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GEOMORPHOLOGICAL AND HYDROCLIMATIC CHARACTERIZATION OF THE CATUMBELA AIVER BASIN AND AUB-BASINS, IN ANGOLA

(Apresentado no 13.º Simpósio de Hidráulica e Recursos Hídricos dos Países de Língua Portuguesa – Silusba, de 13 a 15 de setembro de 2017, no Porto)

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GEOMORPHOLOGICAL AND HYDROCLIMATIC CHARACTERIZATION OF THE CATUMBELA RIVER BASIN AND SUB-BASINS, IN ANGOLA

Jorge E. Matos[1]

ABSTRACT

From all the Atlantic river basins in Angola, which belong to rivers originating in Angolan territory, the largest one is the Kwanza river basin. After this, in order of areas magnitude, there are the basins of the rivers Longa, Queve (Cuvo), Catumbela (in the group of the Center-West Basins) and Coporolo and Kuroca, (in the group of Southeastern Basins), although the latter has a dry bed most of the year. All these rivers and their basins are little studied and documented.

Before Angola's independence (in 1975), the Kwanza, Queve and Catumbela rivers were the subject of several studies, which were the genesis of the hydroelectric plants currently existing on the Catumbela river, namely, President Oscar Carmona dam (now known as the Biópio Dam) and the Lumaum Dam. However, after more than 50 years on the studies carried out, it is necessary to update or even verify them with the help of the new tools that the engineer currently has, namely information collected by satellites and digital information software (GIS).

And that is the main purpose of this study.

This study makes the geographical delimitation of the Catumbela river basin and the various sub-basins of its tributaries and, for each one of them, presents the various geographic characteristics (like drainage area, Gravélius index, shape factor), elevation characteristics (like hypsometry, mean altitudes and heights, watercourses longitudinal profiles, mean slope and slope index of the basin) and characteristics of the drainage systems (drainage density, runoff mean extension and average length). In addition, an average annual rainfall map of the basin is presented on the basis of rainfall data collected from the Tropical Rainfall Measuring Mission (TRMM) satellite over 16 years, between 2000 and 2015.

Keywords: water resources, hydrology, hydropower, rainfall and environmental

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changes.

Theme: The objectives of sustainable development and the improvement of water quality in Africa

1. INTRODUCTION

The watershed of the Catumbela River began to be studied in the 1940's when, from the ministerial order of October 27, 1942, the hydroelectric project of the Catumbela River was analyzed, guided by the Brigade of Studies on the Production and Distribution of Electric Energy in the Urban Centers of Angola and Saint Tomé, headed by the electrotechnical engineer José Colen.

In September 1943, this brigade presented its work entitled "General design of the project relating to the works of a hydroelectric plant in the Lower Catumbela river for the supply of energy to the cities of Lobito and Benguela", in which it considered that the flows of the river were of 15 m^3/s in drought, and 1,600 m^3/s in maximum flood. The estimated area of the river basin, upstream of the dam, was 15,000 km^2.

Between 1956 and 1963 Catumbela River was studied by the Office of Studies and Projects Design of Prof. Dr. Alberto Abecassis Manzanares (later Hydroelectric Portuguesa), where António Quintela, who was the 3rd doctorate in civil engineering by the University of Lisbon, was appointed author, professor and designer of the hydroelectric plant of Alto Catumbela in Angola, and the Cahora Bassa dam in Mozambique, among others. In 1974, Luis Gomes Ferreira (1974), chief engineer of the General Direction of Public Works and Communications, of the Ministry of the Ultramar reported in his article "Hydrological Occupation of Angola" that the basin of the Catumbela River would have 14,120 km^2 of area.

In 2005, in a study carried out for the Angolan government on the country water needs, the Norwegian firm SWECO GRONER (2005) indicates the area of the Catumbela river basin as having an area of 16,532.6 km2, a perimeter of 747.9 km and a format that can be seen in figure 1.

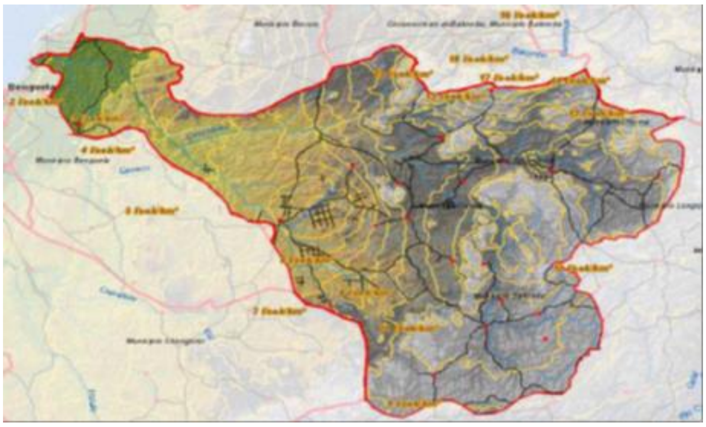


Figure 1 - Map of the Catumbela river basin, according to SWECO (2005), where it points to an area of 16,532 m^2 and a perimeter of 747.9 km.

Therefore, although the two hydroelectric plants built in this river and three more large capacity dams were forecast, there was some uncertainty, not only about the shape and size of the river basin but also about its sub-basins and their respective flows.

