MORPHOMETRIC ANALYSIS OF SILWAY RIVER BASIN IN SOUTHERN MINDANAO, PHILIPPINES FOR FLOOD RISK MANAGEMENT A SUPPLEMENTARY OF FLOOD MODELING

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ABSTRACT. Flood modeling studies in many countries today is not anymore new for the purpose of forecasting, early warning purposes and disaster management of the local government and other disaster agencies. However, with the limitation of the hydrologic data (rainfall and discharge data) for the flood simulation, morphometric information of the river is the auxiliary to understand the flood potential of the river basin. Silway River Basin in Mindanao, Philippines is one of the four major river basins that flows towards General Santos City before discharging into the Sarangani Bay with a drainage area of 63,758 hectares. Among the four major river basins, Silway River Basin poses a greatest risk to the communities downstream when it comes to flooding.
Consuming the 10 meter resolution SAR-DEM, the drainage system of the river basin was delineated in ArcMap 10.1 with the aid of HEC-GeoHMS. Ratio values of elongation (0.90), form factor (0.63) and circularity (0.26) indicated of very low relief and oval in shape. Compact and ovoid shape results to high peak of discharge and runoff during high rainfall events. The relief ratio value (0.07) of the river basin indicates that it is susceptible to flash floods and soil erosion. The river basin bifurcation ratio value (1.69) indicates high risk to flooding in localized areas. Moreover, the low value of drainage density (0.00052) can influence flooding in flat areas especially downstream of General Santos City. The resulting morphometric characteristics of the Silway River Basin show a significant indication of greater risk to flooding. As a result, flood modeling of the river basin is highly recommended to simulate the complete hydrologic process of the river, subsequently for river and floodplain hydraulics.

1. INTRODUCTION

As one of the world's disaster-prone countries, several studies had been conducted flood modeling for the purpose of flood risk management. It is very helpful to analyze flood events for flood protection measures and flood mitigation strategies. However, with the limitation of the hydrologic data (rainfall and discharge data) for the flood simulation, morphometric analysis of the river is the auxiliary to understand the flood behavior and potential of the river basin. It is a measurement and evaluation of the land forms dimension and structures of the earth's surface that provides quantitative description of the river basin characteristics that supports the flood potential of the river basin (Withnage, N.S., et al, 2014). Morphometric information of a river basin is essential in understanding the hydrological response of a river basin. In this connection, without performing the flood modeling especially for rivers with high risk to flooding, river basin morphometric information could give baseline information to the local government for disaster risk management of the river.

One of the identified critical rivers in the Philippines is the Silway River Basin in Southern Mindanao. General Santos City is the lower portion of four major river basins that flows towards the city before discharging into the Sarangani Bay with a drainage area of 63,758 hectares. Among the four major river basins, Silway River Basin poses a greatest risk to the communities downstream when it comes to flooding.

Silway River Basin lies in the southern portion of the province of South Cotabato and western part of the province of Sarangani and drains towards Sarangani Bay (Figure 1). The river basin falls within fifty nine barangay jurisdiction and distributed in four city/municipalities. A significant of 66% populations of General Santos City are prone to flooding during heavy rains. Considering the river basin possess greater risk to flooding, thus, needs to assess the flood potential for disaster risk management using the morphometric features of the river basin. The generated resource information of this study will be useful in providing the information requirements of various sectors in two provinces the river basin within aside from addressing disaster risk reduction.

