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Prioritization of sub watersheds based on hydro morphometric analysis in the Sankarani watershed, upstream tributary of the Niger River

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***Abstract*— Any hydrological study of watersheds requires morphometric analysis. This analysis is a powerful tool in watershed management (Biswas et al., 1999, Yasmin et al., 2013). Climate change coupled with land-use changes raises development issues, including the availability of water resources for people's needs. Faced with these ever-increasing needs of the population, land development becomes a requirement. Thus, the objective is to analyze the morphometric characteristics of the Sankarani basin in order to prioritize its sub-basins. To this end, the satellite images of the digital terrain model (DTM) of the SRTM (30mx30m) type of 2012 were used. Under the Grass GIS open source program, five sub-basins (BV1-I, BV2-M, BV3-Y, BV4-G and BV5-S) have been delimited. The measured parameters are the number of rivers and their classifications, to define the geometry of the basin (area, perimeter, length), the various indices (drainage density, slope ratio, texture ratio, elongation ratio and ratio of form factor) and to determine hypsometric curves. The hierarchy was performed by assigning ranks to the individual indicators and a compound parameter (Cp) value was calculated. The method established that BV2-M (upstream) has the highest priority of the other sub-basins of Sankarani for land conservation actions and the sustainable management of water resources.*

***Keywords*— Geoinformation, Hydromorphology, Subwatershed, Sankarani watershed.**

I. INTRODUCTION

The study of natural hazards in a watershed requires a good hydrological, geological, geomorphological, ecological and climatic understanding to determine the factors that influence the birth of natural hazards (Benzougagh B. et *al*., 2016).

The water resources in the basin on which the Sélingué dam was built are the driving force of development in Mali in particular and the Sahel countries in general where the economy is mainly dominated by agriculture, livestock and fisheries. However, its exploitation currently suffers from a lack of consultation even though climate fluctuation and the ecological evolution of the watershed threaten its resources (Bengaly S., 2012). In order to better manage these water resources, it is essential to know the hydromorphological characteristics of watersheds (Aravinda P. and Balakrishna H., 2013, Faye C., 2014).

Populations in the Sankarani basin upstream and downstream face several types of water-related problems such as water shortages for agriculture, floods, and other hazards (ODRS, 2010; Bengaly S., 2012).

The morphological parameters are decisive because the relief is probably the factor that best reflects the partition of a basin between the upper course and the uplands, the average course with medium relief (medium altitudes) and the lower course with the regions of plains (low altitudes). Morphometric analysis highlights the basic features of geometric features of the watershed, which would be useful for understanding hydrology, sediment transport and landscape evolution in basins for better management of the resource. Morphometric characteristics at the watershed scale may contain important information on its formation and development, as all hydrological and geomorphological processes occur in the basin. Morphometric analysis is important in any hydrological study. Indeed, it is inevitable in the development and management of the watershed (Biswas et al., 1999, Rekha V. et al, 2011, Bharadwaj A., 2014, Faye C., 2014). Quantitative analysis of morphometric parameters is extremely useful for watershed assessment, watershed prioritization for soil and water conservation and natural resource management at the micro level (Kanth T.A.A. and Zahoorul Hassan, 2012, VibhuNayar, Kavitha Natarajan, 2013).

Faced with these shortcomings related to the knowledge of hydromorphological parameters, the techniques of geomatic (geographic information system (GIS) and remote sensing) prove to be essential tools to evaluate its morphometric parameters of the Sankarani basin for a prioritization of its sub watersheds, in order to make a sustainable management of natural resources.

1.1. Goal

The objective of this study is to analyze the morphometric characteristics of the Sankarani basin in order to prioritize its sub-basins.

