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Catchment Characterization to Understand Flooding in Cagayan De Oro River Basin in Northern Mindanao, Philippines

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Abstract

The Cagayan de Oro River Basin is the second largest river basin or watershed in Northern Mindanao, occupying an estimated area of 1,373.84 sq. km. The drainage basin was delineated using Shuttle Radar Topographic Mission (SRTM) 90m digital elevation model (DEM). Geographical features were derived from the DEM using geographic information system (GIS) to perform a morphometric analysis of the river basin and evaluate various parameters of linear, areal and relief aspects. Linear aspect analyses showed that the drainage basin has a 7th order stream with a bifurcation ratio of 1.8. Areal aspect demonstrates that the basin has a drainage density of 2.29 km/mk2 with a circularity and elongation ratios indicating that the basin is less elongated. Relief aspect of the river basin indicates that it has a resistant basement rock formation and susceptible to erosion. Overall evaluation of the various basin parameters revealed that the inherent features of the river basin has made it naturally liable to flooding with anthropogenic activities exacerbating the extent of risks.

Keywords: morphometric analysis, linear aspect, areal aspect, relief aspect, GIS

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1. Introduction

River basins or catchments are physical entities of discrete landforms useful for statistical, comparative and analytical studies. To date there are a number of proposed methods of numerically and qualitatively describing drainage basins. One of the most commonly performed methods is the drainage basin morphometry. Morphometry is typically a quantitative method involving numerical parameters whose values may be derived from digital elevation models. The importance of morphometric analysis is its usefulness for comparison and statistical studies. Globally morphometric analysis has gained wide acceptance and has been used in numerous research studies relating to drainage basin characterization.

Morphometric analysis utilizes drainage basin geometry and involves the measurement of three major components such as linear, areal and relief aspects. The conduct of a morphometric analysis is important in any hydrological study since a variety of important hydrologic phenomenon can be correlated with the geographic features of the drainage basin such as shape and size, slope, drainage density, stream network and etc. (Rastogi and Sharma, 1976). Horton (1945) developed the quantitative method of drainage basin analysis and was modified by Strahler (1964) to its current method. The advancement of geographic information system (GIS) however has made the analysis and visualization of geographic information and has evolved as a highly improved process, providing more reliable and less time consuming results. A hypsometric curve for the Cagayan de Oro River Basin was also created to describe the distribution of elevations across the catchment area and is use to infer the stage of development of the drainage network.

The study is to evaluate the morphometric characteristics of the Cagayan de Oro River Basin and describe its relationship with its various landform features and utilize the result as decision support tool for the preparation of river basin and/or watershed management plan.

2. Methodology

In this study, catchment characterization through morphometric analysis was carried out using the Shuttle Radar Topographic Mission (SRTM) 90 m digital elevation model from the Consultative Group for International Agricultural Research – Consortium for Spatial Information (CGIR – CSI). The digital elevation model is already in ArcInfoGeoTIFF format to facilitate ease of use in a variety of image processing in GIS application. Evaluation of the different linear, areal and relief parameters were all carried out using geographic information system. Evaluation of the linear aspect of the drainage basin requires the digitization of drainage pattern to determine the basin order and stream length. Digitization of drainage pattern was performed in ESRI ArcGIS software using the stream order tool from Spatial

Analyst. Area and perimeter measurement of the drainage basin were also carried out under the ArcGIS environment. For other parameters under the linear aspect such as mean stream length, stream length ratio and bifurcation ratio were calculated using established formula by Horton (1945) and Schumm (1956). Calculation of parameters under the areal aspect was carried out using formula employed by Horton (1945), Schumm (1956), Miller (1953) and Faniran (1963). The evaluation of drainage relief was based on the digital elevation model of the drainage basin and other parameters under the relief aspect were calculated using the formula by Schumm (1956). Calculation formula for the different parameters mentioned are shown in Table 1.