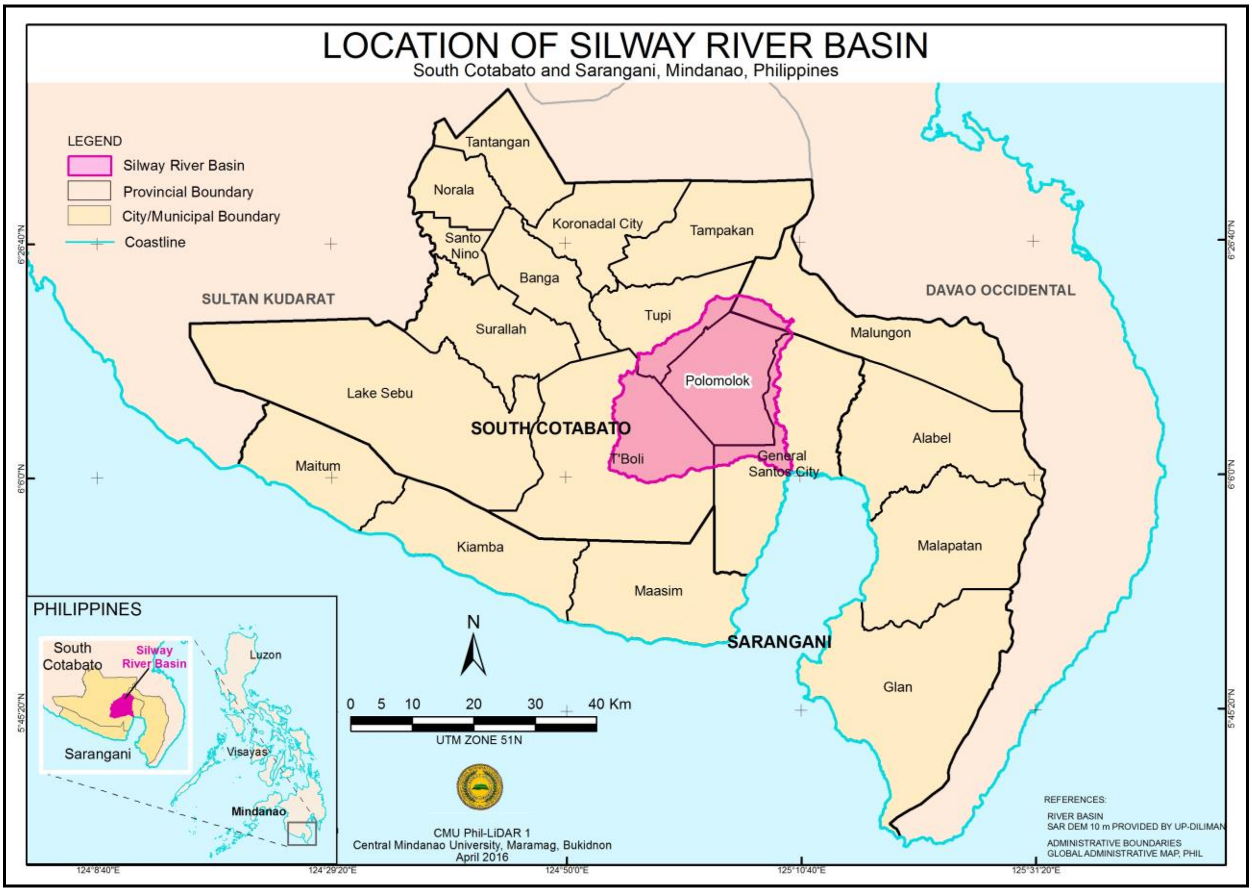

Figure 1. Silway River Basin in Southern Mindanao Philippines.

2. MATERIALS AND METHODS

Digital Elevation Model (DEM) is considered by many for the extraction of the morphometric characteristics and delineates precisely the drainage networks of a river basin (Farhan, Y., et al, 2015). A 10 meter resolution Synthetic Aperture Radar-Digital Elevation Model (SAR-DEM) and digitized river channel in shapefile form are the two main datasets for the delineation of Silway River Basin drainage system. It includes the basin boundary, subbasin and the stream networks. This was done using Geographic Information System software such as ArcMap 10.1 using the surface analyst tool and the Hydrologic Engineering Center-Geospatial Hydrologic Modeling System (HEC-GeoHMS) extension, a pre-processor of Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) software used to simulate river basin hydrologic process. HEC-GeoHMS basically prepares the basin model and assign basic model parameters, subsequently for hydrologic process of the river basin. Default threshold area used is 140 hectares.

Soil type and land cover were extracted from the soil map shapefile (BSWM, 2004) and land cover map shapefile (NAMRIA, 2004). Each subbasin has a corresponding soil and land cover characteristics of the area. Miller (1953), Horton (1945), Schumn (1956) and Strahler (1964) suggested the mathematical equations for the morphometric parameters that are tabulated in Table 1(in Waikar and Nilawar, 2014). Significant morphometric parameters such as relative relief, basin relief and stream features have been quantified and calculated from delineated drainage system.

Table 1. Formulae for computation of morphometric parameters.