1.2. Framework

Sankarani is a tributary of the Niger River that is located in the upper Niger between the Milo basin in the southwest and the Baoulé basin in the southeast (figure 1 below). The Sankarani Basin covers six (6) geological formations: alluvial formations, Birrimianmicaschists, schists and quartzists, granites, dolerites and horizontal sandstones. The estimated area of the basin is approximately 33 288 km2 with a perimeter of 1,118,694 km. The basin is characterized by a tropical climate of sub-Guinean and Sudanese type with an average annual rainfall which varies between 1800mm in the South and 900mm in the North. The drainage density of the basin is estimated at 2.36 km / Km² with a total of 122,113 of watercourses with nine (9) order according to the Strahler classification.

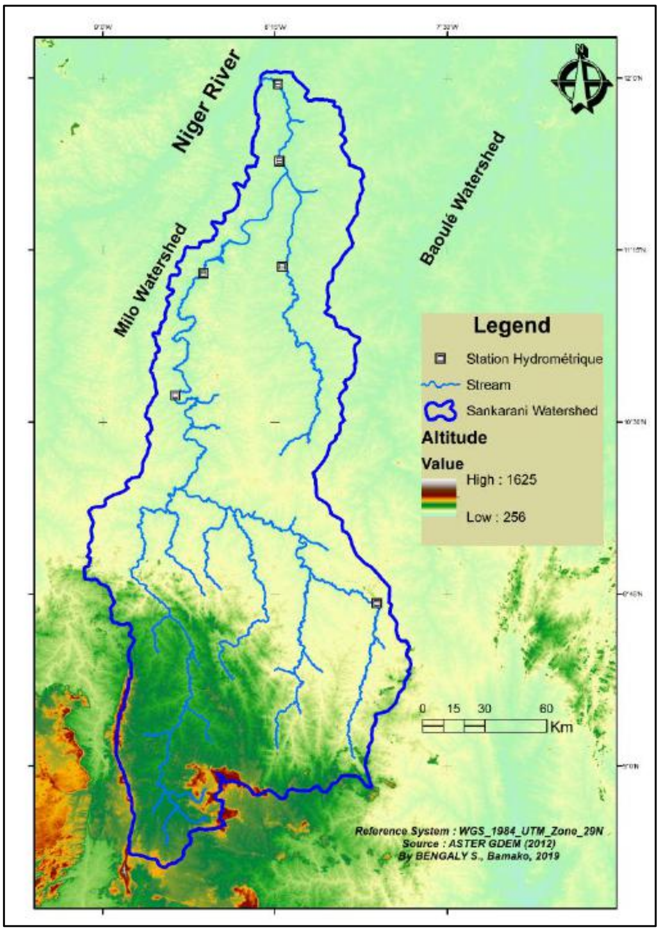


Fig.1: Sankarani Watershed

II. METHOD OF STUDY

Extraction of a watershed boundary, hydrographic network and allocation of a flow order from a topographic map for an extended area is a tedious task. In this study, the morphometric parameters of the Sankarani Basin are extracted from the 2012 SRTM Digital Elevation Model (DEM) with a spatial resolution of 30m. Thus, the characteristics on the geometry of the basin (area, perimeter, length), the classification of the rivers, the various indices (bifurcation ratio, drainage density, slope ratio, texture ratio, elongation ratio and time concentration).

And the hypsometric curves were digitally generated in Grass GIS open source software. In the table below, the morphometric parameters used.

Table 1: List of morphometric parameters used

Type Index	***Settings / Formulas***	***References***
Linear Indices	Number of stream order	*Strahler (1964)*
	Basin length Lb (km)	*Horton (1945)*
	Area A (km2)	-
	Perimeter P (Km)	-
	River frequency (Fs = N / A)	*Horton (1945)*
	Texture Ratio (Rt = Dd × Fs)	*Smith (1950)*
	Density of drainage Dd = Lu (river length) / A (area)	*Horton (1945)*
Shape Indices	Elongation Index $Re = 1{,}129\,\frac{\sqrt{A}}{Lb}$	*Schumm (1956)*
	Form factor ratioFf = A / L b ^{2}	*Schumm (1956)*
Relief Indices	Average height (m) $h = \frac{Hmax+Hmin}{2}$	*Horton (1945)*
	Ratio of slope (Rs = R (medium slope) / L (basin length)	*Schumm (1963)*

