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Physiographic Characterization of the Tshopo River and Hydroelectric Dam Using Geomatics and Remote Sensing Tools

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***Abstract*: The Tshopo River watershed offers significant potential in terms of both energy and navigability. For example, hydroelectric developments have been underway since 1955, and the Kisangani River is supplied with water from this dam. A 2m x 2m spectral band was used to approximate reality, and a 30m x 30m pixel was used to visualize drainage densities and the shape (sinuation) of the watercourses. Maps presenting the study area, the length of the main watercourse, and the boundaries and watercourses were also produced using ArcGIS 10.8 and HEC-HMS 6.4.1 software, which were essential for carrying out this study. We were able to extract 839 sub-watersheds with physiographic characteristics (geometric, topographic/ hypsometric, and hydrographic features) with a total area of 19,306–19,317.31 km², a perimeter ranging from 1,030.1 to 1,142.04 km, and a main channel length of 561.7361 km. The Tshopo River has a low drainage density (i.e., less than 1). Our Tshopo River watershed is very elongated, as the gravel coefficient varies from 2.1 to 2.3 depending on the pixel size and spatial resolution; the steepest slopes are concentrated in the south-central part of the Tshopo watershed, with values ranging from 7 to 66 degrees, while the gentler slopes are much more concentrated around the dam (outlet) to the west. The vegetation cover (less dense and dense forest occupies more than 90%. And 10 altitudes classes according to their areas have been identified ranging from 455-506 m and 916-967 m with Time of Concentration (Tc) of 3766.8 minutes.**

***Keywords*: Physical characteristics, Tshopo River, Hydroelectric dam, Geomatics tools, Remote sensing.**

1. Introduction

In any hydrological study, the fundamental unit is the study of a river's watershed; therefore, our study will focus on the Tshopo River. The Tshopo River is one of the rivers within the hydrographic networks of the Democratic Republic of Congo. It originates in the Bafwasende territory but is largely located in the Ubundu territory and flows into a larger river called the Lindi River, which itself flows into the Congo River, specifically at the village of Yelenge.

In this study, we will focus on determining the physical characteristics of the river to allow other researchers to make use of them. The outlet for our study is the Tshopo hydroelectric dam. This data will allow any researcher to determine the peak flow and storage volume in order to model them, and will also allow them to determine the gross (hydraulic) power.

2. Problem Statement

At the Tshopo hydroelectric dam, large quantities of water are sometimes released during flood periods, and the gates are closed during low-water periods. Therefore, we focused on understanding the physical characteristics of the river, which constitute basic data, before delving into the research of other hydrological and hydraulic parameters. As researchers, allow us to pose a series of questions, namely:

- What are the physical characteristics of the Tshopo River at the hydroelectric dam?
- What are the key elements, using geomatics tools, that can influence the visualization of our satellite images?
- In the case of our outlet (dam), which hydrographic element should we consider most?

3. Hypothesis

We will attempt to answer the questions posed in the problem statement to facilitate our work.

- Geometric, topographic/hypsometric, and hydrographic characteristics are the physical characteristics to be determined for our study.
- Pixel size and spatial resolution are two essential elements for clearly visualizing the details of sub-watershed images and closely representing real-world conditions.

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- The hydrographic element we can consider is drainage density.

4. Methodology

A. Presentation of the Study Area

1) Presentation of the Study Area (Tshopo River Watershed)

The studied watershed is drained by the Tshopo River in the north-central part of the Democratic Republic of Congo. It is located between latitudes −0.23°S and 1.24°N and longitudes 25.12° and 27.45°E. It is bordered by the Maïko watershed to the south, the Lindi watershed to the north, and the Congo River valley to the southwest. The Tshopo River is the one that gave its name to the province. Its source is located within the province itself, in the Bafwasende territory, and it flows into the Lindi without ever leaving this provincial area (Otemikongo et al.)[1] and cited by MASUNDI F, 2024).

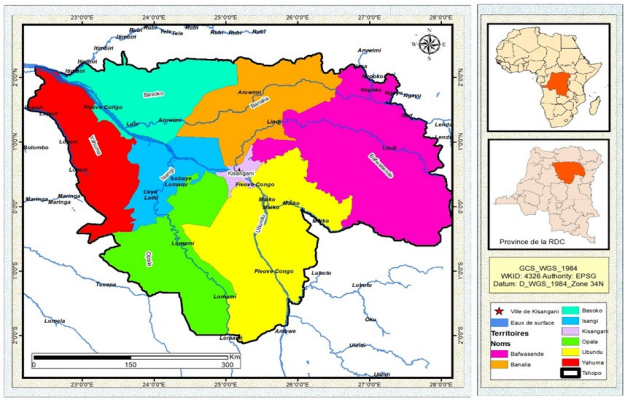

Fig. 1. Administrative map of Tshopo province using ArcGIS 10.8 software

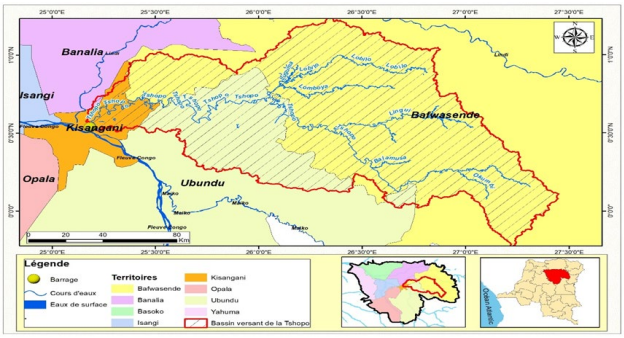

Fig. 2. Map showing the location of the Tshopo river within the territory using ArcGIS 10.8 software