PARAMETERS	METHODS	REFERENCES
LINEAR ASPECTS		
Stream Order (U)	Strahler's Method	Strahler,1964
Stream Length (L_u)	GIS (Spatial Analysis)	ESRI
Bifurcation Ratio (R_b)		Horton, 1945
RELIEF ASPECTS		
Watershed Relief (Wh)	Diff. bet. Highest and lowest elev.	Schumn, 1956
Relief Ratio (R_h)		Schumn, 1956
Ruggedness Number (R_n)	$Rn = Wh \times Dd$	Schumn, 1956
Highest Elevation (m)	GIS (Spatial Analysis)	ESRI, 2010
Lowest Elevation (m)	GIS (Spatial Analysis)	ESRI, 2010
Mean Elevation (m)	GIS (Spatial Analysis)	ESRI, 2010
Steepest Slope (*Degree*)	GIS (Surface Analysis)	ESRI, 2010
AREAL ASPECTS		
Watershed Area (A)	ArcGIS &MapWindow GIS	ESRI/MapWindow
Perimeter (P)	GIS(Spatial Statistics)	ESRI, 2010
Watershed Length (Lw)	GIS (Query Analysis)	ESRI, 2010
Watershed Width (Ww)	GIS (Query Analysis)	ESRI, 2010
Drainage Density (D_d)	$Dd = L/A$	Horton, 1945
Stream Frequency (F_s)	$Fs = N/A$	Horton, 1945
Texture Ratio (T)	$T = N_1/P$	Horton, 1945
Form Factor (R_f)	$Rf = A/(Lw)^2$	Horton, 1932
Circularity Ratio (R_c)	$Rc = 4\pi A/P^2$	Miller, 1953
Elongation Ratio (R_e)	$Re = 2\sqrt{(A/\pi)}/Lw$	Schumn,1956
Length of Overland Flow (L_{of})	$Lof = 1/2Dd$	Horton, 1945
Constant of Channel Maintenance (C)	$C = 1/Dd$	Horton, 1945

Where; U = stream order, N_u = total number of stream segment of order U, N_s = number of segment of next higher order, Wh= watershed relief, Lw= watershed length, Ww = watershed width, Dd= drainage density, L = total length of streams, A = area of watershed, N = total number of streams, N_1=total number of first order streams, P= perimeter of watershed, Lu= total stream length of order U, $Lu\text{-}1$= stream length of next lower order.

3. RESULTS AND DISCUSSIONS

3.1 Linear Aspects

Silway River Basin is one of the four major river basins in South Cotabato that drains towards the Sarangani Bay. According to the contingency plan of General Santos City Disaster Risk Reduction and Management Office (CDRRMO), tributaries namely, Klinan, Sinawal, Apopong significantly contributed run-off during heavy rains and caused of larger extent of inundation downstream. Silway River consists of seventy-five (75) streams including the seasonal streams with the total length of three hundred thirty-four (334) kilometers (Figure 2). Longer length is generally an indicative of flat terrain which is aided by the river basin elevation and slope classification (see Figures 3 & 4). The bifurcation ratio on the other hand, using the threshold area of 500 hectares has a value of 1.70 indicates higher risk of flooding in localized areas but not the entire river basin. Schumn (1956) said, "bifurcation ratio (R_b) is maybe defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order" (in Waikar and Nilawar, 2014).

Table 2. Silway River Basin Linear Aspects.

No. of Streams	75
Stream Total Length (m)	33,4097
Mean Slope of River (%)	0.0261
Bifurcation Ratio	1.70
L. of 1st Order Stream (m)	204,158
No. of 1st Order Stream	38