Table 1. Calculation methods for drainage basin morphometric parameters

	Morphometric Parameters	Methods	References
LINEAR ASPECT	Basin order, U	Hierarchical order	Strahler, 1964
	Stream length (km), L_u	Length of the stream	Horton, 1945
	Mean stream length (km), L_{sm}	$L_{sm} = L_u/N_u$ where, L_u = Stream length of order 'U' N_u = Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio, R_l	$R_l = L_u/L_u\text{-}1$; where Lu = Total stream length of order 'U', L_u-1 = Stream length of next lower order	Horton, 1945
	Bifurcation ratio, R_b	$R_b = N_u/N_u+1$; where, N_u = Total number of stream segment of order 'u'; N_u+1 = Number of segment of next higher order	Schumm,1956
AREAL ASPECT	Drainage density (km/km^2), D_d	$D_d = L/A$ where, L = Total length of streams; A = Area of watershed	Horton, 1945
	Stream frequency (km^2), F_s	$F_s = N/A$ where, N = Total number of streams; A=Area of watershed	Horton, 1945
	Form factor, R_f	$R_f = A/(L_b)^2$;where, A = Area of watershed, L_b=Basin length	Horton, 1932
	Circularity ratio, R_c	$R_c = 4\pi A/P^2$;where, A = Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio, R_e	$R_e = 2\sqrt{(A/\pi)}/L_b$;where, A=Area of watershed, π=3.14, L_b = Basin length	Schumm,1956
	Constant of channel maintenance (km), C	$C = 1/D_d$ where, D_d = Drainage density	Horton, 1945
	Length of overland flow (km), L_g	$L_f = 1/2D_d$ where, D_d = Drainage density	Horton, 1945
	Infiltration number, I_f	I_f = Dd*Fs where D_d = Drainage density; F_s=Stream frequency	Faniran 1968
RELIEF ASPECT	Relief (m), B	Vertical distance between the lowest andhighest points of watershed	Schumm, 1956
	Relief ratio, R_h	$R_h = B_h/L_b$; Where, B_h = Basin relief; L_b = Basin length	Schumm, 1956
	Ruggedness number, Rn	$R_n = B_h \times D_d$ Where, B_h =Basin relief; D_d = Drainage density	Schumm, 1956

For the creation of the hypsometric curve, information from the attributes table of the delineated digital elevation model of Cagayan de Oro River Basin was exported as ASCII format and imported into MS Excel. Values column in the attributes table represents the elevation information and count column represents number of pixel of particular elevations. These values were then arranged in descending order. Area is represented in terms of pixel (since pixel size is fixed and hence represent fixed area). Elevation above baseline, normalized area and normalized elevation were then calculated.

3. Results and Discussions

Digitization of drainage basin using the digital elevation model revealed that Cagayan de Oro River Basin exhibits a parallel drainage pattern which form where there is a pronounced slope to the surface. Tributary streams tend to stretch out in a parallel-like fashion following the slope of the surface. Parallel drainage patterns are often found in areas with steep relief or where flow is over non-cohesive materials. Figure 1 is the digital elevation model of the Cagayan de Oro River Basin and Figure 2 is the drainage pattern of the basin showing 7th order stream based on the Strahler stream order.

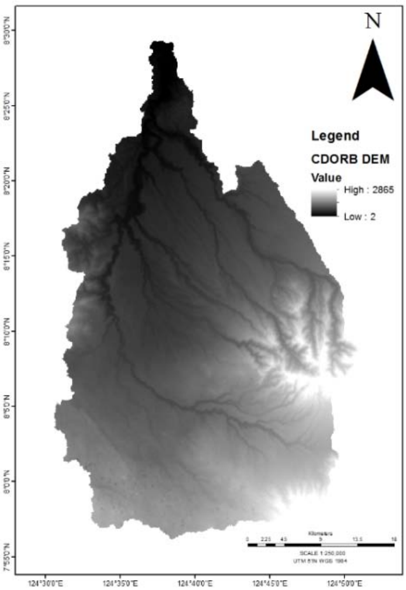

Figure 1. Digital elevation model of CDORB

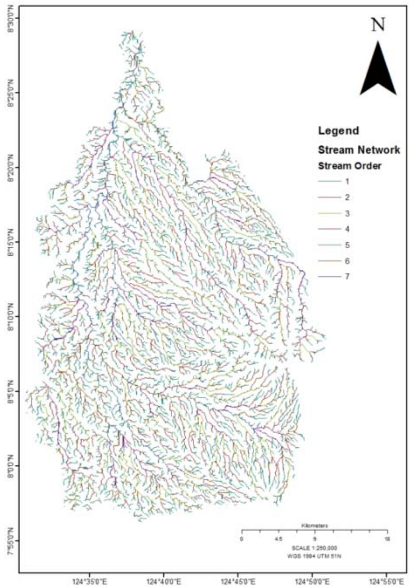

Figure 2. Drainage pattern of CDORB

3.1 Hypsometric curve

The hypsometric curve for Cagayan de Oro River Basin reveals a gradual sloping pattern increasing towards a steeper curve. Figure 3 shows the hypsometric curve for the Cagayan de Oro River Basin.