After generating all the indices of each parameter (linear / relief and shape), a composite mean value was calculated to determine the degree of prioritization of the sub-basins (Biswas et al., 1999). Thus, the highest value of the linear parameter has been ranked as rank l, the second highest value as rank 2, and so on. On the contrary, shape parameter indicators have an inverse relationship with erodibility. The lower their value, the greater the erodibility. The smallest value of the parameter has been noted as rank 1 and the second lowest in rank 2 and so on. Results from each of the standard parameters (form and linear) were added for each of the 5 subwatersheds to arrive at a final composite value (Biswas *et al*., 1999, Ratnam N. *et al*, 2005, Kanth T.A.A. and Zahoor ul Hassan, 2012). Finally, the hypsometric curves are generated by sub-basin in order to further confirm the priority sub-basins identified for soil conservation and water resource conservation actions.

III. RESULTS AND DISCUSSIONS

Subsequent geoprocessing of the SRTM image (DEM) yields five (5) sub-basin (BV1-I, BV2-M, BV3-Y, BV4-G and BV5-S) of the Sankarani basin. The indices used in this research are chosen according to their importance and ability to better illustrate each type of parameter.

3.1. Linear parameters

The linear parameters characterize the drainage density profile and the topography of the Sankarani basin. The indicators used are:

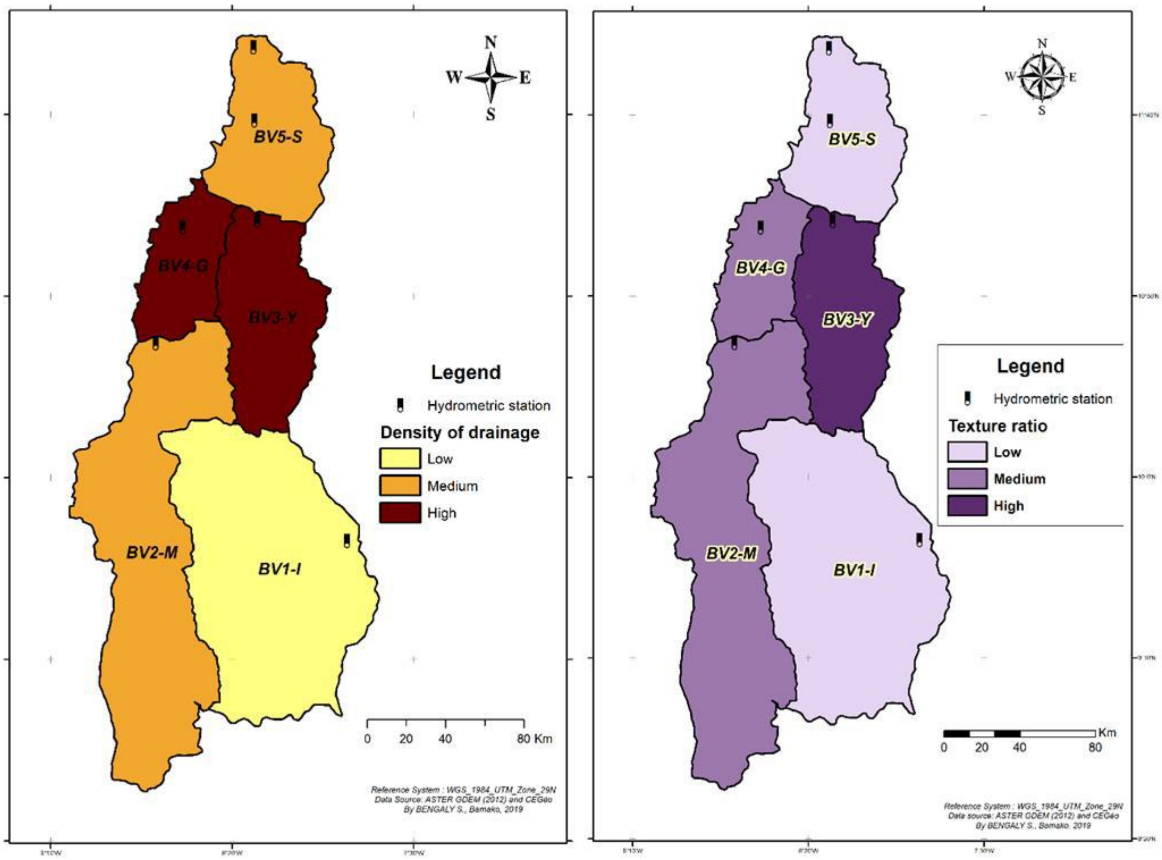
- ✓ The classification of rivers is made on the basis of the method of Strahler (1964). The non-affluent streams are of order (1), the confluence of two rivers of order (n) gives an order (n + 1) and the confluence of a watercourse of order n with an order (n + 1) gives a stream of order (n + 1). The order of the river arriving at the outlet is therefore the maximum order of the basin. The maximum orders of the BV1-I, BV2-M, BV3-Y, and BV5-S sub-basins are five and four for the BV4-G sub-basin (Table 1). The densest sub-basin is the BV1-I with 1337 rivers upstream against 320 downstream rivers and the lowest at BV4-G.