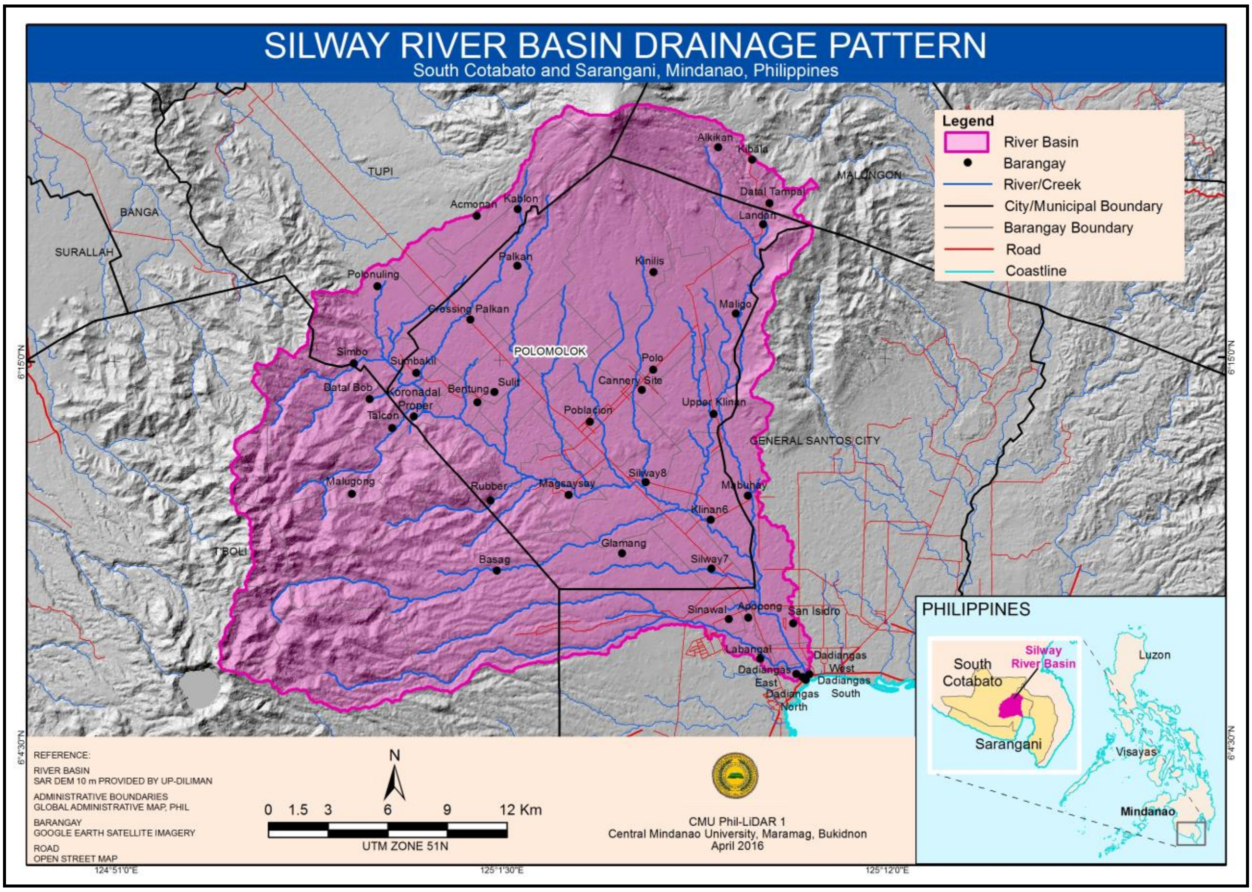

Figure 2. Drainage Pattern of Silway River Basin.

3.2 Relief Aspects

The river basin has varied elevation ranging from 0.54 meters to 2,251.26 meters above sea level (masl). It is surrounded with high peaks of Mount Matutum on the northern part and Mount Parker on the western part of the river basin (Figure 3). The mountainous regions of municipality of T'Boli and Polomolok are headwaters source of the river basin. Lower elevations ranging from 0.54 meters to 300 meters above sea level are situated in the city of General Santos City and southern part of the Municipality of Polomolok.

Table 3. Silway River Basin Relief Aspects.

Basin Relief (m)	2,250.72
Relief Ratio	0.07
Ruggedness Number (Rn)	1.18
Highest Elevation (m)	2,251.26
Lowest Elevation (m)	0.54
Mean Elevation (m)	553.08
Maximum slope (%)	235.49
Mean Slope (%)	18.61
Mean Aspect	168.56 (South)

