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Watershed conservation prioritization using morphometric parameters applied with principal component analysis approach

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Abstract

The present study analyzed and quantified the different morphometric aspects of the Upper Pulangi Watershed in Bukidnon, Philippines using a 10-m spatial resolution digital elevation model. The study was carried out using geospatial techniques to quantify morphometric parameters relative to the tendency of the watershed to erosion threat to provide basis and guidelines in prioritizing watersheds that need an immediate rehabilitation and conservation. Morphometric analysis applied with Principal Component Analysis was used in prioritizing watersheds. Principal Component Analysis is a dimension-reduction tool that can be used to reduce a large set of variables to a small set that still contains most of the information in the large set. It also decreases the dimensionality of the data set and identifies a new meaningful underlying variable. Results showed that Nabalintungan sub watershed with a compound ranking value (Cp = 4.17) was classified under very high priority followed by the Maapag sub watershed with (Cp = 4.25) thus, implying more attention for conservation measures. Upper pulangi sub watershed with (Cp = 6.75) was classified under very low priority followed by the Sawaga sub watershed with (C_p = 6.00), signifying promising environmental condition among the nine sub watershed areas. The study provides significant information that are helpful to watershed managers and planners in coming up with an informed decision and actions in relation to planning for watershed management, for soil and water conservation programs and project implementation under limited resources.

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Introduction

The current status of natural resources within the watershed like land, soil and water are getting degraded, eroded and polluted. A watershed is an ideal unit for the management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development (Ali *et al.*, 2014). In the pursuit of sustainable development, watersheds need protection and conservation as well as rehabilitation of degrading areas (Francisco and Rola, 2004; Javier, 1999). Watersheds are regarded as important life support system. In fact, 75% of the Philippines is located within watersheds (Lasco *et al.*, 2010). The Philippine Government has implemented some watershed rehabilitation through the Department of Environment and Natural Resources (DENR) as part of their Rivers for Life Program and their Integrated Natural Resources and Environmental Management Project (INREMP). The DENR Office has also issued a memorandum circular mandating the agency to prepare feasible and integrated watershed management plan for all critical watersheds in the country (DENRmc Series, 2008). However, these projects of the government cannot possibly rehabilitate the whole watershed at a time, so there is a need to prioritize those watersheds which need an immediate action based on the severity of the problems therein. Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management (Iqbal *et al.*, 2014). Morphometric analysis has been commonly applied to the prioritization of watersheds (Javed *et al.*, 2009). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms (Agarwal, 1998; Obi *et al.*, 2002; Iqbal *et al.*, 2012; Iqbal *et al.*, 2013). Integrated watershed management planning involves a comprehensive characterization of the drainage area, however most watersheds in the region are ungagged with no adequate data available for analysis. At this point, morphometric quantification studies are a useful alternative course of action. Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The linking of geomorphologic parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrological behaviour of different basins (Meshram *et al.*, 2017). The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics (Iqbal *et al.*, 2014). The geomorphologic studies are helpful in regionalizing the hydrologic models since most of the basins are either ungauged or sufficient data are not available for them (Meshram *et al.*, 2017). The need for accurate information on watershed runoff and sediment yield has grown rapidly during the past decades because of the acceleration of watershed management programs for conservation, development, and beneficial use of all-natural resources, including soil and water (Gajbhiye & Mishra 2012; Mishra *et al.*, 2013; Gajbhiye *et al.*, 2014).

It is not feasible to take the whole watershed area at once for its management. Thus, the whole basin is divided into several smaller units, as sub watersheds or micro watersheds, by considering its drainage system. Prioritization of sub watershed is a method of ranking of sub watershed units based on the extent of denudation due to accelerated soil erosion and criticality condition of drainage areas (Pandy *et al.*, 2007). Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps (Iqbaluddin *et al.*, 1984; Wani *et al.*, 2011). Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation is done in Geographic Information System (GIS) environment using Digital Elevation Model (DEM) either prepared from contour map or directly taking DEM from reliable sources, e.g., ASTER 30 m DEM. GIS is a set of tools made up of hardware, software, data and users, which allows us to capture, store, manage and analyse digital information, as well as make graphs and maps, and represent alphanumeric data (López Trigal, 2015). According to Burrough (1994) GIS can also be a computer model of geographic reality to meet specific information needs, i.e., create, share, and apply useful information based on data and maps. GIS and remote sensing have become an indispensable scientific tool for mapping and monitoring of natural resources (Kasturirangan *et al.*, 1996) and frequently used in the characterization of the soil resources (Saxena *et al.*, 2000; Srivastava & Saxena, 2004) and prioritization of watershed (Suresh *et al.*, 2004) for planning.