The Portuguese firm GESTO Energy Consulting (2014), in a study carried out for the Ministry of Energy and Waters of Angola, found that the Kwanza, Queve, Catumbela and Cunene rivers represent 86% of Angola's electricity potential. This potential can be used for large hydropower projects but also for small hydro power plants (up to 10 MW) which will be an important source of renewable energy.

The construction sites for this dams are yet to be identified, although GESTO has already forecast about 100 suitable sites for small hydropower stations across the country. According to the United Nations Development Program, (2015) it is necessary to deepen this study in order to locate more locations for small and mini hydroelectric plants.

This study also intends to contribute to the identification of these sites, not only in the main Catumbela River, but also in some tributaries with flows that allow energy production, helping to identify the characteristics of the sub-basins and their flows.

2. GEOMORPHOLOGICAL CHARACTERIZATION

The catchment area of the Catumbela River occupies a substantial part of the territory of Benguela province. The Catumbela River flows into the city of the same name, located approximately between the main cities of Lobito and Benguela. Figure 2 shows the relative position of the basin relative to the country and the province of Benguela.

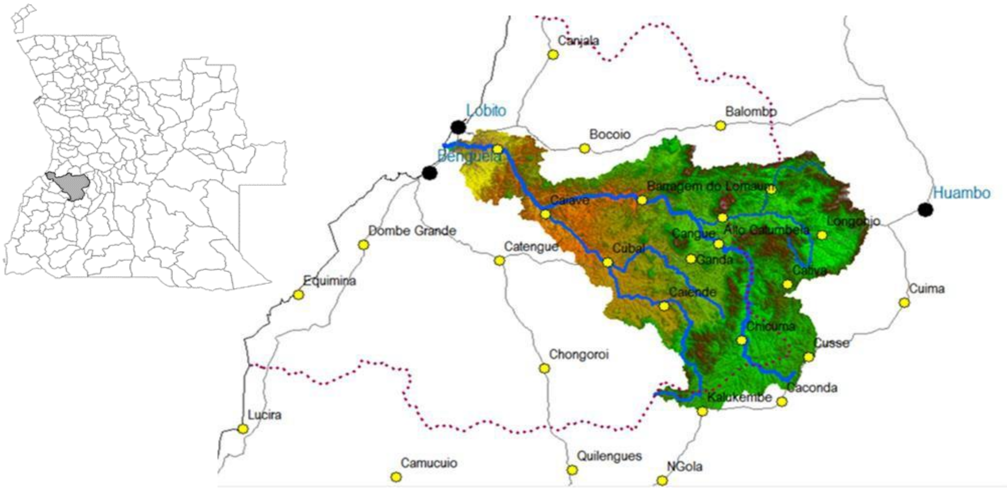


Figure 2 - Location of the Catumbela river basin relative to the country and to the province of Benguela (source: author)

The survey of the area and topography of the basin was obtained based on raster files of the digital elevation models (DEM) of the zone, spaced 30 m, downloaded from the USGS (United States Geologic Survey) website. These DEMs were then worked on with GIS (geographic information system) softwares (in this case Qgis and SAGAGis) in order to obtain relevant information for the desired effect.

The general basin was divided into nine sub-basins, and for each of them its main watercourse and its tributaries were analyzed. Figure 3 shows the division of the general basin into nine sub-basins, which was given the name of the main river, which are the following: Low Catumbela, Middle Catumbela, Lower Hanha Cubal, Upper Hanha Cubal, Cubal da Ganda, Low Cuiva, Alto Cuiva, Cubal and finally Alto Catumbela where the source of this river is located.

Figures 4 to 21 present the hypsometric charts of each of the sub-basins, where the main water line and its tributaries can be seen, as well as the longitudinal profile of the main water course of each sub-basin.

For each sub-basin, the following characteristics were studied, which are presented in Table 1: area (A), perimeter (P), average width (l), main waterline length (Lr), compactness index (Kc), form factor (Kf), elongation index (K1), total length of water lines (Lt), drainage density (Dr), mean runoff (Ps), mean basin altitude (Z), height (H), mean slope of the main waterline (Dm) and global slope index of the basin (Id).