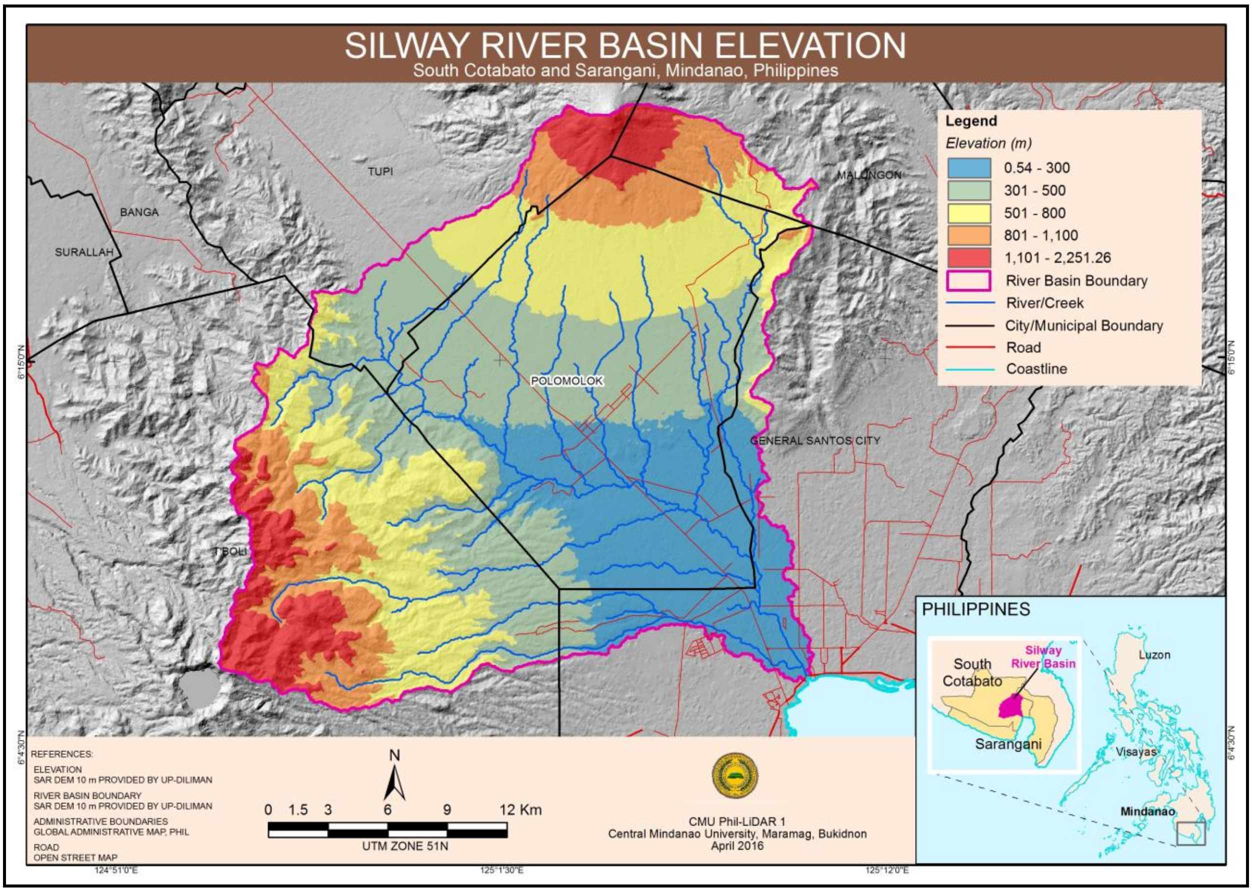

Figure 3. Elevation of Silway River Basin.

Silway River Basin is composed generally of flat to nearly surface classification of slope specifically in most areas of Polomolok and General Santos City. This range is recommended and ideal for urban development, agro-industrial and can be utilized for eco-tourism purposes. The northern and western part of Silway River Basin composed of rolling to hilly areas to very steep hill and mountains in which the Mount Matutum (northern) and Mount Parker (western) are situated (Figure 4). Accordingly, General Santos City has severe social, economic and environmental impact in flooding for it is the catchment of all water inflows from the mountainous portion of T'Boli, Tupi, Polomolok, Malungon and Alabel as reported by CENRO General Santos City. In 2012, Typhoon Bopha (Pablo) caused casualties in General Santos City of 4 people dead and 311 missing with an estimated total amount of damages of PhP 9.6 billion (Gen. San. CDRRMO, 2015).

In addition, the relief ratio value indicates that the river basin is susceptible to flash floods and soil erosion especially during heavy rain. This is exacerbated with the land classification (Figure 5) and soil type (Figure 6) of the river basin that signify of sparse vegetative cover and low permeable subsoil material.