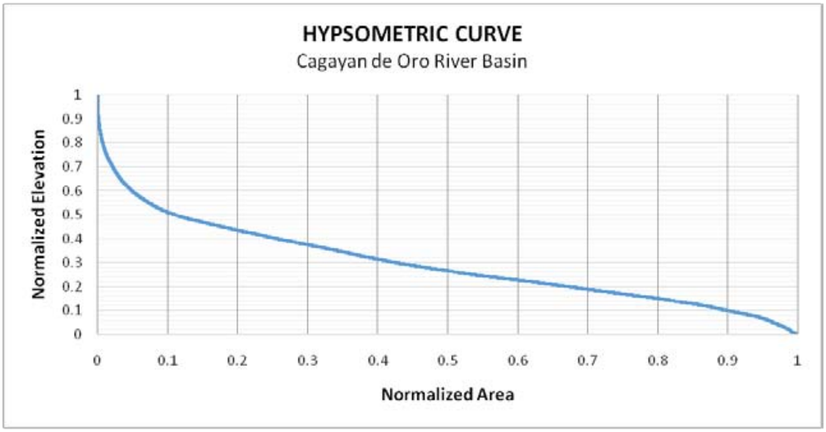

Figure 3. Hypsometric curve of Cagayan de Oro River Basin

The hypsometric curve can also be related to Davis' (1909) concept on erosion cycle and landscape development where rivers can be classified according to specific characteristics. This concept categorizes a river as a "Youthful", "Mature" and "Old Age". A "Youthful" river can be described as a river found at higher elevations, in mountainous areas where the slope of the land is steeper. Water that flows over such a landscape will flow very fast. Youthful rivers can be a tributary of a larger and older river, several distance away and they may be close to the headwaters of a larger river. A "Mature" river on the other hand can be described as an in-between stage where the river still downcuts though to a much lesser degree than the youthful river does, but it also erodes laterally, though not as extensive. The landscape over which it passes is steep enough that the river's slope enables a velocity capable of moving not only the finer sediments but also the larger ones by way of rolling, bouncing and saltation along the river bed. Mature rivers generally flows in hilly landscape and exhibits a U-shaped channel but deeper that and not as wide as an "Old Age" river's channel.

The last classification of a river according to Davis is the "Old Age" river which can be describe as one having slow movement with heavy suspended sediments. During flood stages, Old Age rivers can overflow its banks and attain velocities not only capable of moving large boulders but also large houses. When old age rivers are filled to capacity due to extensive periods of rainfall, extensive property and agricultural damage as well as loss of life can result. Figure 4 below shows the various hypsometric curves associated with a "Youthful", "Mature" and "Old Age" rivers.

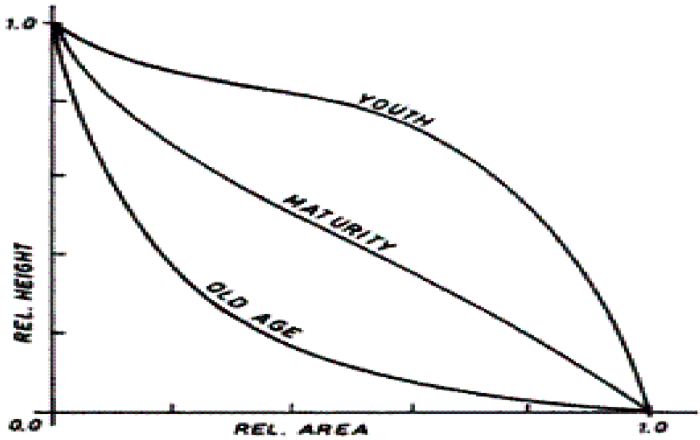

Figure 4. Interpretation of hypsometric curve

The shape of a hypsometric curve is an indicator of dominant geomorphic processes at work in a watershed (diffusive or fluvial). A convex curve indicates more of the watershed's area (or volume of rock and soil) is held relatively high in the watershed. In this case, diffusive hill slope processes such as land-sliding, rain-splash, inter-rill erosion, soil creep, etc., play a larger role. A concave curve indicates the bulk of the basin's area (or volume of rock and soil) resides at relatively low elevation. More material has been removed from higher areas and either transported to lower areas or advected out of the basin completely. Concave curves indicate channelized/linear/fluvial/ alluvial processes dominate.