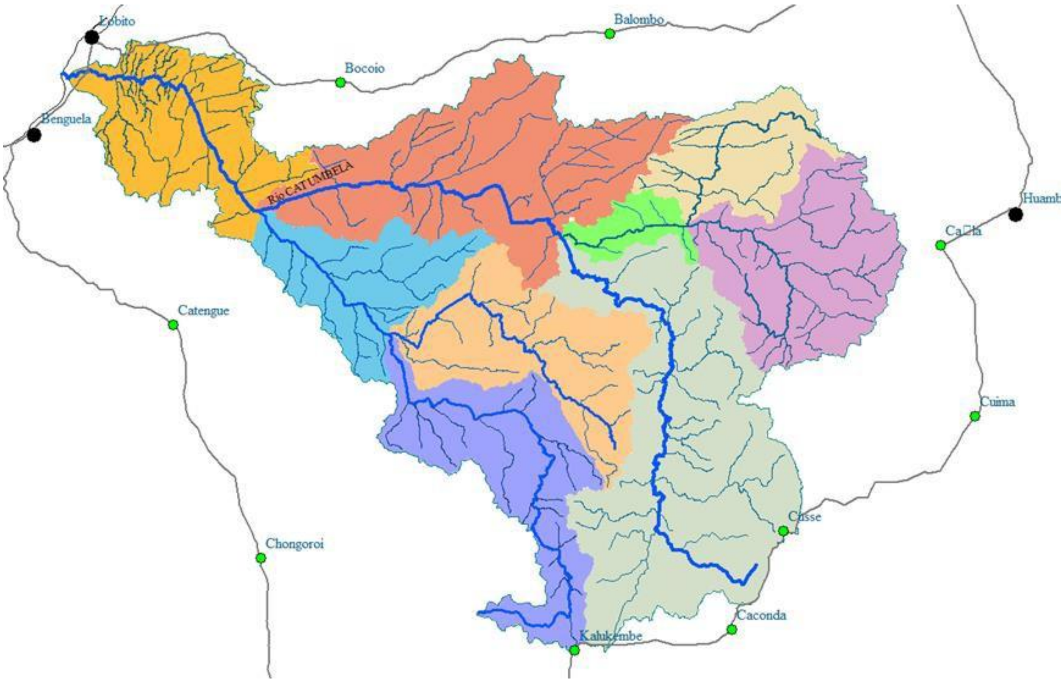
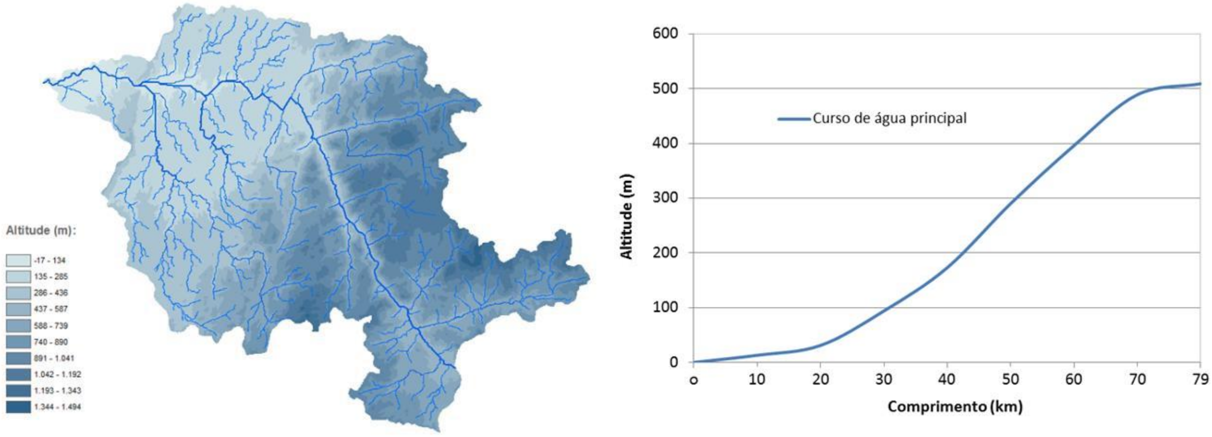
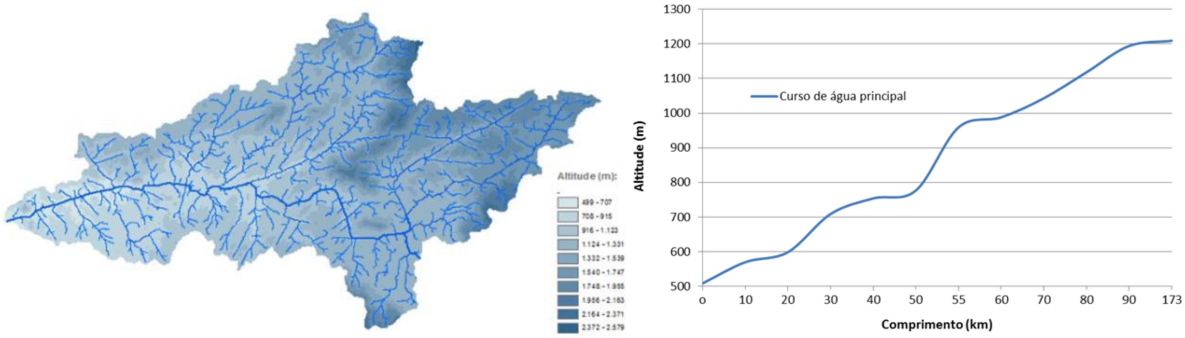


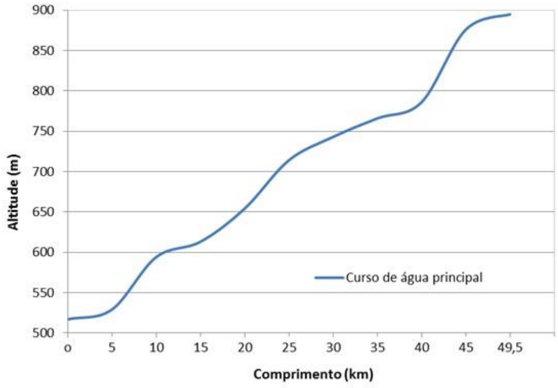
Figure 3 - Division of the area of the Catumbela river basin, in nine sub-basins. (Source: author)