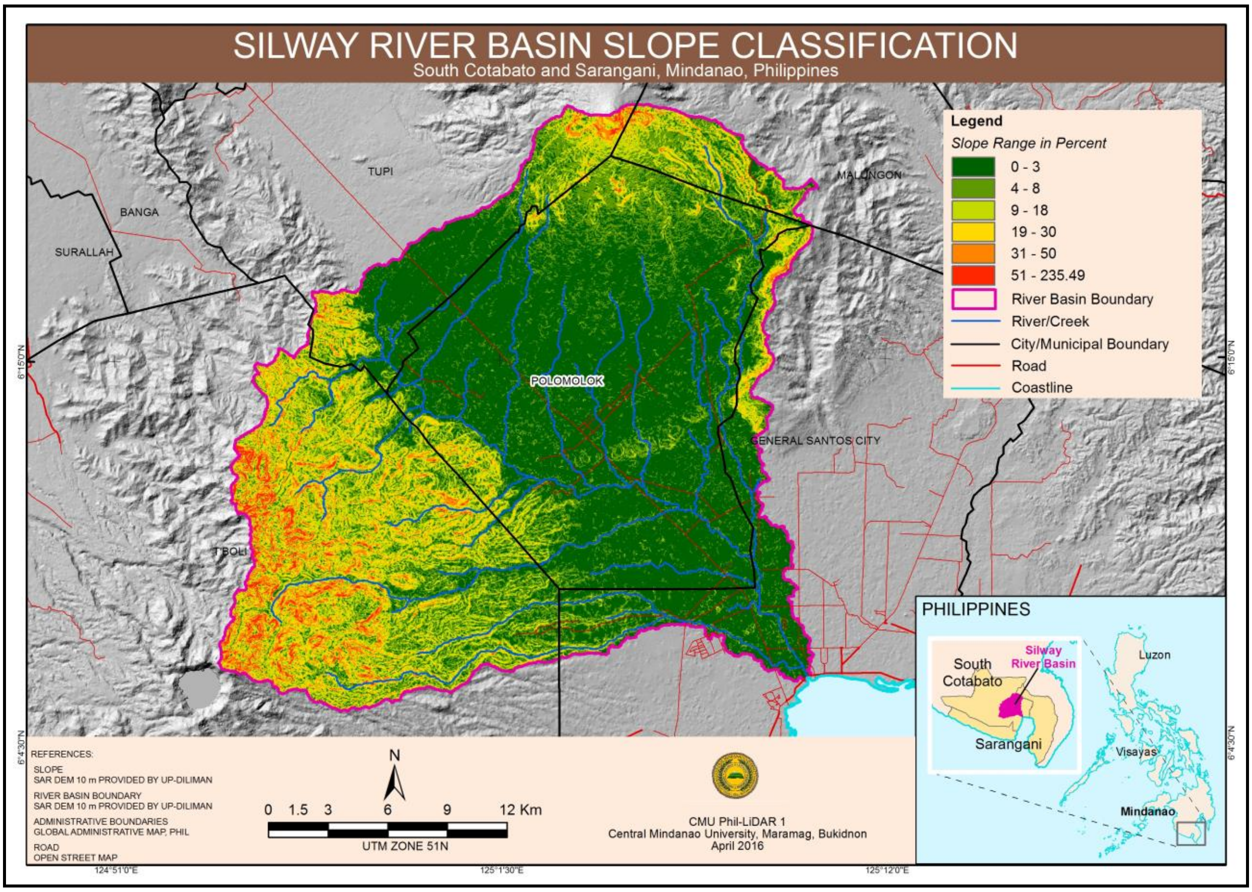

Figure 4. Slope Classification of Silway River Basin.