From Figures 3 and 4, the Cagayan de Oro River can be described as a "Mature" river, showing a more S-shaped feature and displays a concave upward feature at higher elevation and concave downwards at lower elevations which characterizes a mature drainage basin.

3.2 Linear aspect

The following results show the different parameters of the Linear Aspect of the Cagayan de Oro River. Table 2 provides information on the stream order, stream length and perimeter of the drainage basin. Accordingly, a 7th order stream or larger basically constitute a river while 4th to 6th order streams are considered medium streams. From the digital elevation model and using geographic information system, the number of 7th order stream segments totalled to 115 and total stream length of 50.22 km as shown in Table 2.

Table 2. Stream drainage network of Cagayan de Oro River Basin

Basin/Watershed	Stream Order	Stream Length, km	Perimeter, km
Cagayan de Oro River Basin	1	1506.76	225.58
	2	782.48	
	3	453.69	
	4	215.66	
	5	81.66	
	6	50.64	
	7	50.22	

Streams exhibiting longer lengths generally indicate flatter gradients. Such features are illustrated in the slope map of the Cagayan de Oro River Basin where flatter gradients of land areas can be found from the north going towards the southern portion of the basin. The mean stream length of a channel is the characteristic size of drainage network components and its contributing basin surface. Generally the mean stream length of any given order is greater than that of lower order, a deviation of this can be attributed to the variation in slope and topography as exhibited by Cagayan de Oro River Basin in Table 3 below.

Table 3. Linear aspect parameters of Cagayan de Oro River Basin

Basin/Watershed	Mean Stream Length, km	Stream Length Ratio	Bifurcation Ratio
Cagayan de Oro River Basin	0.46	1.21	2.33
	0.55	0.95	1.64
	0.53	0.89	1.87
	0.47	0.84	2.22
	0.39	1.03	1.66
	0.41	1.06	1.07
	0.43	-	-

For the stream length ratio, the CDO River Basin exhibits anomalous variation among successive order. This variation in stream length ratio among successive orders could be due to the differences in slope and topographic conditions, and has an important relationship with the surface flow discharge and erosional stage of the basin. Such variation also indicate that the drainage basin is already in its late youth to early mature stage of geomorphic development of streams. In Figure 1, the CDO River Basin depicts a drainage area having multiple stream segments of different stream orders which is a characteristic of a well-drained drainage basin. In a well-drained basin, a large number of streams of smaller lengths, e.g. 1^{st} order streams, are developed where the formation are less permeable.

Cagayan de Oro River Basin showed low value of bifurcation ratio, with an average of 1.8 for the whole drainage basin. Such low values in bifurcation ratio is an indication that the drainage basin had not been affected by structural disturbances, e.g. dam. Accordingly, long narrow basins with high bifurcations would be expected to have attenuated flood – discharge periods, whereas round basins of low bifurcation ratio would be expected to have sharply peaked flood discharges.In homogeneous bedrock, bifurcation ratio influences the landscape morphometry and plays an important control over the "peakedness" of the runoff hydrograph (Chorley 1969). Waugh (1996) noted that the human significance of the bifurcation ratio is that as the ratio is reduced so the risk of flooding within the basin increases. It also indicates the flood risk of part, rather than all, of the basin. Chorley (1969) had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. The low average bifurcation ratio of the basin under study of 1.80 is an indication that parts of its segments are liable to flooding.

3.3 Areal aspect

Table 4 shows the different parameters of the areal aspect for Cagayan de Oro River Basin. It can be noted that drainage density for the whole CDO River Basin is 2.29 km/km2, indicating that the drainage basin is moderately resistant to erosion. A high drainage density also reflects a highly dissected drainage basin with a relatively rapid hydrologic response to rainfall events, depicting a well-drained basin, while a low drainage density means a poorly drained basin with a slow hydrologic response.

Table 4. Areal aspect elements of Cagayan de Oro River Basin

Name of Watershed	Basin Area (A), km^2	Drainage Density (D_d), km/km^2	Stream Frequency (F_s)	Form Factor (R_f)	Circularity Ratio (R_c)	Elongation Ratio (R_e)	Constant of Channel Maintenance (C)	Length of Overland Flow (L_g)	Infiltration Number (I_f)
Cagayan de Oro River Basin	1373.84	2.29	4.72	0.46	0.34	0.77	0.44	0.22	10.79