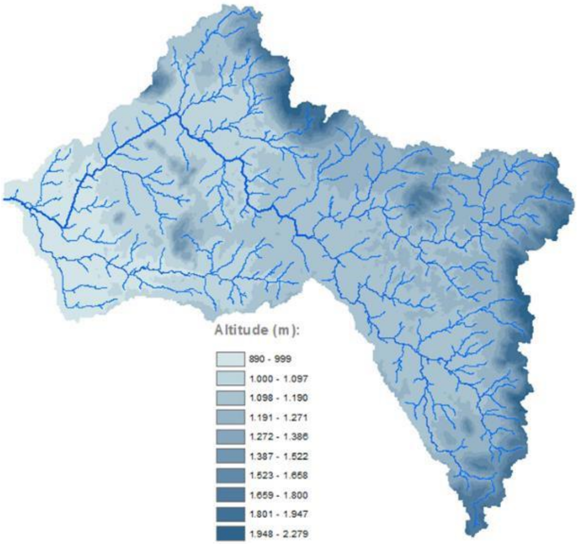
Figures 4 and 5 - Hypsometric chart of the Low Catumbela sub-basin and its longitudinal profile.

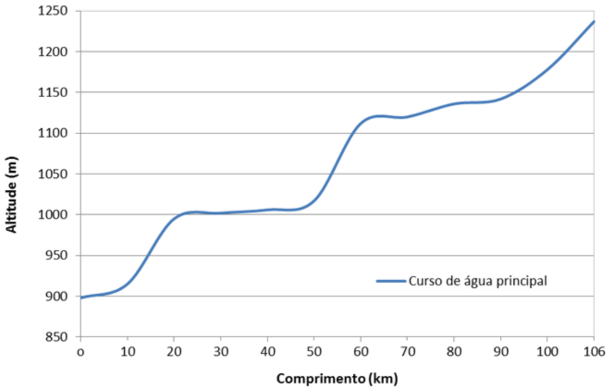


Figures 6 and 7 - Hypsometric chart of the Medium Catumbela sub-basin and its longitudinal profile.

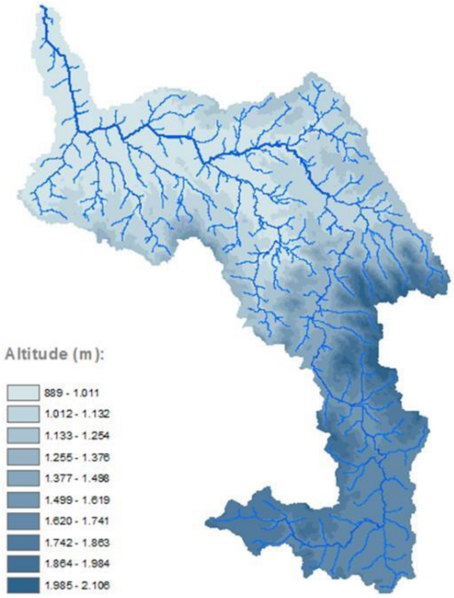


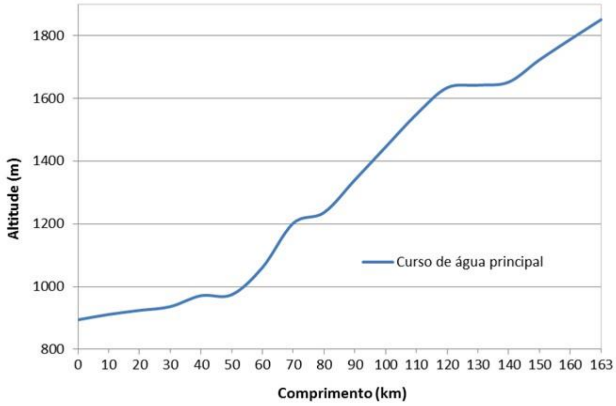
Figures 8 and 9 - Hypsometric chart of the Lower Hanha Cubal sub-basin and its longitudinal profile.



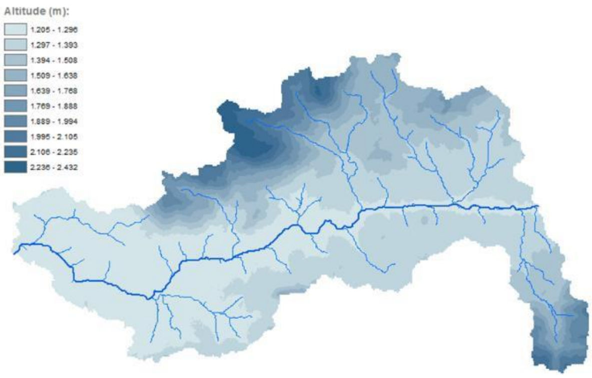


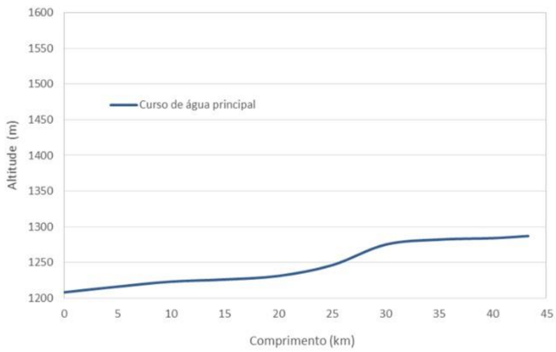
Figures 10 and 11 - Hypsometric chart of the Cubal da Ganda sub-basin and its longitudinal profile.