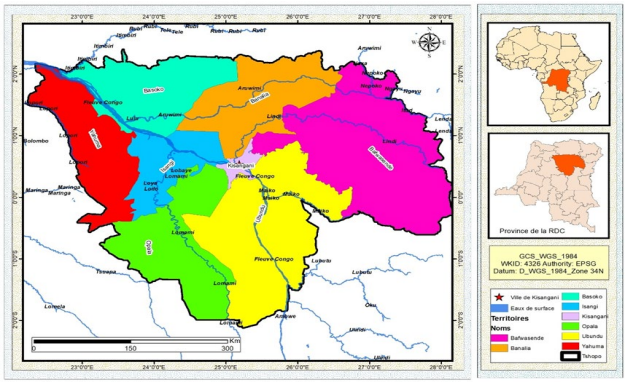

Fig. 3. Administrative map of Tshopo province using ArcGIS 10.8 software

The Tshopo River is located in the Democratic Republic of Congo (DRC), specifically in Tshopo Province.

It is a tributary of the Lindi River, which itself flows into the Congo River downstream from the city of Kisangani. The Tshopo River basin extends into this region, in the northeast of the DRC, in an area characterized by tropical rainforest. The city of Kisangani, one of the largest cities in the country, is located at the confluence of the Tshopo and Lindi rivers, very close to the mouth of the Tshopo and Lindi rivers. The basin covers an estimated area of approximately 17,200 km² [Omasombo Tshonda, J. (Dir.), Otemikongo Mandefu, J., et al. (2021)]**[2]**.

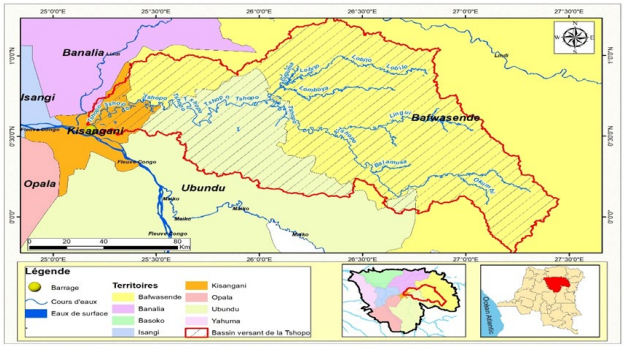

Fig. 4. Map showing the location of the Tshopo river within the territory using ArcGIS 10.8 software

An important point to note regarding the representations on the administrative maps is that, according to the CENI (Independent National Electoral Commission) mapping, the Tshopo River is largely located within the Ubundu Territory, while it is actually found primarily within the Bafwasende Territory (see figure below).

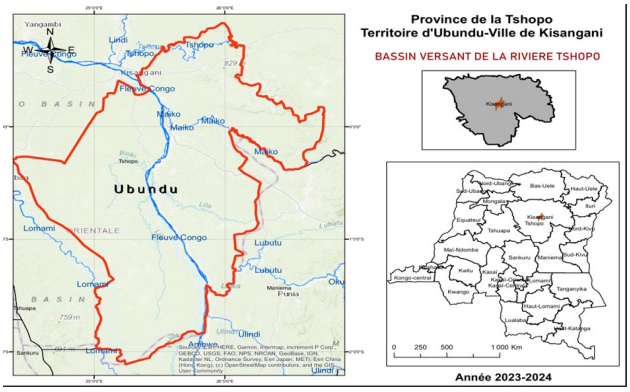

Fig. 5. Map delineating the Tshopo river watershed from the dam using QGIS software

The Tshopo River is located in the Democratic Republic of Congo (DRC), specifically in the Tshopo Province [3] [Taken from the book published by (Beeckman, H., et al. 2021) And Mashauri, F., Mbuluyo, M., & Nkongolo, N.; 2023)].

It is a tributary of the Lindi River, which itself flows into the Congo River downstream from the city of Kisangani. The Tshopo River watershed therefore extends into this region, in the northeast of the DRC, in an area characterized by tropical rainforest. The city of Kisangani, one of the largest cities in the

country, is located at the confluence of the Tshopo and Lindi rivers, very close to the mouth of the Tshopo River. The watershed covers an estimated area of approximately 17,200 km².

2) Physiographic Characteristics of the Tshopo River and its Watershed

The Tshopo River watershed is located in the north-central part of the Democratic Republic of Congo, within the Tshopo Province.