Table 2: Order and total number of streams in each sub-basin

Sub-basin	**Area (km ^{2})**	**Perimeter (Km)**	**Maximum order**	**Number of rivers**
BV1-I	11341.4	503.7	5	1337
BV2-M	10619.2	696.9	5	1315
BV3-Y	4563.4	333.6	5	578

BV4-G	2677.0	264.3	4	320
BV5-S	4083.7	297.7	5	457

- ✓ The frequency of rivers (Fs) is the total number of flow segments of all orders by basin area. In the Sankarani Basin study the river frequency index varies between 0.11 to 0.13 (Table 3 below).
- ✓ The drainage density (Dd) is the length of the stream per unit area introduced by Horton (1945). This is another element of drainage analysis that allows a better quantitative expression of dissection and relief analysis. The lowest sub-basin drainage density is 0.41 to BV1-I (upstream) and the highest 0.44 to BV3-Y (downstream).
- ✓ The texture ratio (Rt) depends on the underlying lithology, the infiltration capacity, the vegetation cover and the relief aspect of the terrain. From Figure 2, we see that the ratio is low at BV5-S and BV1-I against a high texture ratio to BV3-Y.



(a) (b)

Fig.2: Class of the drainage density (a) and the texture ratio (b) of the sub-basins

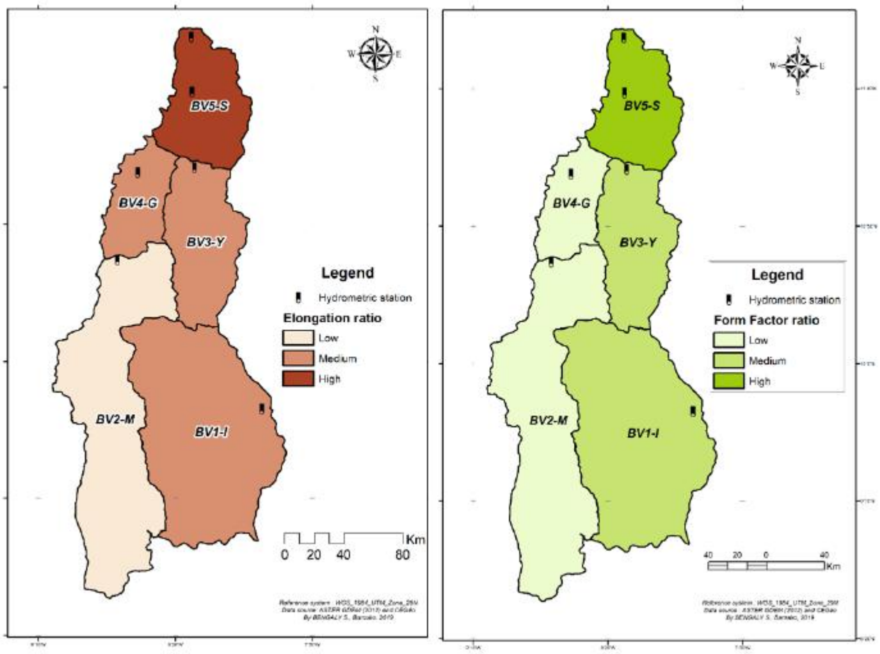
- ✓ The slope ratio (Rs) is an important parameter for watershed analysis because water velocity and material transport depend on the slope. The indices of the sub-basins calculated vary between 1.24 at BV1-I and 1.54 at BV5-S (Table 3 below). There is an average variation between these slope indices.

3.2. Shape parameters

- ✓ The elongation ratio (Re) is defined as the ratio of the diameter of a circle of the same area as the basin to the maximum length of the basin. This is a very significant index in the analysis of the shape of a basin that gives an idea of the hydrological nature of a watershed. The sub-basin elongation ratio ranges from 0.27 for the BV2-M (the most elongated) to 0.59 for the BV5-S (the most circular) in the study area (Figure 3a).