The morphometric parameters are usually many times correlated. The correlation indicates that some of the information contained in one variable is also contained in some of the other remaining variables (Meshram *et al.*, 2017). Factor analysis technique is very useful in the analysis of data corresponding to large number of variables; analysis via this technique produces easily interpretable results (Praus, 2005). Principal Component Analysis (PCA) is a dimension-reduction tool that can be used to reduce a large set of variables to a small set that still contains most of the information in the large set. In recent years, many studies have been done using PCA in the interpretation of water quality parameters (Gajbhiye *et al.*, 2010, 2015b), geomorphometric parameters (Sharma *et al.*, 2004), etc. This study mainly aims to quantify morphometric parameters relative to the tendency of the watershed to erosion threat to provide basis and guidelines in prioritizing watersheds that need an immediate rehabilitation and conservation. This study has been carried out in sub watersheds of Upper Pulangi River located within the province of Bukidnon, Mindanao, Philippines in 2019.

Materials and methods

Watershed study

Pulangi River is the longest river in Bukidnon, Philippines. It lies within the geographic coordinates of 7°01'60.00"N latitude and 124°29'59.99"E longitude as shown in Fig. 1. It has one reservoir type power plant, the Pulangi IV Hydroelectric Plant and watershed which provides for 25% of Mindanao's power needs. The reservoir and dam are also the main water source for the province of Bukidnon, both for drinking water and for irrigation through the National Irrigation Administration (Bukidnon, 2012). Pulangi River has a length of 320 kilometres and traverses through most of the cities and municipalities of Bukidnon from its source in Barangay Kalabugao, Impasugong,

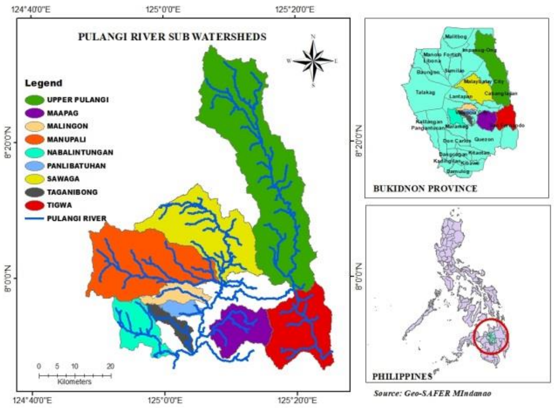

Fig. 1. Map of the study site.

Bukidnon. Records from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) shows that rainy season in the province of Bukidnon where most of the watershed area is located occurs in June to November with mean annual precipitation of 1,703mm for the period 1981-2011 (INREMP, 2018).

Watershed Delineation and Morphometric Analysis

A 10-meter resolution DEM Synthetic Aperture Radar (SAR) digital elevation data of the National Mapping and Resource Information Authority (NAMRIA) of DENR acquired through the Geo-informatics for the Systematic Assessment of Flood Effects and Risk for Resilient Mindanao (Geo-SAFER Mindanao) was used to outline watershed boundary and stream network using Arc Hydro Tool of ArcGIS version 10.2.2. A threshold of 10, 60, 150, 50, 20, 20, 5, 30, and 10 hectares for Taganibong, Sawaga, Upper Pulangi, Manupali, Nabalintungan, Maapag, Panlibatuhan, Tigwa, and Malingun, respectively, were arbitrarily chosen in delineating perimeter and channels of the watersheds that are representative to the actual configuration on the ground. An open source of Map Window GIS software was used to automatically delineate stream orders which follow the technique commonly applied in previous studies (Kadam *et al.*, 2016). The designation of stream order was the first step in the morphometric