- *Watershed Area*: The Tshopo watershed has an estimated area of approximately 17,200 km² (according to Wikipedia) or up to 19,335 km² (according to a ResearchGate source), making it a medium-sized watershed in the Congolese context.
- *Topography and Geomorphology*: The watershed lies at the boundary between the vast Congo Basin and the eastern mountain region. It is primarily composed of unconsolidated formations of the central basin, which makes it subject to significant water erosion, particularly during heavy rainfall. The shape of the watershed is described as elongated.
- *Hydrographic Network*: The Tshopo River is a tributary of the Lindi River, which itself flows into the Congo River downstream from Kisangani. The basin has a dense hydrological network.
- *Vegetation and Forest Cover*: The Tshopo watershed is primarily covered by Guineo-Congolian rainforests (dense, humid tropical forests). However, this forest cover is under pressure from deforestation (slash-and-burn agriculture, charcoal production), which exacerbates erosion and sedimentation problems.
- *Average Flow*: The average flow of the Tshopo River is estimated to be between 300 and 450 m³/s, with extremes ranging from a minimum of 30 m³/s to a maximum of 1,100 m³/s. This variability is crucial for hydroelectric power generation.
- *Altitude*: Kisangani, located at the confluence of the Tshopo and Lindi rivers, has an altitude of approximately 393 meters.

B. Extraction/Delimitation of the watershed and its Sub-Watersheds Using HEC-HMS

Two software programs were used: ArcGIS 10.8 and HEC-HMS 4.6 for extracting the watershed and its sub-watersheds.

1) First Case: HEC-HMS 4.6

Table 1
Altitude class du bassin versant de la rivière extraite à partir Du logiciel Arcgis 10.8

Class	Interval
1	357 – 375
2	375 – 387
3	387 – 397
4	397 – 405
5	405 – 413
6	413 – 421
7	421 – 429
8	429 – 437
9	437 - 445
10	445 - 482

The HEC-HMS 4.6 software was used to begin the extraction and generation of the 13 sub-watersheds. It subdivided the Tshopo basin into 10 classes with the following DEM (Table 1).

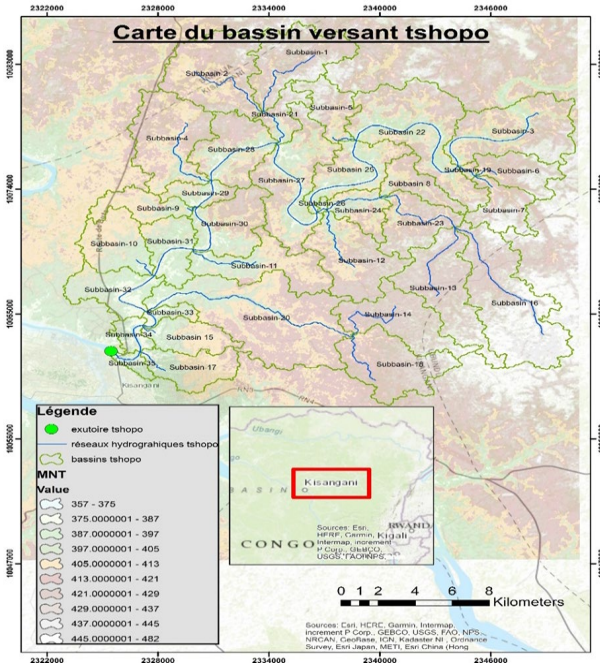

Fig. 6. Map of the Tshopo river basin with the software HEC-HMS 6.4.1

2) Second Case: Extraction of the Tshopo River Basin with ArcGIS 10.8

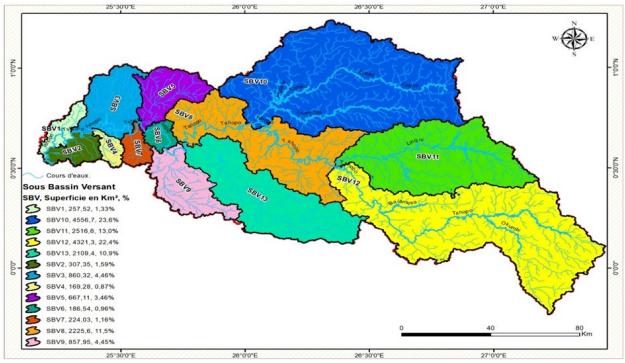

Fig. 7. Map delineating the Tshopo river watershed using ArcGIS 10.8

3) Third Case: Extracting the Tshopo River watershed

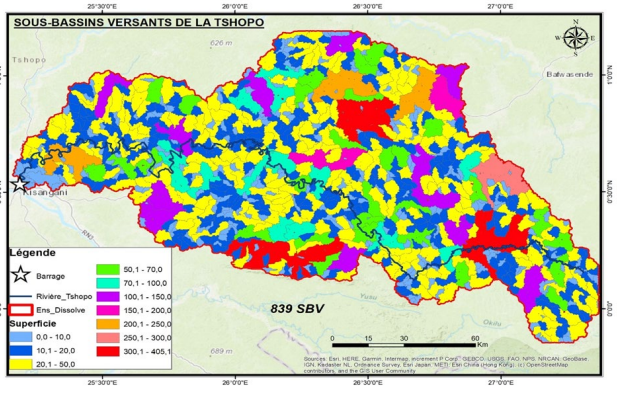

Fig. 8. Map of the 839 sub-watersheds of the Tshopo river using ArcGIS 10.8 software

To better reflect reality, as we are working in geomatics, we chose to reduce the pixel size. Thus, to generate this map of the 839 sub-watersheds, we reduced the pixel size of the SRTM satellite image from 30m x 30m to 2m x 2m using the "resample" tool in ArcGIS 10.8. However, to create the map of the 16 sub-watersheds, the pixel size must be maintained at 30m x 30m.