- ✓ The form factor (Fr) is defined as the ratio of the basin area (Km^2) over the length of the basin squared. For example, catchments with high form factors have a shorter response time with high

peak flow rates, whereas elongated catchments with lower form factors have low peak flow rates and a slower response rate.

In our case, the BV5-S (downstream and on which the Sélingué dam is located) with an index of 0.27 has the shortest response time against the BV2-M (upstream) with a form factor estimated at 0.05 at the longest response time (Figure 3b below).



(a) *(b)*

Fig.3: Class of elongation ratio (a) and the form factor (b) of sub-basins

3.3. Prioritization of subwatersheds

The prioritization relates to the average value calculation of the composite parameter (Cp) of the linear and shape parameter indicators.

- ❖ Linear parameter indicators have a direct and proportional relationship with erodibility, the higher the value, the higher the erodibility and the lower the erodibility.
- ❖ The shape parameter indices have an inverse relationship with erodibility, the lower the value of these parameters, the higher the erodibility and the stronger the erodibility, the lower the erodibility.

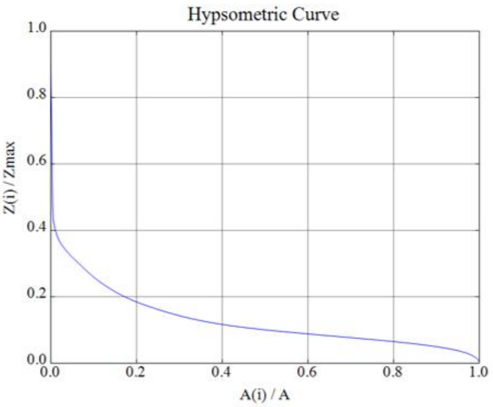
The composite parameter (Cp) estimated from the two types of parameters made it possible to classify each sub-basin as a priority. The highest rank was assigned to the sub-basin (BV2-M) with the lowest Cp value, the average rank at BV1-I, BV3-Y and BV4-G with a mean value and the low rank at BV5-S whose Cp value is low compared to the others (Table 3).