Table 1. Methods and sources used to derive watershed morphometric values

Parameters symbols and Units	Formulas/Methods	References
Number of stream (N_u)	$N_u = N_1 + N_2 ...+N_n$	Horton (1945)
Total Stream length (L_u), km	$L_u = L_1 + L_2 + ...+ L_n$	Horton (1945)
Bifurcation ratio (R_b)	$R_b = \frac{N_u}{N_{u+1}}$	Schumn (1956)
Basin length (L_b)	$L_b = 1.312\ x\ A^{0.568}$	Nookaratnam *et al.* (2005)
Drainage density (D_d)	$D_d = \frac{L_u}{A}$	Horton (1945)
Constance of channel maintenance (C)	$C = \frac{1}{D_d}$	Rama (2014)
Infiltration number (I_f)	$I_f = F_s D_d$	Adhikary and Dash (2018)
Stream frequency (F_s)	$F_s = \frac{N_u}{A}$	Horton (1945)
Drainage Texture (T)	$T = \frac{N_u}{P}$	Horton (1945)
Form factor (R_f)	$R_f = \frac{A}{L_b 2}$	Horton (1945)
Circularity ratio (R_c)	$R_c = \frac{4\pi A}{P^2}$	Miller (1953)
Elongation ratio (R_e)	$R_e = \left(\frac{2}{L_b}\right) x \left(\frac{A}{\pi}\right)^{0.5}$	Schumn (1956)
Compactness constant (C_c)	$C_c = \frac{0.2821P}{A^{0.5}}$	Horton (1945)
Total relief (H) m	H = Z- z	Adhikary and Dash (2018)
Relief ratio (R_h)	$R_h = \frac{H}{L_b}$	Rama (2014)
Relative relief ratio R_{hp}	$R_{hp} = H\left(\frac{100}{P}\right)$	Melton (1957)
Ruggedness number (N_r)	$N_r = D_d\left(\frac{H}{1000}\right)$	Adhikary and Dash (2018)

analysis of drainage basin based on the hierarchical making of the stream as proposed by Strahler (1964) which was used in this study. The fundamental parameters, namely: number of streams, stream length, area, perimeter, and basin length were derived from the drainage layer. The morphometric parameters, i.e., mean bifurcation ratio (R_{bm}), drainage density (D_d), mean stream length (L_{sm}), compactness coefficient (C_c), stream frequency (F_s), drainage texture (T), length of overland flow (L_o), form factor (R_f), circularity ratio (R_c) and elongation ratio (R_e) are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds (Meshram *et al.*, 2017). The morphometric parameters for the delineated watershed area were calculated based on the formula suggested by different authors (Table 1).

Prioritization of Sub Watersheds

The linear/channel parameters such as drainage texture, drainage density (D_d), stream frequency (F_s), bifurcation ratio (R_b), length of overland flow (L_{of}) have a direct relationship with erodibility; higher the value, more is the erodibility (Singh *et al.*, 2013; Nookaratnam *et al.*, 2005). For the prioritization of sub-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Areal parameters such as elongation ratio (R_e), compactness constant(C_c), circularity ratio (R_c), basin shape, and form factor (R_f) have an inverse relationship with erodibility (Nookaratnam *et al.*, 2005; Javeed *et al.*, 2009). The lower the value the higher is the erodibility. Thus, the lowest value of shape parameters was rated as rank 1, the next lower value was rated as rank 2 and so on and the highest value was rated last in rank. The ranking of the nine (9) sub-watersheds of Pulangi River was determined by assigning the highest priority/rank based on the highest value of linear parameters and the lowest value in the case of shape parameters. When the ranking of the nine sub-watersheds was done in every single parameter, the ranking values of all the morphometric parameters of each sub-watersheds were added up to arrive at a compound value (C_p). Based on the average value of these parameters, the sub-watershed having the least rating value was assigned as the highest priority for rehabilitation; the next higher value was assigned as second and so on (Iqbal *et al.*, 2014; Javed *et al.*, 2009; Suji *et al.*, 2015; Javed *et al.*, 2011; Ali *et al.*, 2015).

Another approach using Principal Component Analysis

The morphometric parameters are usually many times correlated. The correlation indicates that some of the information contained in one variable is also contained in some of the other remaining variables (Meshram *et al.*, 2017). Principal Component Analysis (PCA) is a dimension-reduction tool that can be used to reduce a large set of variables to a small set that still contains most of the information in the large set. The principal component analysis was applied for all morphometric parameters to calculate the correlation matrix and to derive principal components and find out the most effective parameter. This approach was analysed using SPSS Software.