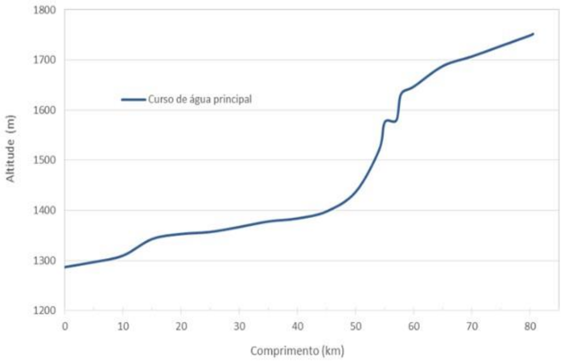


Figures 12 and 13 - Hypsometric chart of upper Hanha Cubal River sub-basin and its longitudinal profile.

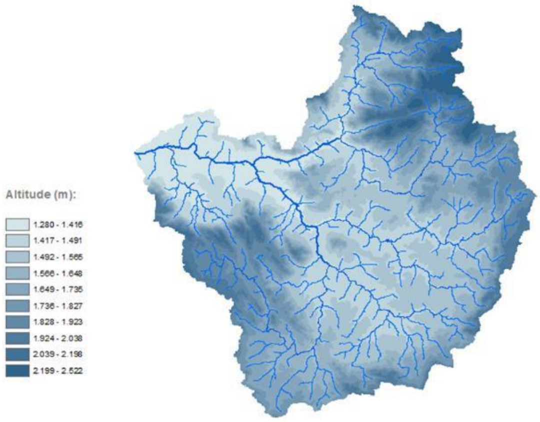


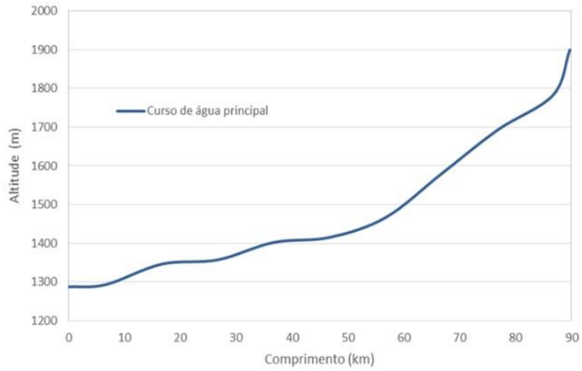


Figures 14 and 15 - Hypsometric chart of the Baixo Cuiva River sub-basin and its longitudinal profile.

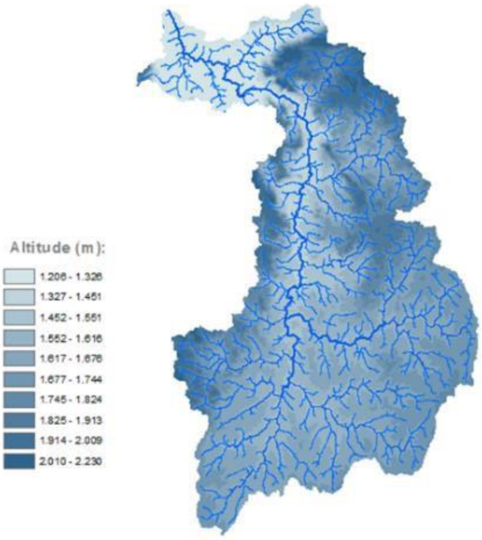


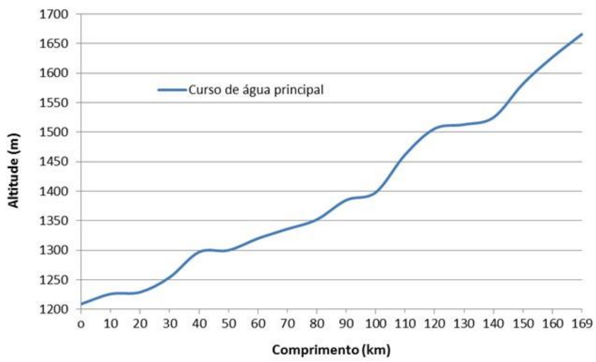
Figures 16 and 17 - Hypsometric chart of the Cubal River sub-basin and its longitudinal profile.