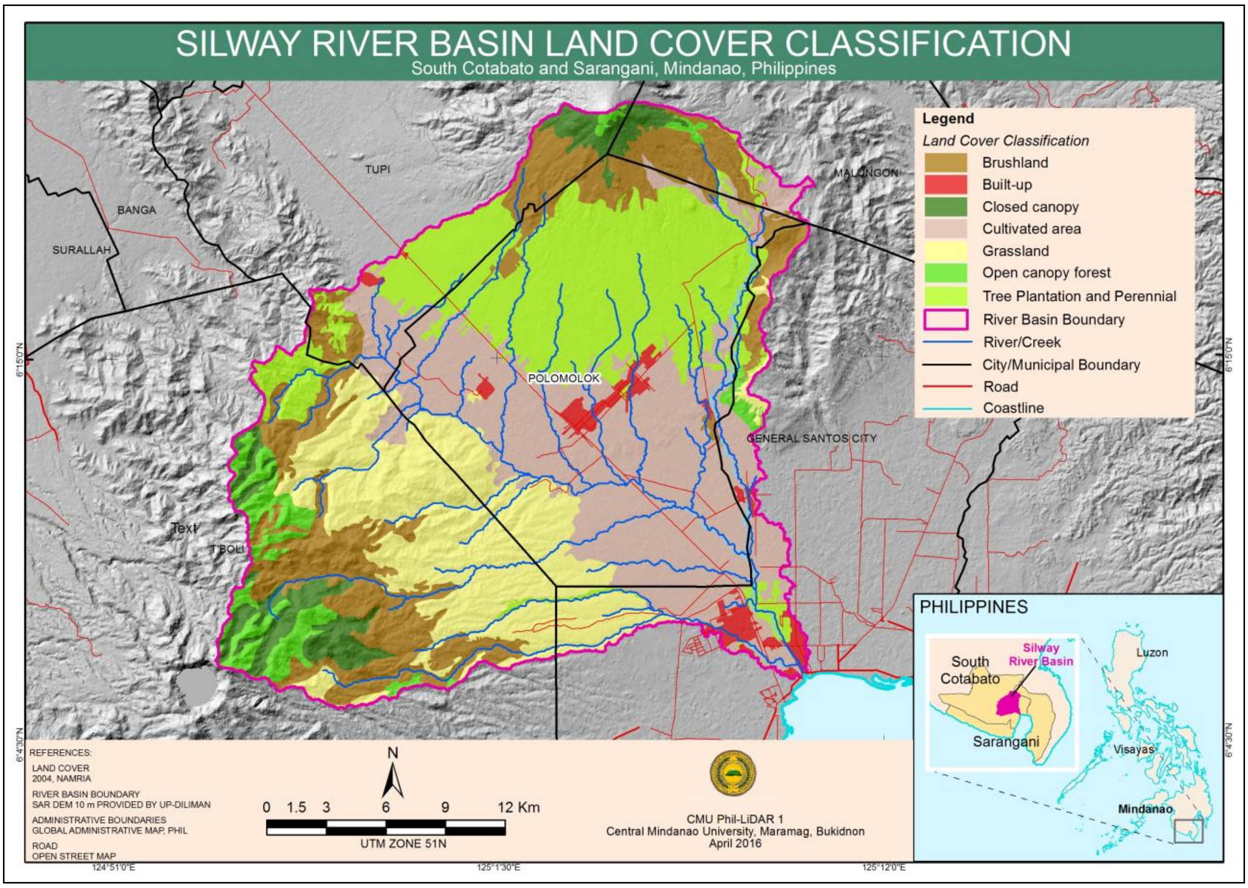

Figure 5. Land Cover Classification of Silway River Basin

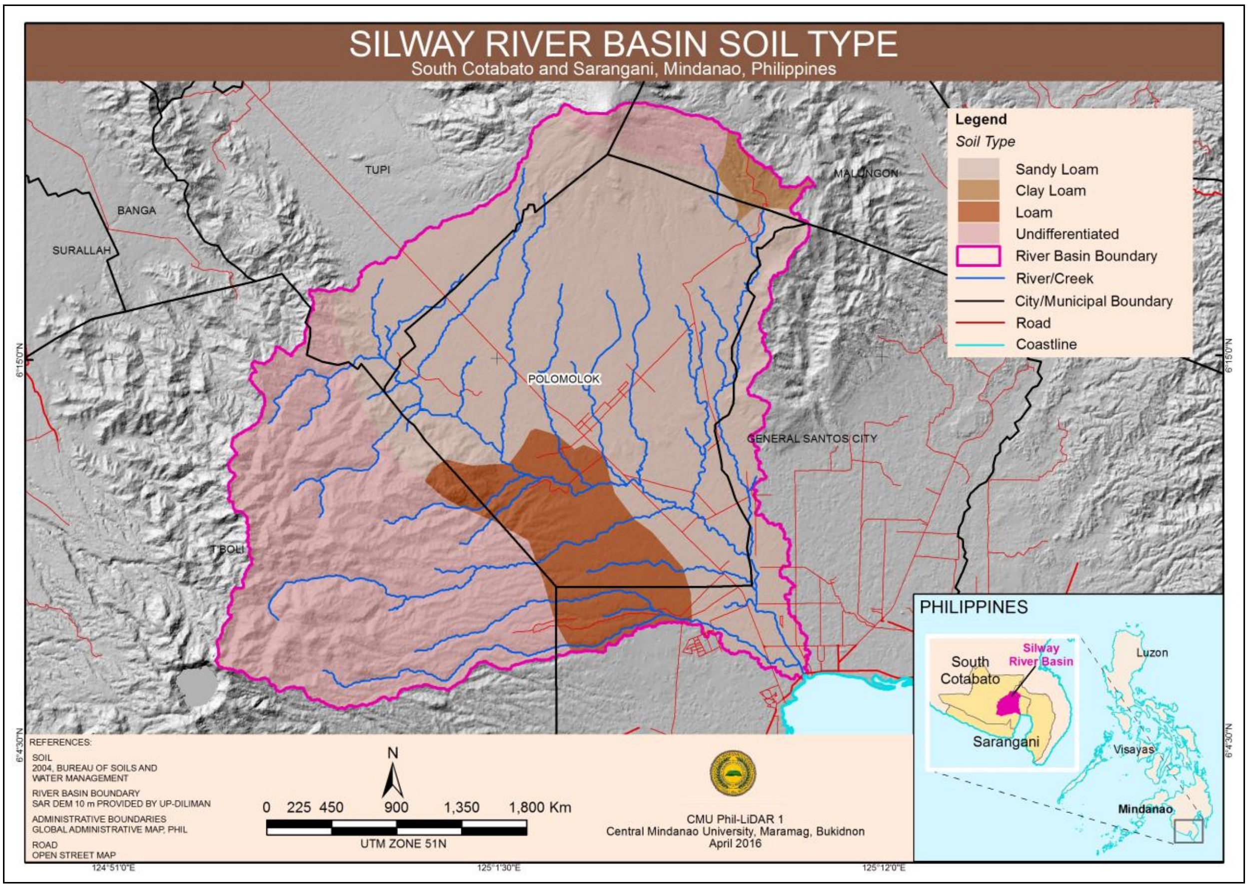

Figure 6. Soil Type of Silway River Basin

3.3 Areal Aspects

Silway River Basin has the total land area of 63,757 hectares. Area and perimeter are important parameters of the quantitative description of a river basin and can be used as an indicator of the river basin area and shape. However, ratio values in elongation (Re), circularity (Rc) and form factor (Rf) implying of low relief and oval in shape indicating of high flood potential of the river basin. River basin of compact and ovoid shape results to larger peak and low permeable of the subsoil condition (see Figures 5 & 6). Run-off will have relatively short distance to travel to reach a stream and to leave the river basin at its mouth. These characteristics can influence flooding in the river basin. Drainage density of Silway River basin is very low that manifest of weak coarse drainage texture and high potential run-off and potential erosion of the river basin. Low drainage density also demonstrates of slow hydrological response of rainfall events which is contrasting the Re, Rc and Rf.

Table 4. Silway River Basin Areal Aspects.

Area (ha)	63,757
Perimeter (m)	175,380
Basin Width (m)	60,880
Basin Length (m)	31,658
Drainage Density (m)	0.000524006
Stream Frequency	1.1763E-07
Texture Ratio (T)	0.0002167
Form Factor Ratio	0.64
Circularity Ratio	0.26
Elongation Ratio	0.90
L. of Overland Flow (m)	0.000262003
Constant of Channel Maintenance (C)	1,908.37

4. CONCLUSIONS AND RECOMMENDATIONS

In drainage delineation and on the analysis of the morphometric characteristics, GIS and Remote sensing techniques have proved to be accurate and efficient tool. Environmental factors such as rainfall and aspects such as slope and relief also had significantly contributed to the basin morphometric. Morphometric information provides baseline information of the river basin. The complete morphometric analysis of drainage basin indicates that the given area possess high potential and greater risk to flooding. Therefore, flood modeling of the river basin is highly recommended to simulate the complete hydrologic process of the river, subsequently for river and floodplain hydraulics. Hydrologic modeling is essential for the use of disaster preparedness of the local government for the affected and flood prone areas along the river. It can be used for water level monitoring and forecasting and gives lead time for the vulnerable community for the preparation of evacuation to the identified safe places nearby by the local government unit. Furthermore, the simulations provide hydrologic details about quantity, variability and source of run-off in the river basin.