Priority Indices

Final priority ranking of the nine sub watersheds was determined based on the compound value of morphometric parameters. Final priority values were then classified into five corresponding to very low, low, moderate, high, and very high (Gumma *et al.*, 2016) and were illustrated through the priority index map. Sub watershed with the lowest compound value was assigned with very high priority and recommended for an immediate need of treatment to control erosion while sub watershed with highest compound value was classified under very low priority suggesting a sound environmental condition within those areas.

Results and discussion

Cross tabulation of morphometric values

The watershed morphometric parameters are classified into three categories corresponding to linear/channel morphology, areal aspect, and relief features of the watershed. Channel morphometric parameters includes total stream length (L_u), number of streams (N_u), bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), length of overland flow (L_{of}), infiltration number (I_s), drainage texture (T), and constant of channel maintenance (C). Also, areal aspect for the nine sub watersheds consists of the watershed area (A), perimeter (P), basin length (L_b), watershed width (W_w), circularity ratio (R_c), elongation ratio (R_e), form factor (F_f) and compactness constant (C_c) while the relief aspects were the highest elevation (Z), lowest elevation (z), total watershed relief (H), relief ratio (R_h), relative relief ratio (R_{hp}), and ruggedness number (N_r).

Table 2. Stream order and stream length values.

Watersheds	Stream Order					Mean Bifurcation Ratio
	I	II	III	IV	V	
Taganibong						5.01
No. of streams	125	23	5	1	-	
Stream Length (km)	71.35	29.90	17.57	13.17	-	
Sawaga						3.80
No. of streams	170	61	17	6	1	
Stream Length (km)	230.14	154.18	62.48	14.65	25.78	
Upper Pulangi						3.88
No. of streams	175	48	11	2	1	
Stream Length (km)	320.52	180.74	68.86	20.91	66.15	
Manupali						3.98
No. of streams	242	61	13	4	1	
Stream Length (km)	354.37	186.42	62.21	34.59	33.11	
Nabalintungan						3.90
No. of streams	183	41	8	2	1	
Stream Length (km)	135.89	70.66	37.53	7.19	16	
Maapag						4.23

Watersheds	Stream Order					Mean Bifurcation Ratio
	I	II	III	IV	V	
No. of streams	291	62	16	3	1	
Stream Length (km)	152.81	76.34	40.38	32.99	9.82	
Panlibatuhan						3.67
No. of streams	147	31	7	2	1	
Stream Length (km)	57.71	25.32	12.83	15.01	2.49	
Tigwa						4.22
No. of streams	274	62	17	6	1	
Stream Length (km)	197.74	104.09	45.71	30.56	21.76	
Malingun						3.71
No. of streams	129	21	5	2	1	
Stream Length (km)	63.28	39.80	16.82	6.30	10.19	

Stream Order (u)

Stream order expresses the hierarchical relationship between stream segments (Ali *et al.*, 2015). The first step in the geomorphological analysis of a drainage basin is the designation of stream order. Stream ordering as suggested by Strahler (1964) was used for this study. Strahler's system has been followed because of its simplicity (Waiker *et al.*, 2014), where the smallest, unbranched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channels segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. The order of a basin is the order of the highest stream (Meshram *et al.*, 2017). After analysis of the drainage map, it was found out that only Taganibong sub-watershed is of fourth order whereas the other sub watersheds are of fifth order (Table 2).

Stream Number (N_u)

Stream number was observed to gradually decrease as the ordering of the streams increases. This is in accordance with the Horton's (1945) law which states that the "number of stream segments of each order forms an inverse geometric sequence with order number". It is observed from Table 2 that the maximum frequency is in case of first-order streams. It is also noticed that there is a decrease in stream frequency as the stream order increases. Maapag sub-watershed has maximum total number of (N_u = 373), among all other comparisons.

Total Stream Length (L_u)

Total stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing sub-basin surfaces (Strahler, 1964). It was computed based on the law proposed by Horton (1945), for all the nine watersheds. Generally, the total length of stream segments decreases as the stream order increase (Horton, 1945; Iqbal *et al.*, 2014).

In four watersheds i.e., Taganibong, Manupali, Maapag, and Tigwa watersheds, the stream length followed Horton's law. But in the other five watersheds i.e., Sawaga, Upper Pulangi, Nabalintungan, Panlibatuhan, and Malingun watersheds, the stream segments of various orders showed variation from general observation. This change may indicate flowing of streams from high altitude, lithological variations, and moderately steep slopes (Singh *et al.*, 1997; Vittala *et al.*, 2004). Manupali watershed has the longest total stream length (L_u= 670.7 km), while Panlibatuhan watershed has the shortest value of L_u = 113.4 km.