Figures 18 and 19 - Hypsometric chart of the Upper Cuiva River sub-basin and its longitudinal profile





Figures 20 and 21 - Hypsometric chart of the Upper Catumbela River sub-basin and its longitudinal profile

	Sub-Basin	A (Km²)	P (km)	l (km)	L_r (km)	K_c	K_f	K_L	L_t (km)	D_r (km/km2)	Ps (km)	Z (m)	H (m)	D_m	I_g
1	Baixo Catumbela	1707.28	277.18	30.00	80.10	1.89	0.27	9.14	1169.6	0.69	0.36	572.3	572.3	0.0064	0.0076
2	Médio Catumbela	2939.22	444.07	33.40	95.90	2.31	0.32	14.70	1727.7	0.59	0.43	1241.4	742.4	0.0076	0.0054
3	Cubal Hanha Inf.	1238.71	287.32	23.20	50.10	2.30	0.49	14.59	732.8	0.59	0.42	883.2	379.2	0.0076	0.0035
4	Cubal Hanha Sup.	1822.96	401.00	18.00	164.90	2.65	0.07	20.00	1058.0	0.58	0.43	1285.7	396.7	0.0058	0.0048
5	Cubal da Ganda	1799.00	348.00	19.00	107.00	2.31	0.16	14.76	1114.0	0.62	0.40	1190.6	300.6	0.0032	0.0042
6	Baixo Cuiva	349.00	161.00	9.00	42.90	2.43	0.19	16.51	203.1	0.58	0.43	1430.0	225.0	0.0014	0.0086
7	Cubal	1028.30	190.00	29.00	80.60	1.67	0.16	6.63	547.7	0.53	0.47	1612.0	332.0	0.0058	0.0081
8	Alto Cuiva	1914.00	311.00	36.00	90.10	2.00	0.24	10.54	1053.8	0.55	0.45	1650.0	370.0	0.0068	0.0045
9	Alto Catumbela	3855.00	523.00	35.00	173.00	2.38	0.13	15.67	2121.0	0.55	0.45	1626.6	420.6	0.0026	0.0027
	General Basin	16653.47	968.00	89.00	346.00	2.12	0.14	11.98	9727.6	0.58	0.43	1307.4	1307.4	0.0048	0.0034

Table 1: Geomorphological elements of the basin and sub-basins of the Catumbela River

3. HYDROCLIMATIC CHARACTERIZATION

The hydro climatic characterization of the Catumbela river basin is still under study. At present, only a study of the rainfall occurred between the years of 2000 and 2016 is presented.

The study of precipitation, temperature and evaporation in Angola has been the subject of several international consultants at the request of the Angolan government. The most recent are: "The Rapid Water Resources and Water Use Assessment for Angola" of the Norwegian company SWECO, submitted in March 2005 to the National Water Directorate of the Ministry of Energy and Water and the National Director of Irrigation of Angola - PLANIRRIGA, from the Portuguese firm COBA, in 2010. Figure 22 shows temperature and precipitation maps of the Angolan territory, presented in this last study.

These studies, which cover the whole country, lack the necessary detail for local engineering projects, be they small hydropower, irrigation channels for agriculture, or even roads.

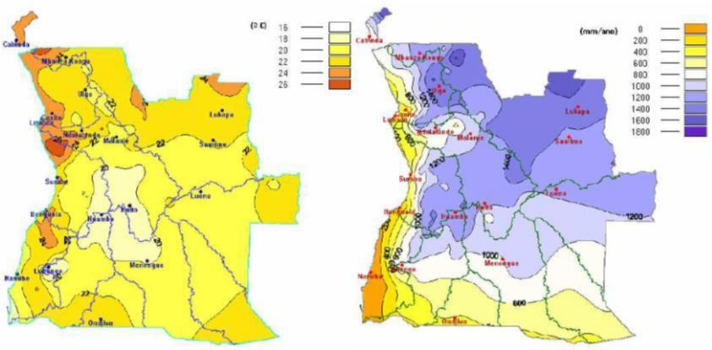


Figure 22 - Annual average temperatures and rainfall maps in Angola (COBA, 2010).

Precipitation data in the area of the general basin were well documented until country independence, in 1975. Up to that year, according to Ferreira (1974), there were 8 limnígrafos in the Catumbela river basin (corresponding to a ratio of 1765 km^2/station), 7 evaporimeters and 8 evapotransporímeters. (2017 km^2/evaporímeter) which was well above recommended by the World Meteorological Organization which recommended one evaporímeter per 30,000 km^2. The udometric network was quite complete as well, as can be seen from figure 23 which is a part of an annex of this related work.

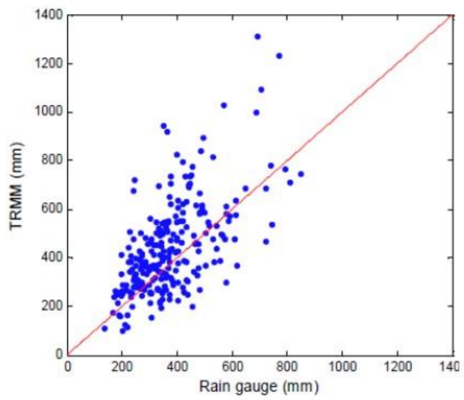
As of 1975 there was interruption in the collection of data associated with the disappearance of measuring devices. According to the SWECO study (2005), in 2005, the National Institute of Meteorology and Geophysics of Angola had 15 weather stations scattered throughout the country according to the map of figure 24. Of these, only two (Benguela and Huambo) could be of interest to this study, which makes it impossible the detailed statistical analysis of rainfall in an area of 16,000 km^2.