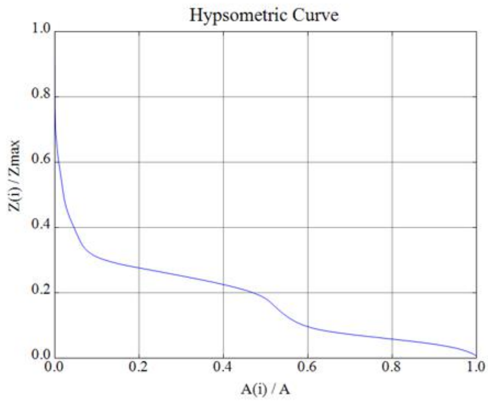
Table 3: Prioritization of sub-basins from morphometric analysis

	Linear Parameters				*Shape Parameters*			
Sub-Basin	***Fs***	***Dd***	***Rs***	***Rt***	***Re***	***Fr***	***Cp value***	***Final Priority***
BV1-I	0.12	0.41	1.25	0.05	0.41	0.13	*0.39*	*Medium*
BV2-M	0.12	0.42	1.27	0.05	0.27	0.06	*0.37*	*High*
BV3-Y	0.13	0.44	1.20	0.06	0.36	0.10	*0.38*	*Medium*
BV4-G	0.12	0.43	1.32	0.05	0.33	0.09	*0.39*	*Medium*
BV5-S	0.11	0.42	1.54	0.05	0.59	0.27	*0.50*	*Low*

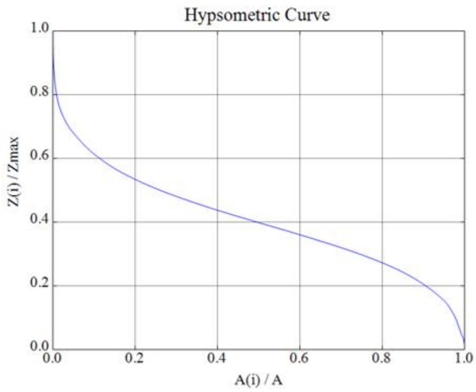
- The hypsometric curves initiated by *Langbein*(1947) are related to the volume of soil mass in the basin and the amount of erosion that has occurred in a basin relative to the remaining mass. Thus, hypsometric curves can be used to prioritize sub-basins for the adoption of soil and water conservation measures in watershed systems (Khadri, S.F.R and Nitin R. Kokate, 2015).

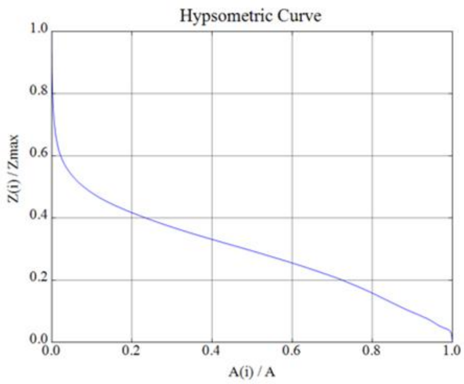
An upward convex hypsometric curve indicates a basin whose topography is young and the reverse indicates an old relief. When it takes the shape S concave up at higher altitude and concave down at lower altitude, this basin has a mature topography (Omvir Singh et *al.*, 2008; DembéléN'djidit Jacques, 2012). Thus, we note that BV1-I, BV2-M curves indicate more mature and more eroded basins, BV4-G and BV3-Y relatively mature while BV5-S represents a young relief in our study area. Therefore, in terms of prioritization for soil and water conservation and conservation actions, BV2-M is the priority sub-basin (rank 1 or high) followed by BV1-I, BV3-Y and BV4- G, and the BV5-S is the last on which the Sélingué threshold is located (Figure 4).