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REFERENCES

Genral Santos City DRRMO, 2015. Contingency Planning for Emergencies.

Farhan Y., et al. 2015, Quantitative Analysis of Geomorphometric Parameters of Wadi Kerak, Jordan, Using Remote Sensing and GIS, pp. 456-475. Retrieved August 15, 2016 from http://file.scirp.org/pdf/JWARP_2015041015310205.pdf

Horton, R. E., 1945, Erosional Development Of Streams And Their Drainage Basins; Hydrological Approach to Quantitative Morphology, Geological Society of American Bulletin, 56, pp 275-370. http://www.geos.ed.ac.uk/homes/s0451705/horton_1945.pdf

Kotei R., et al. 2015. Morphometric Analysis of the Sumanpa River Catchment at Mampong-Ashanti in Ghana, pp. 67-75. Retrieved August 15, 2016 from http://www.arpnjournals.com/jes/research_papers/rp_2015/jes_0615_41.pdf

Mogholi, M., 2014. Assessment of Zonation of Watersheds Based on Flooding Risks Using GIS (A case study of Varband River Basin in Larestan, Fars, Iran), pp. 164-171. Retrieved August 15, 2016 from http://iicbe.org/upload/2331C714054.pdf

Nikhil Raj, P. P., P. A. Azeez. 2012. Morphometric Analysis of a Tropical Medium River System: A Case from Bharathapuzha River Southern India, pp. 91-98. Retrieved August 15, 2016 from http://file.scirp.org/pdf/OJMH20120400003_87880664.pdf

Nageswara Rao. K., et al. 2010. Morphometric Analysis of Gostani River Basin in Andhra Pradesh State, India Using Spatial Information Technology, pp. 179-187. Retrieved August 15, 2016 from http://www.ipublishing.co.in/jggsvol1no12010/EIJGGS1018.pdf

Waikar, M.L., A. P. Nilawar., 2014. Morphometric Analysis of a Drainage Basin Using Geographical Information System: A Case study, pp. 179-184. Retrieved August 15, 2016 from http://ijmcr.com/wp-content/uploads/2014/02/Paper32179-184.pdf

Withanage N.S., et al. 2014, Morphometric Analysis of the Gal Oya River Basin Using Spatial Data Derived from GIS, pp. 175-188. Retrieved August 15, 2016 from http://www.pgia.ac.lk/files/Annual_congress/journel/v26/Journal-No%201/Papers/16.%20Ms.%20Withanage-%2047.pdf