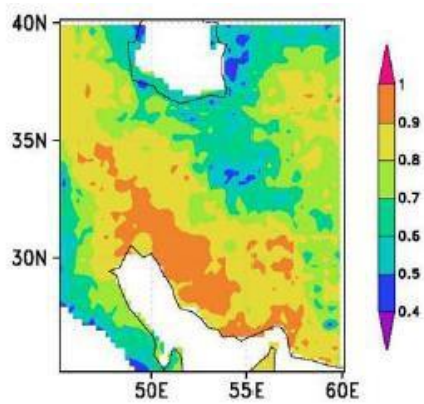
Figures 23 and 24 - Positioning of udometers and udographers in the Catumbela river basin in 1974. (Source: Ferreira 1974) and location of rainfall measuring devices currently operating in Angola in 2005 (source: SWECO 2005).

In this study rainfall data were collected by TRMM 3B42 and 3B43 V7 satellites (Tropical Rainfall Measuring Mission). The TRMM program was a joint space mission between NASA of the United States of America and JAXA (Japan Aerospace Exploration Agency) of Japan. This space program was carried out to monitor and study tropical rainfall. The term TRMM serves to designate the mission itself but also the satellite that the program used for data collection and was launched on 27 November 1997 from the Tanegashima Space Center in Japan. From July 2014, NASA completed the maintenance maneuvers, allowing its orbit to decay until re-entry into the Earth's atmosphere, which occurred on June 16, 2016. Rainfall data obtained by this satellite are available to the public at NASA's GIOVANNI website (https://giovanni.gsfc.nasa.gov/giovanni), by simply entering the coordinates of the places to study.

Several studies have shown that TRMM satellite data may show significant differences for the data collected on the ground on a daily basis, but for monthly and annual averages, these data show a high correlation (correlation coefficient between 0.71 and 0.80) with the values obtained on the ground. This may be related to the fact that the satellite calibration is based on monthly data. Figure 25 shows a graph (Ouatiki H. et al., 2017) showing the correlation between the rainfall data collected in ground meteorological stations in a Moroccan zone and the TRMM data for the same site.

Figure 26 shows a map of Iran (the Caspian Sea in the north and the Persian Gulf in the south) with the correlations obtained by Javanmard (2010) between TRMM data and those obtained by meteorological stations on the ground. As can be seen, in much of the country the correlation is higher than 0.8.





Figures 25 and 26 - Relation between TRMM data and surface gauge in Morocco (Ouatiki H. et al. (2017), and in Iran (Javanmard et al., 2010)

Neumann (2012), and Mantas (2015) have shown that TRMM data have difficulty collecting information on the amount of precipitation in mountainous regions, noting greater differences compared to the data collected at the ground. In the case of Angola and other countries where there is a shortage of data collected by meteorological stations on the ground, the use of TRMM data seems to be a very acceptable alternative for conducting precipitation studies for practical application.

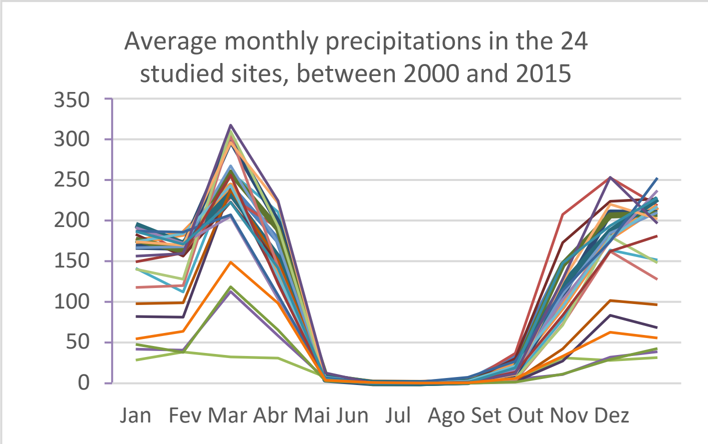
For this study, 24 locations in and around the area of the Catumbela River basin were selected, in order to obtain more reliable weighted results. For each site, the coordinates of an area corresponding to 1 km2 were introduced in the GIOVANNI portal. The result obtained is therefore the average of the precipitation occurred in that place and in an area of 1 km2. The overall results can be seen in Table 2.

N	Localidade	Coordenadas		Precip. Médias		N	Localidade	Coordenadas		Precip. Médias	
		W	S	Anuais	Mensais			W	S	Anuais	Mensais
1	Alto Catumb.	14,76	-12,94	1361	113	13	Chicuma	14,86	-13,42	1297	108
2	Balombo	14,76	-12,34	1500	125	14	Chongoroi	13,94	-13,57	1058	88
3	Benguela	13,4	-12,58	234	20	15	Cubal	14,23	-13,03	1182	99
4	Biópio	13,73	-12,47	349	29	16	Cuima	15,63	-13,24	1211	101
5	Bocoio	14,13	-12,46	1135	95	17	Cusse	15,18	-13,52	1256	105
6	Caconda	15,05	-13,73	1256	105	18	Ganda	14,63	-13,01	1427	119
7	Caiende	14,5	-13,26	1377	115	19	Huambo	15,73	-12,77	1273	106
8	Camatenda	15,01	-12,68	1375	115	20	Kalukembe	14,68	-13,79	1135	95
9	Cangue	14,78	-12,82	1379	115	21	Lobito	13,55	-12,35	358	30
10	Catengue	13,74	-13,03	717	60	22	Lomaum	14,4	-12,73	1462	122
11	Cativa	15,08	-13,15	1318	110	23	Longonjo	15,24	-12,91	1317	110
12	Cayave	13,93	-12,76	836	70	24	Canjala	13,99	-11,99	529	44