Using ArcGIS 10.8 software, we determined the following geometric characteristics: the area and perimeter of the 936 sub-watersheds.

Notes :

- The smaller the spatial resolution, the more detailed the information. In this case, we used a pixel size of 5 meters.
- In this work, to better reflect reality, as we are working in geomatics, we chose to reduce the pixel size. Thus, to generate this map of the 839 sub-watersheds, we reduced the pixel size of the SRTM satellite image from 30m x 30m to 2m x 2m using the "resample" tool in ArcGIS 10.8. However, to run the map of the 16 sub-watersheds, the pixel size must be maintained at 30m x 30m.

5. Results and Discussions

A. Results

1) Geometric Characterization of the Tshopo River

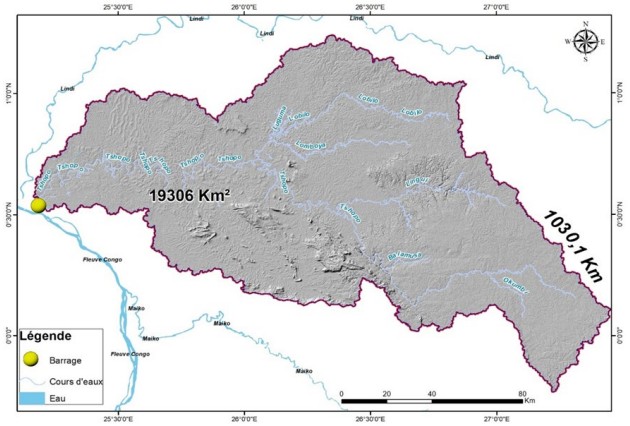

Fig. 9. Map showing the area of the catchment basin, with the Tshopo hydroelectric dam as its outlet

- *Compactness Index*

The Gravelius compactness index (1914, in Roche 1963), KG, is also called the shape coefficient (Strahler, 1964). It is defined as the ratio of the catchment perimeter (P) to the perimeter of a circle of the same area. It provides an indication of the shape of the catchment basin, which influences the overall flow of the watercourse and, in particular, the shape of the hydrograph (a graphical representation of the evolution of the flow rate QP as a function of time TC in our case), resulting from a given rainfall event, at the basin outlet.

$$K_G = 0.28\ P/\sqrt{A}$$

- *Horton Shape Index, KH* [5]

The KH shape index of a watershed is the relationship between the watershed area (km²) and the length of the main watercourse (km⁴). It is less than 1 for an elongated watershed and greater than 1 for a compact watershed.

$$KH = A/L^6$$

For the Tshopo watershed, with an area A = 19,305.5 km² and the length of the main watercourse L = 561.7 km, the Horton shape index, KH = 0.06, is less than 1. Consequently, the watershed is elongated and therefore prone to generating torrential runoff during periods of heavy rainfall.

- *Equivalent rectangle*

[or Gravelius rectangle] is a theoretical geometric construction allowing the comparison of watersheds of different shapes by reducing them to a rectangle having the same area (A), the same perimeter (P) and, consequently, the same compactness index (KG)][7] [(F., Rousselle, J., & Lauzon, N. (2021)].

The lengths of the equivalent rectangle;

The widths of the equivalent rectangle;

$$L = \frac{K_G\sqrt{A}}{1.12}\left[1 + \sqrt{1 - \left(\frac{1.12}{K_G}\right)^2}\right]$$

$$l = \frac{K_G\sqrt{A}}{1.12}\left[1 - \sqrt{1 - \left(\frac{1.12}{K_G}\right)^2}\right]$$

The length of the main watercourse is 541 km, found using the geomatics tool, ArcGIS 10.8.

2) Topographic/Hypsometric Characteristics

The hypsometric map and hypsometric curve are fundamental tools for analyzing the vertical structure of a watershed. They allow us to translate the spatial distribution of altitude, a parameter that directly influences climate, vegetation, and runoff regime, as cited by (Musy, A., Higy, C., & Reynard, E.) [8]. Let's start with the slope, then the hypsometric map, and finally the hypsometric curve.

Table 2
Watershed geometric characteristics

Geometric Parameters		Values	Units
Area		19306 -19317.31	Km²
Perimeter		1030.1 – 1142.04	Km
Gravelius Compaction Index, KG		2.1- 2.3	Cte
Equivalent Rectangle	Length	481,8 – 534.9	Km
	Width	36.11-39.1	Km
Horton Shape Index, KH		0.06	Cte

- *Slopes of the Tshopo Watershed*

Analysis of Figure 14 shows that the steepest slopes (in red) are concentrated in the south-central part of the Tshopo River basin, with values ranging from 7 to 66 degrees, while the gentler slopes (in blue) are much more concentrated around the dam (outlet) to the west.

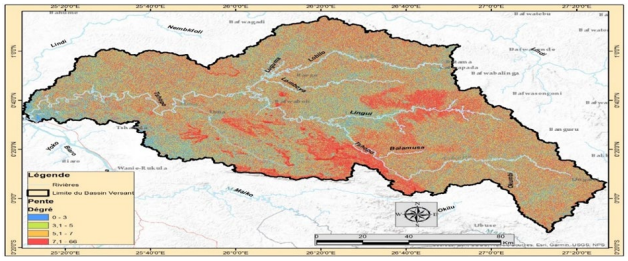

Fig. 10. Hypsometric map of the Tshopo river basin using ArcGIS 10.8

- *Hypsometric curve*

The figure above shows the hypsometric map of the Tshopo River basin with 10 elevation classes. From this map, we have constructed the hypsometric curve below, as well as the table of cumulative areas.