Bifurcation ratio (R_b)

The bifurcation ratio (R_b) is the ratio between stream numbers of a particular order and next higher order (Schumm, 1956). Horton (1945) considered the bifurcation ratio as index of relief and dissection. Lower R_b values are the characteristics of structurally less disturbed watershed without any alteration in drainage pattern (Nag, 1998). Taganibong watershed has the highest R_b= 5.01 while Panlibatuhan watershed has lowest R_b = 3.67 (table 2). This may indicate that Panlibatuhan watershed is characterized as less disturbed compared to others. All watersheds are falling under normal basin category as indicated by Ali *et al.* (2015) where bifurcation ratios range between 2.0 to 5.0.

Drainage density (D_d)

Drainage density indicates the closeness of spacing between channels and is a measure of the total length of the stream segment of all orders per unit area (Meshram *et al*., 2017).

It has been observed that low drainage density is more likely to occur in regions of highly permeable subsoil material under dense vegetative cover and where relief is low while the higher drainage density is due to weak and impermeable subsurface material, mountainous relief, and sparse vegetation (Ali *et al*., 2015; Iqbal *et al*., 2014; Javed *et al*., 2009; Nag, 1998; Nautiyal, 1994). In this study, high drainage density was found in Panlibatuhan watershed (D_d = 2.93) while lowest was found in Upper Pulangi watershed (D_d = 0.68) as shown in Table 3. Upper Pulangi has low relief and has dense vegetative cover while Panlibatuhan has sparse vegetation cover and higher relief, thus, these results support the study of Ali *et al.* (2015); Iqbal *et al.* (2014); and Javed *et al.* (2009).

Stream frequency (F_s)

Stream frequency is the total number of stream segments of all orders per unit area (Horton, 1932). It is one of the channel morphologic parameters that have a direct effect to erosion. Panlibatuhan watershed has the highest value (F_s = 4.86) while Upper Pulangi watershed has the lowest stream frequency value (F_s = 0.25). Low stream frequency values indicate low relief and the occurrence of subsurface permeability of the material (Javed *et al*., 2011).

Table 3. Morphometric values for channel parameters.

Watersheds	Lu	Nu	Rb	Dd (km/km2)	Fs (Strm/km2)	Lof (km)	If	T (Strm/km)	C
Taganibong	132.0	154	5.01	2.30	2.68	1.15	6.16	3.08	0.44
Sawaga	487.2	255	3.80	1.00	0.52	0.50	0.52	1.50	1.00
Upper Pulangi	657.2	237	3.88	0.68	0.25	0.34	0.17	1.10	1.46
Manupali	670.7	321	3.98	1.33	0.63	0.66	0.84	1.91	0.75
Nabalintungan	267.3	235	3.90	1.79	1.57	0.89	2.82	3.39	0.56
Maapag	312.4	373	4.23	1.90	2.27	0.95	4.32	5.33	0.53
Panlibatuhan	113.4	188	3.67	2.93	4.86	1.47	14.25	5.60	0.34
Tigwa	399.9	360	4.22	1.32	1.19	0.66	1.57	4.07	0.76
Malingun	136.4	158	3.71	1.94	2.24	0.97	4.34	2.79	0.52

Length of Overland Flow (L_{of})

Overland flow refers to the flow of precipitated water that moves over the land surface leading to the stream (Rama, 2014; Horton, 1945). As shown in Table 3, Panlibatuhan watershed was observed to have the highest tendency to erosion while Upper Pulangi has the least due to the inherent lowest length of overland flow value. The value of the length of overland flow lesser than 0.2 denotes very low water potential for water flow and infiltration (Ali & Ikbal, 2015). The overland flow is dominant in smaller watersheds compared to larger watersheds. The length of overland flow value of 1.42 in Panlibatuhan watershed implies more water potential for overland flow and high infiltration over the area.