Table 2: Annual and monthly average rainfall for 24 locations in and around the Catumbela river basin, between 2000 and 2015

Throughout the year the pluviometric regime in this basin is divided into three distinct epochs. The dry season runs from May to August and the rainy season runs from September to April. However the months of March and April stand out as the months where there is greater rainfall. Figure 26 shows a graph showing the mean monthly rainfall between 2000 and 2015.

Figure 26 - Monthly average precipitation chart in the 24 locations studied, between 2000 and 2015.



These data were then worked on GIS software to obtain precipitation isolines. Figure 27 shows the annual mean precipitation isolines of the Catumbela river basin between 2000 and 2015, inclusive.

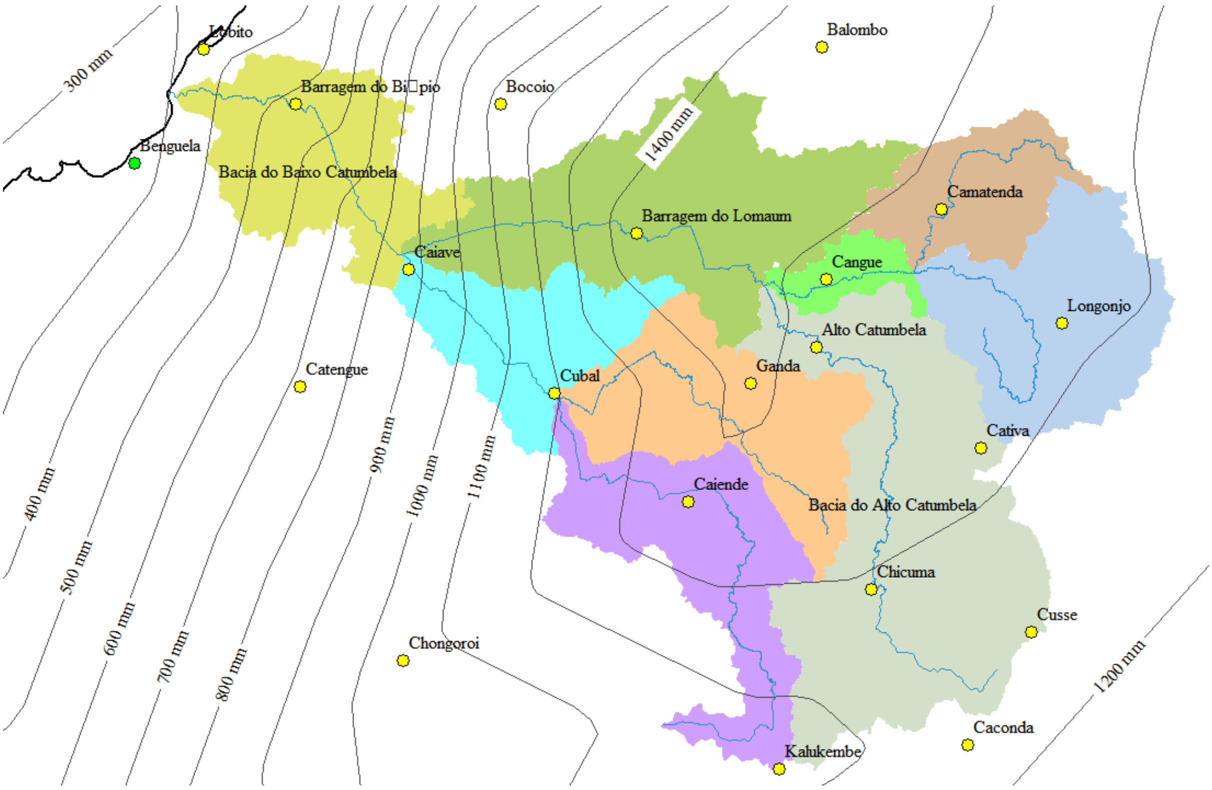


Figure 27 - Mean annual precipitation isolines between the years 2000 and 2015, in the Catumbela river basin (author)

4. CONCLUSION

In this study, the geomorphological characteristics of the basin and sub-basins of the Catumbela River, in Angola, were detailed. This characteristics are essential for the management of the water resources of this basin, and will enable more detailed studies on the flows of the watercourses of each of the sub-basins. It can be concluded that almost all the sub-basins, except for the low Cuiva, have slopes of the main water line that allow the use of hydro energy.

In terms of rainfall, it was detected that the area of greatest precipitation in this basin is the Balombo-Ganda axis, which is located in the medium Catumbela sub-basin and where the average annual rainfall is over 1400 mm. In around 75% of the area of the basin, the annual catch is over 1000 mm, making this watershed an important source of hydroelectric energy for the Angolan energy network and which has potential for agricultural and tourism development not yet explored.

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