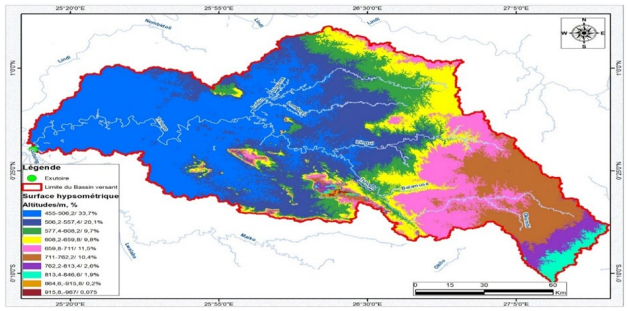

Fig. 11. Hypsometric curve of the Tshopo river basin avec le logiciel Arcgis 10.8

Table 3
Classification of altitudes based on the area of the tshopo river Sub-Watersheds

Altitude Class	Area in km²	Percentage	Cumulative
455-506	6500,9	33,7	100,0
506-557	3884,3	20,1	66,3
577-609	1874,4	9,7	46,2
608-660	1883,8	9,8	36,5
660-711	2226,4	11,5	26,7
711-762	2012,8	10,4	15,2
762-813	510,9	2,6	4,8
813-847	360,2	1,9	2,1
865-916	36,8	0,2	0,3
916-967	14,6	0,1	0,1

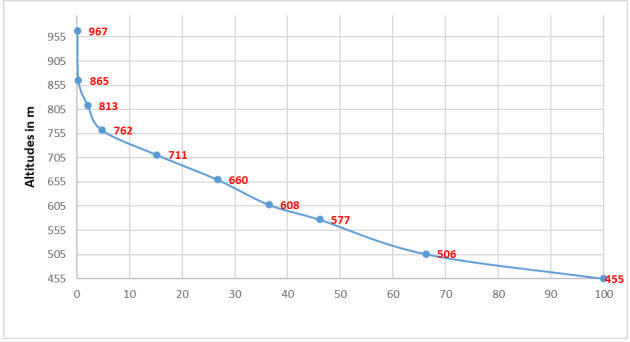

Fig. 12. Longitudinal profile graph of the Tshopo river using ArcGIS 10.8

- *Elevation difference*

D: Elevation difference is the difference between Za% and Zb%. Za%: High elevation greater than a given height representing a% (Z5) of the basin area. Zb%: Low elevation greater than a given height representing b% (Z95) of the basin area.

$$D = Za\% - Zb\%$$

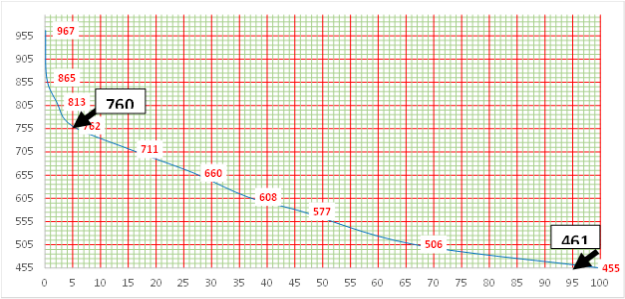

Fig. 13. Graph showing maximum and minimum elevations produced by ArcGIS 10.8

The overall slope index (Ig) is the square root of the basin area (A). It is expressed in meters and is theoretically independent of the basin area. Several relief classes are distinguished based on Ds (see table below). It is calculated using the formula:

$$Ds = Ig \sqrt{A}$$

Table 4
Relief classification according to the ORSTOM 9 method (FAO-hydrological database, 2022)

Relief	Type Classes	DS
R1	Very slight relief	10
R2	Slight relief	10-25
R3	Fairly slight relief	25-50
R4	Moderate relief	50-100
R5	Fairly significant relief	100-250
R6	Significant relief	250-500
R7	Very significant relief	>500

- *Elevations*

Average Altitude

$$\textbf{\textit{Average altitude}} = \sum \frac{\textbf{\textit{Ai.hi}}}{\textbf{\textit{A}}}$$

Altmoy: average altitude in m; A: basin area in km²;
Ai: area between two consecutive contour lines (km²);
hi: average altitude between two contour lines (m).

Table 5
Classification of Altitudes based on the surface areas of the sub-watersheds of the Tshopo river

Altitude Class	Ai	hi	Ai.hi
455-506	6500,9	480,5	3123682,45
506-557	3884,3	531,5	2064505,45
577-609	1874,4	593	1111519,2
608-660	1883,8	634	1194329,2
660-711	2226,4	685,5	1526197,2
711-762	2012,8	736,5	1482427,2
762-813	510,9	787,5	402333,75
813-847	360,2	830	298966
865-916	36,8	890,5	32770,4
916-967	14,6	941,5	13745,9
Total	**19305,1**	**7110,5**	**11250476,8**

- *The Median Altitude*

It corresponds to the point with an abscissa of 50% on the hypsometric curve.