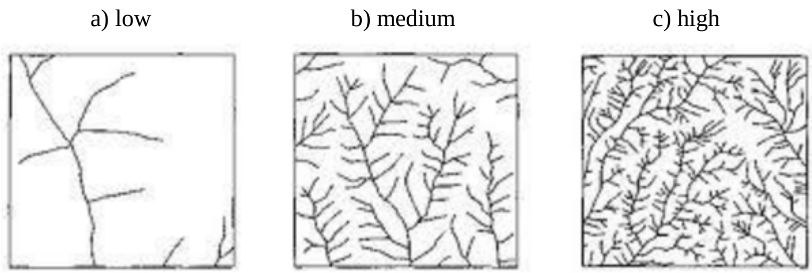

Figure 5. Characteristics of high and low-density drainage basins (FAO)

Source: Food and Agricultural Organization of the United Nations 2002

Characteristics of high and low-density drainage basins:

High density (+2km per km^2)	Impermeable land surface, steep slopes, limited vegetation cover, limited rainfall, gentle slopes, large channel frequency (tributaries).
Low density (-km per km)	Permeable rock, for example, chalk, much vegetation cover, limited rainfall, gentle slopes, lower channel frequency.

Figure 5 above shows the characteristics of high and low-density drainage basins and based on this description, a drainage density of 2.29 km/km2 indicates that Cagayan de Oro River Basin has an impermeable land surface, gentle to steep slopes and a large channel frequency capable of producing large amount of runoff.

In terms of stream frequency, the CDO River Basin shows a higher value of stream frequency which is indicative of steeper slopes, lower permeability of rocks and a larger surface runoff. Being able to describe the shape of the drainage basin is important as understanding how flood occurs. The form factor is another parameter that can be directly linked to peak discharge. Typically form factor is between 0.1- 0.8. For CDO River Basin, form factor is 0.45, revealing that the drainage basin is moderately elongated depicting its fan-shaped appearance. Drainage basins exhibiting higher form factor values generally have high peaks flows of shorter duration whereas elongated drainage basins with low form factor have low peak flow of longer duration.

Another basin parameter that has direct link to drainage basin shape is the circularity ratio. The higher the value represents more circularity in the shape of the basin and vice-versa. Circularity ratio for Cagayan de Oro River Basin is calculated at 0.26 which depicts a slightly circular drainage basin. Naturally all basins have a tendency to become elongated to get the mature stage.The elongation ratio is another parameter related to the shape of the drainage basin. Thus, higher value elongation ratio describes a more circular shaped basin and vice-versa. The Table 5 defines a typical groupings of elongation ratio values depicting basin shapes of particular drainage basins.

Table 5. Groupings of elongation ratio

Elongation Ratio	Basin Shape
< 0.7	Elongated
0.8 – 0.7	Less elongated
0.9 – 0.8	Oval
> 0.9	Circular

From the calculated elongation value of CDO River Basin, a value of 0.78 depicts a less elongated basin shape, e.g. a fan-shaped or pear-shaped drainage basin. Normally, values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope. The basin parameter constant of channel maintenance indicates the requirement of units of watershed surface to bear one unit of channel length. Drainage basins having higher values of this parameter will have lower value of drainage density. In the case of CDO River Basin, computed value of 0.46 would indicate that the drainage basin has a relatively high erodability, low permeability, steep slopes and high surface runoff.

The length of overland flow is an important independent variable, which greatly affect the quantity of water required to exceed a certain threshold of erosion and bears an effective relationship with the drainage density and constant channel maintenance. Length of overland flow for CDO River Basin is measured at 0.23 an indication that the drainage basin will have a quicker surface runoff will enter the streams. The lower value also represents a well-developed drainage network with higher slope. In a relatively homogeneous area, therefore less rainfall is required to contribute a significant volume of surface runoff to stream discharge when the value of overland flow is small than when it is large. Measurement of the infiltration number for Cagayan de Oro River Basin resulted in a high value of 9.86, indicating that the drainage basin is capable of producing high runoff.

3.4 Relief aspect

Another basin parameter of due importance to understanding flooding is the basin relief which plays a relevant role in drainage development. Relief ratio is a dimensionless height-length ratio and allows comparison of the relative relief of any basin regardless of difference in scale or topography.

The parameter is an indicator of the intensity of erosion processes operating on the slopes of the basin. For CDO River Basin drainage basin a relief ratio of 0.05 was computed. This low value of relief ratio is mainly due to the resistant basement rocks of the basin and low degree of slope (see Table 6). Assessment of the ruggedness number indicates that Cagayan de Oro River Basin is susceptible to erosion. Calculated basin relief for CDO River Basin reveals that the drainage basin has a high relief value, indicating the gravity of water flow, low infiltration and high runoff conditions.