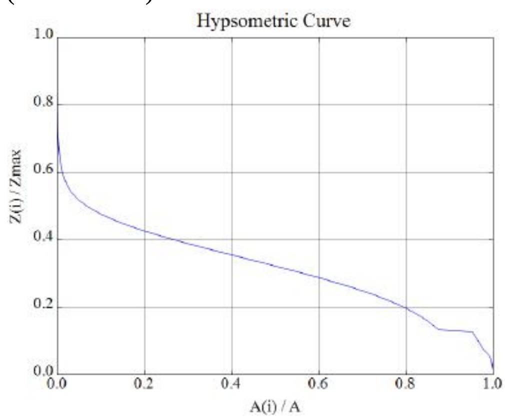


a; BV1-I (upstream)b; BV2-M (upstream)





c; BV3-Y (downstream)d; BV4-G (downstream)



e; BV5-S (downstream)

Fig.4: Hypsometric curves of the sub-basins of Sankarani

3.4. Discussions

The hydro morphological study is based on the systematic study of the current landforms of a basin that may be related to their origin, their nature, their development, their geological modifications and their relations with other underlying structures.

We can see that several authors (Omvir Singh et *al.*, 2008, Aravinda P. and Balakrishna H., 2013, Faye C., 2014, Khadri, SFR and Nitin R. Kokate, 2015) highlight the interest of DEM / DEM images in a GIS environment for the study of the morphological characteristics of a watershed.

Linear parameters are directly related to soil erosion because streams are the dynamic agents of erosion (VibhuNayar and Kavitha Natarajan 2013, Ashok S. Sangleand Pravin L. Yannawar 2015). Values (average 0.42) of drainage density indicate a low permeability subsoil. Thus, these indices less than 1 are close to those of Praveen Kumar Rai et *al.*, 2014; A.K.Bharadwaj et al, 2014; Ashok S. Sangle and Pravin L. Yannawar, 2015 and BenzougaghBrahim et al., 2016 found that a watershed with a fairly high drainage density indicates that much of the rainfall is dripping due to the presence of impervious rocks. In addition, a low density of drainage indicates a higher infiltration in the presence of permeable rocks. According to Vandana (2013), texture ratio and river frequency are also important factors in morphometric analysis, which depends on lithology and the relief of land.

The form factor and elongation ratio are major indicators for describing the shape of a watershed. Based on our results, we can say that most of the Sankarani sub-basins have an elongated shape with an average index of 0.13 of form factor and 0.39 of elongation ratio on average. According to Horton (1932), the smaller the value of the form factor, the longer the catchment will be. Thus, the same conclusions were emitted by Sangita Mishra S. and Nagarajan R. (2010); Sujit Das and Krishnendu Gupta (2014); and BenzougaghBrahim et *al*., (2016) who report that the pelvis elongated with a low form factor and indicates that the peak flow of the basin will be low and spread over time and the opposite is seen when the basin is circular.

Thanks to the method of the value of the composite parameter (Cp) applied to the linear parameters and the shape parameters, a priority ranking has been established for each sub-basin. The highest rank was assigned to the sub-basin with the lowest composite parameter score and so on. Thus, the BV2-M has been classified as the high priority sub-basin (rank 1) by its low composite parameter value. Some authors such as Sangita Mishra S. and Nagarajan R. (2010), Vandana M. (2013) and BenzougaghBrahim et *al*., (2016) succeeded in prioritizing the sub-basins via the parameter approach composed of hydromorphological parameters.

IV. CONCLUSION

The morphometric characteristics of the different sub watersheds show their relative characteristics with respect to the hydrological response of the watershed. The prioritization of watersheds based on morphometric parameters is essential for designing a sustainable watershed management plan. Geoinformation (remote sensing and GIS) is one of the most appropriate tools on morphometric studies for the prioritization of sub-basins for soil conservation and water resources.

Indeed, the analysis showed that the BV2-M sub-basin is in a high priority category based on water retention capacity in relation to morphometric analysis.

Thanks to the limitations that this method may have, it would be interesting to link it to other indicators such as land use, vegetation cover, soil and geological formation, in order to better identify the priority sub-basins within the framework of sustainable management of the natural resources of the Sankarani watershed.

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