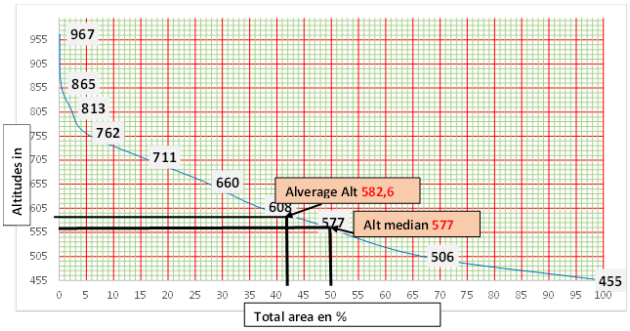

Fig. 14. Graph showing the mean and median elevations of the Tshopo river basin using ArcGIS 10.8

- *Slope Indices*
- Average Slope of the Watershed
-

$$Im = 100\ (Eq * Lcn)/A$$

Where,

Lcn: Total length of contour lines [km]

This can be measured using GIS software such as ArcGIS or Global Mapper.

Eq: Equidistance between two contour lines [km]

A: Watershed area [km²]

Im: Average slope [m/km or %]

- *Rock Index*

$$\mathbf{Ir} = \frac{1}{\sqrt{L}} \sum ai.di$$

ai is the percentage of the area between the contour lines.

di is the distance between the contour lines, also called the elevation difference.

Table 6

Classification of percentages of altitudes and elevation changes based on area

Altitude Class	Area in km²	Percentage (ai)	Elevation Change (di)	√((ai.di))
455-506	6500.9	33.7	51	41.5
506-557	3884.3	20.1	51	32.0
577-609	1874.4	9 ,7	32	17.6
608-660	1883.8	9.8	52	22.6
660-711	2226.4	11.5	51	24.2
711-762	2012.8	10.4	51	23.0
762-813	510.9	2.6	51	11.5
813-847	360.2	1.9	34	8.0
865-916	36.8	0.2	51	3.2
916-967	14.6	0.1	51	2.3
Totals	19305.	1	100	185.9

- *Overall Slope Index*

$$Ig=D/L$$

D: Elevation difference Za% - Zb% defined on the hypsometric curve between 5% and 95% or visually on the topographic map

L: Length of the equivalent rectangle

3) Hydrographic Characteristics of the Tshopo River

The hydrographic characteristics of the Tshopo River basin are as follows:

- Drainage Density (Dd);
- Length Ratios (Rl);
- Confluence Ratio (Rc);
- Frequency of Watercourses (Fc);
- Torrentiality Coefficient (Ct);
- Sinuosity Coefficient;
- Time of Concentration (Tc)
- Watershed Time of Concentration

The time of concentration is the time required for runoff to travel from the hydraulically furthest point in the watershed to its outlet. This parameter is used in most methods for determining peak flows. Several formulas exist for estimating the time of concentration (tc):

- Giandotti's Formula:

$$tc = (4\sqrt{(A + 1.5L)})/(0.8\sqrt{h})$$

Where:

tc: time of concentration of the watershed in hours

Table 7

Topographic/Hypsometric characteristics of the Tshopo river basin

Hypsometric/Topographic Parameters		**Values**	**Units**
Overall The altitudes	Elevation Difference	299	m
	Specific Elevation Difference Specific Elevation Difference	86	Cte
	Elevations Mean Altitude	582,8	m
	Median Altitude	577	m
	H5%	760	m
	H95%	461	m
	Max Alt	967	m
	Min Alt	455	m
Slopes	Mean Slope	0.07	%
	Rock Slope Index	0.62	%
	Overall Slope Index		0.62%

A: size of the watershed in km²
L: length of the main thalweg in km
h: difference between the average watershed elevation and that of the outlet, in m.
h=Alt.average-Altminimum
L: 561.7 km
A: 19,305.1 km²

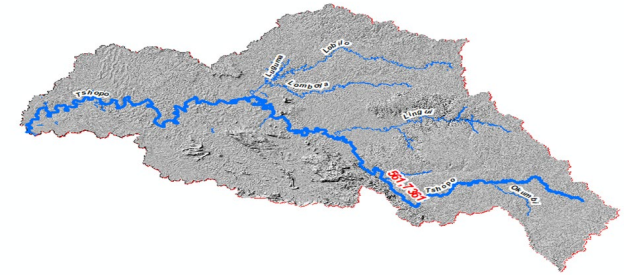

Fig. 15. Map showing the length of the main watercourse

- *Drainage density*

Drainage density is the total length of the drainage network per unit area of the catchment:

$$Dd = \frac{\sum_{i=1}^{n} Li}{A}$$

Dd: drainage density [km/km²];
Li: total length of all watercourses of order i [km];
A: catchment area [km²].

In practice, drainage density values vary from 3 to 4 for regions where runoff is very limited and centralized; they exceed 1000 for some areas where runoff is highly branched with little infiltration.