Table 6. Relief Aspect elements of Cagayan de Oro River Basin

Basin/Watershed	Relief	Relief Ratio	Ruggedness Number
Cagayan de Oro River Basin	2862	0.05	0.80

The drainage basin ruggedness number is a potential indicator of the hazardousness of a basin, especially hazards that are related to water movement and sediment mobilization, slope and fluvial erosions. Table 10 below is a postulated direct relationship between ruggedness number and extreme geomorphic events as well as an inverse relation between basin area and extreme geomorphic events. Based on Table 7, Cagayan de Oro River Basin could potentially experience a debris flow and fluvial geomorphic process with incidence of hazards from intermediate to high.

Table 7. Theoretical characteristics of basins with variable ruggedness number

Drainage Density, km/km2	Height (m)	Ruggedness Number	Geomorphic Process	Incidence of Hazards
Mountains				
> 10	> 1000	> 10	Debris flow	High
1 – 10	300 – 1000	c. 1	Fluvial	Intermediate
<< 1	>> 1000	< 1	Mass Movement	High
Non-mountains				
>> 10	< 300	> 3	Badlands	Highs
< 1	< 300	< 0.3	Desert	Low

Source: Ayala and Goudie, 2010

4. Conclusions and Recommendations

From the results and discussions above, Table 8 provides a summary of the calculated values of the different drainage basin parameters for Cagayan de Oro River Basin. Results showed that Cagayan de Oro River Basin (CDORB) is “naturally designed” to flood. The drainage basin’s natural features demonstrate its inherent capability to produce high runoff and high sediment loss as indicated in its low bifurcation ratio and high drainage density. However, anthropogenic activities in both down and upstream portions of the drainage basin exacerbate the sensitive features of the basin.

Table 8. Morphometric parameters of Cagayan de Oro River Basin

Morphometric Parameters	Result
Drainage area (km^2), A	1373.84
Perimeter (km), P	225.58
Basin order, U	7.0
Basin length (m), Lb	61710
Bifurcation ratio, Rb	1.80
Drainage density (km/km^2), D	2.29
Stream frequency (km^2), Fs	4.72
Form factor, Rf	0.46
Circularity ratio, Rc	0.34
Elongation ratio, Re	0.77
Constant of channel maintenance (km^2/km), C	0.44
Length of overland flow (km), Lg	0.22
Infiltration number, If	10.79
Relief (m), Bh	2862
Relief ratio, Rh	0.05
Ruggedness number, Rn	6.54

The drainage basin elongation ratio of 0.77, form factor of 0.46 and circularity ratio of 0.34 and these suggest that Cagayan de Oro River Basin is slightly elongated which is usually associated with high relief and steep ground slope and moderately high peak flow of slightly shorter duration.

The lower value of length of overland flow and high value of infiltration ratio are indications that the drainage basin will have a quicker surface run-off that will enter the streams. The Ruggedness number of 6.54 suggests that the Cagayan de Oro River Basin has higher basin relief with gradual change in slope of uniform nature similar to the hypsometric curve described in Figure 2.

The study also reveals that geographic information system (GIS) provides an ideal and convenient approach in the quantitative evaluation of drainage basin parameters and their influence on landform characteristics as well as in understanding the workings of the Cagayan de Oro River Basin.

While there had been significant undertakings carried out to mitigate climatic and hydrological impacts and reduce the risk of flooding, results of the research study showed that important components in the adequate acquisition of science-based information to understand flooding and mitigate the impacts of extreme water event are still inadequate. As such the research study recommends the following:

a. Additional research should be conducted to improve existing river basin information particularly on the short-term and long-term impacts of natural and anthropogenic influences with the river basin;

b. Thorough analysis of overtime landcover and landuse changes influencing river basin response to climatic and hydrological changes to make this information more useful and appropriate for decision making;

c. Overtime bathymetric measurements or hydrographic surveys along Cagayan de Oro River as well as its tributaries to establish geomorphic change detection as the channel and bed of the river system and its tributaries undergoes changes over time which may have considerable impact in conveying flood waters;

d. Generation of flood and sediment models as well as their periodic calibration including new techniques, datasets and other information in coming up with more realistic and less speculative flood and sediment models overtime;

e. Establishment of additional hydrological monitoring instruments along major tributaries to strengthen data gathering and information generation to improve risk reduction strategies and river basin management plan.

5. Acknowledgement

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