion

In conclusion, the morphometric characterization of the Lova river sub-basin, located in the concession perimeter of Sociedade Mineira de Catoca, Lda., allowed us to understand the physical characteristics and hydrological processes associated with the study area. From the data obtained, it was possible to establish practical and scientific implications for the planning and sustainable management of the basin, as presented below:

- The sub-basin has a total area of 162.00 km² and a perimeter of 77.33 km, which reflects an intermediate configuration between elongated and compact. These basic data allow the calculation of essential morphometric indices, such as the Gravelius index (1.7140), which indicates a less compact basin with a longer hydrological response time;
- The analysis of the altimetric distribution revealed that most of the sub-basin is between 700 m and 1100 m of altitude. The concentration of area at higher altitudes, especially around 1080 m (representing 26.05% of the total area), indicates critical zones for erosion and sediment transport;
- The median altitude of 1035 m and the weighted average of 1020.49 m show a balanced but asymmetrical altimetric distribution, with greater concentration at intermediate altitudes;
- The form factor (0.1383) and the equivalent rectangle, with dimensions of 34.15 km x 4.734 km, confirm that the basin has an elongated shape. This implies longer concentration times and a moderate hydrological response, which reduces the risk of rapid flooding, but can prolong water accumulation in areas of low drainage;
- The average slope of the main river (8.51%) indicates that the sub-basin has stretches with significant slopes, increasing the speed of surface runoff and the potential for erosion. However, the average slope of the basin (9.795%) suggests a predominance of moderately inclined areas, while regions with slopes below 5% have a greater potential for water infiltration and sediment retention;
- The sub-basin has a drainage density of 0.41 km/km² and a channel frequency of 0.210 channels/km², values that indicate a relatively less dense drainage network. This configuration results in a concentration time of 7,580 hours, pointing to a slower hydrologic response. The average extent of surface runoff (0.616 km) reflects an efficient network, but with limitations to quickly capture surface runoff in extreme events;

The morphometric characterization of the Lova River sub-basin provides detailed and indispensable information for integrated environmental management. The data obtained guide Sociedade Mineira de Catoca, Lda., in the implementation of effective strategies for the sustainable use

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of natural resources and the mitigation of environmental impacts, ensuring a balanced relationship between mineral exploration and environmental preservation.

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