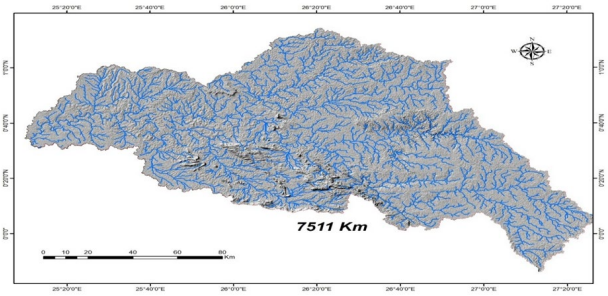

Fig. 16. Map showing the drainage density of the Tshopo river using ArcGIS 10.8

In practice, drainage density values vary from 3 to 4 for regions where the flow is very limited and centralized; they exceed 1000 for some areas where the flow is highly branched with little infiltration (KISANGALA MUKE, 2009).

- *Hydrographic Density*

Hydrographic density represents the number of drainage channels per unit area.
F: hydrographic density [km⁻²];
Ni: number of watercourses
A: basin area [km²]

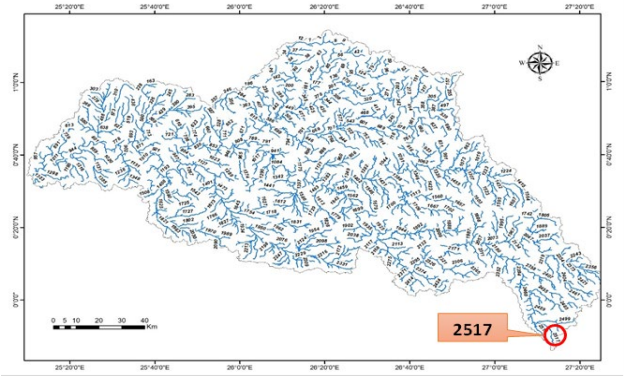

Fig. 17. Map representing the hydrographic frequency of the Tshopo river using ArcGIS 10.8 software

[Since determining the order of watercourses (hierarchy) is a crucial step in the morphometric analysis of a watershed, as it involves assigning a number to each segment of the network according to its position and importance in the overall structure, the most widespread method being Strahler's method; its role is thus to: i) quantify branching (bifurcation ratio), ii) assess network maturity, iii) model pollutant fluxes and biodiversity, iv) standardize comparisons][10] (Musy, André; Higy, Christophe; Reynard, Emmanuel, 2024).

- *Confluence Ratio*

This is the ratio of the number of streams of order n to the number of streams of order n + 1.
Rc(n) = (number of streams of order n)/(number of streams of order n + 1) = N(n)/N(n + 1) = Constant

- Length ratio

$$Rl = \frac{L(n+1)}{L(n)}$$

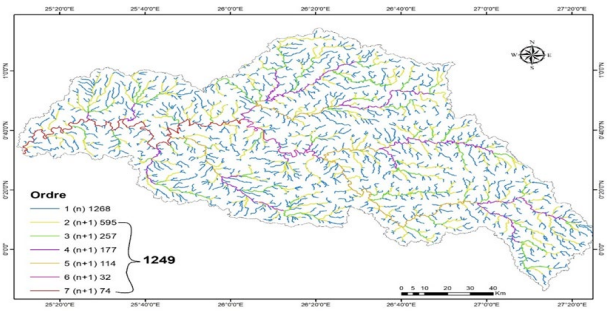

Fig. 18. Map showing the order and ratio of confluences of the Tshopo River using ArcGIS 10.8

- *Longitudinal profile of the Tshopo River*

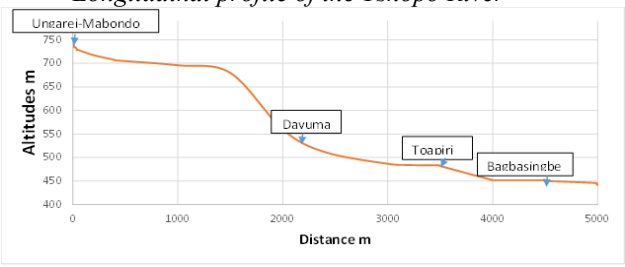

Fig. 19.

Table 8
Hydrographic characteristics of the Tshopo river

Hydrographics parameters	Values	Units
Time of Concentration	3766.8	Minutes
Drainage Density	0.38	Km/Km²
Hydrographic Density	0.13	Km^{-2}
Confluence Ratio	1.015	Cte
Length Ratio	0.967	Cte
Torrentiality Coefficient (Ct); Sinuosity Coefficient; Watershed Time of Concentration		

Notes: avec le logiciel HEC-HMS, nous avons trouvé les résultats que voici:

- Drainage Density: 0.00 – 1,6
- Torrentiality coefficient: 0.10 – 3.01
- Soil indexing coefficient: 54 – 64
- Length ratio: 1.48 – 8.8

Les caractéristiques hydrographiques seront étudiées en détails dans le prochain articles « intitulé caractéristiques géospatiales du bassin versant de la rivière Tshopo »

- *Land cover*

Forests regulate stream flow and mitigate low- to medium-amplitude floods; their effect on extreme flows is reduced. Bare soil promotes rapid runoff and significant erosion.

- Forest cover index K = (Forest area)/(Watershed area) x 100

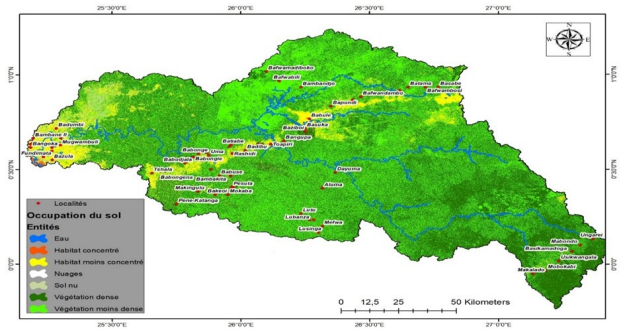

Fig. 20. Land cover map of the study area

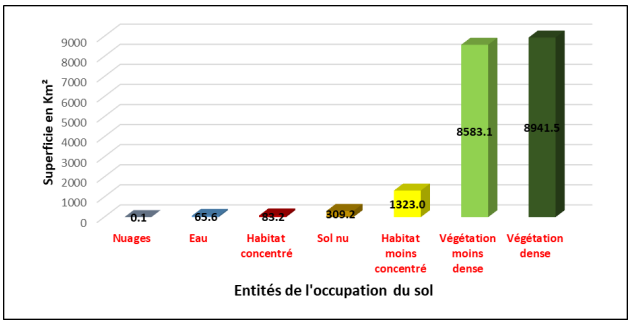

Fig. 21. Graph representing land cover features

Urbanized areas

- Imperviousness rate = (Impervious surface area) / (Watershed area) x 100

According to this figure, vegetation covers a large area in the Tshopo River Basin, accounting for over 90% of the total area, estimated at 19,306 km². Habitats occupy only 5.1%. Water bodies cover 65.6 km², or 0.34% of the total area. These values were extracted from Landsat 8 satellite imagery from 2023 and processed using ArcGIS 10.8 software to identify the different land cover classes shown in this figure.

Table 9
Land cover parameters

Land Cover Parameters	Values	Units
Forest Cover Index K	90,8	%
Seamless Rate	5,1	%

B. Discussions

1) Geometric Characteristics

The shape of a watershed is determined by the Gravelius equation, and its classification is as follows:

Based on the gravel coefficient, we can say that the Tshopo watershed is very elongated, as KG varies from 2.1 to 2.3 depending on the pixel size and spatial resolution.

2) Topographic/Hypsometric Characteristics

Analysis of Figure 14 shows that the steepest slopes, shown in red, are concentrated in the south-central part of the Tshopo watershed, with values ranging from 7 to 66 degrees, while the gentler slopes, shown in blue, are much more concentrated around the dam (outlet) to the west.

3) Hydrographic Characteristics

The drainage density of a hydrographic network can be classified (inspired by the work of Horton and Strahler) and cited by [NZANGO, 2024 and Mashauri, F., Mbuluyo, M., & Nkongolo, N. (2024).][12]:

The drainage density of the Tshopo River's hydrographic network is either very low or low (0.38 to 1.3 km/km²), while the hydrographic density is 0.13 km². Therefore, the Tshopo River is characterized by both low drainage density and low hydrographic density.

Analysis of Figure 18 shows that the Tshopo River's hydrographic network is of order 7.

4) Land Use

I quote: "Land Use and Land Cover (LULC) studies consist of mapping and analyzing the nature of land surfaces (forests, crops, urban areas, water bodies) and their uses by humans." In hydrology and land-use planning, these studies are crucial because the nature of the vegetation cover determines the distribution between infiltrating and runoff water.

- Both sparse and dense forests significantly influence the climate in this Tshopo River basin, even though drainage and hydrographic densities are low;

Table 10
Watershed Shape Classification[11]

KG Value	Watershed Shape	Impact on Runoff
1,00 < KG < 1,12	Circulaire à carrée	Réponse hydrologique rapide; les pointes de crues des affluents arrivent simultanément.
1,12 < KG < 1,25	Ovale à intermédiaire	Forme standard; drainage équilibré.
1,25 < KG < 1,50	Allongé	Temps de concentration plus long; atténuation naturelle des débits de pointe.
KG > 1,50	Très allongée	Écoulements très étalés dans le temps; risque de crue plus faible.

Taken from the book published by [Musy, A., Higy, C., & Reynard, E. (2024)][11]

Table 11
Classification of drainage densities

Density Class	Value (km/km²)	Interpretation and Characteristics
Very low	< 1,0	Terrains très perméables (ex: sables, karsts), relief plat, forte infiltration.
Low	1,0 - 2,0	Roches perméables, végétation dense, drainage peu efficace.
Medium	2,0 - 4,0	Conditions mixtes, drainage modéré.
High	4,0 - 6,0	Roches imperméables, relief accentué, faible infiltration, réponse rapide aux pluies.
Very high	> 6,0	Zones arides à forte érosion (Badlands) ou terrains montagneux très imperméables.

Other researchers have also given this classification [André Musy, Christophe Higy and Emmanuel Reynard][13]

- The water surface area is very small: 269.3 km² (or 1.4%) of the total watershed area of the Tshopo River hydrographic network.

6. Conclusion

With geomatics and remote sensing tools, we can solve many problems, events, and phenomena in life, but certain parameters such as clouds, winds, pixel size, and spatial resolution must be taken into account to achieve the desired results.

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Availability of Data and Materials: The data and tools used in this modest work are available upon request from the authors. Details regarding access to the data and tools can be obtained by contacting this email address: emmanuelmokili754@gmail.com.

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