Drainage Texture (T)

Drainage texture is the total number of stream segments of all orders per perimeter of the area (Horton, 1945). It is classified by Smith (1950) into five namely very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). Six of the sub watersheds of Upper Pulangi River namely Sawaga, Upper Pulangi, Manupali, Malingun, Nabalintungan and Taganibong are generally classified under coarse drainage texture while Tigwa, Panlibatuhan, and Maapag watersheds are classified under moderate drainage texture as described based on the similarity to previous studies. Watersheds under course drainage texture is more prominent in impermeable material which depends primarily on natural factors corresponding to rainfall, vegetation, lithology, infiltration capacity, soil type, stage of formation, and relief (Ali & Ikbal, 2015; Ahmed & Rao, 2014).

Constance of channel maintenance (C)

Constance of channel maintenance is the inverse of drainage density. It is reported from the previous study that the lower value of constant channel maintenance indicates that the watershed is influenced by the occurrence of structural disturbances having high runoff and low permeability (Puno *et al.*, 2019). In this study, the values of constant channel maintenance range from 0.34 to 1.46 (Table 3). The lowest and the highest values were observed in Panlibatuhan and Upper Pulangi respectively, suggesting high possibility to land degradation in the former watershed over the latter.

Areal morphology parameters

Areal morphology parameters are helpful to initially assess the hydrologic processes in the absence of actual data from the field as they have an inverse effect on the dependent erosion variable.

Form factor (R_f)

Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1932). The values of form factor would always be less than 0.7854 (perfectly for a circular basin), thus smaller the value of R_f the more elongated will be the basin (Londhe *et al.*, 2010; Iqbal *et al.*, 2014). The form factor for all watersheds varies from 0.23-0.35 (table 4).

The observation shows that Upper Pulangi, Sawaga, and Manupali watersheds are highly elongated while Panlibatuhan, Taganibong, and Malingun watersheds are less elongated. Elongated watersheds with low form factor indicate that the basin has a flatter flow for longer duration whereas the basin with high form factor has a high peak flow of shorter duration (Iqbal *et al.*, 2014; Nageswara *et al.*, 2010). Flood flows of such elongated basins are easier to manage than from the circular basin (Iqbal *et al.*, 2014).

Circularity ratio (R_c)

Circularity ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the stream density, stream frequency, geological features, land use/land cover, climate, relief, and slope of the watershed (Javed *et al.*, 2011; Waikar *et al.*, 2014; Iqbal *et al.*, 2014; Gajbhiye *et al.*, 2014; Mahadevaiah & Narendra, 2014; Dikpal *et al.*, 2017). In terms of predicting peak time at the outlet of the watershed, circularity ratio becomes very useful (Ali *et al.*, 2018). As shown in Table 4, Sawaga watershed has minimum value (R_c = 0.21) while Tigwa watershed has maximum value (R_c = 0.49). According to the Miller (1953) range, watersheds are elongated in shape, with low discharge of runoff and high permeability subsoil condition.

Elongation ratio (R_e)

Elongation ratio is defined as the ratio of the diameter of a circle having the same area as the basin and the maximum basin length (Schumn, 1956). Elongation ratio values can be categorized into four namely elongated, less elongated, oval, and circular with the corresponding values of <0.7, 0.7-0.8, 0.8-0.9, and >0.9, respectively (Chandrashekar *et al.*, 2015; Ket-ord *et al.*, 2013). Higher elongation ratio value indicates high infiltration capacity and low runoff. Analysis of elongation ratio indicates that the rest of the sub watersheds were classified under elongated suggesting low infiltration and high runoff within these areas, hence, they need more attention for soil conservation (Ali *et al.*, 2018). But for the purpose of ranking, Upper Pulangi sub watershed was the first in rank for conservation because of its lesser value among the other sub watersheds.

Table 4. Morphometric values for areal parameters.

Watersheds	A (km2)	P (km)	Lb (km)	Ww (km)	Rc	Re	Rf	Cc
Taganibong	57.43	49.96	13.10	4.39	0.29	0.65	0.33	1.86
Sawaga	488.90	169.51	44.20	11.06	0.21	0.56	0.25	2.16
Upper Pulangi	962.26	215.78	64.93	14.82	0.26	0.54	0.23	1.96
Manupali	505.53	168.34	45.05	11.22	0.22	0.56	0.25	2.11
Nabalintungan	149.34	69.38	22.54	6.63	0.39	0.61	0.29	1.60
Maapag	164.20	69.96	23.78	6.90	0.42	0.61	0.29	1.54
Panlibatuhan	38.67	33.58	10.46	3.70	0.43	0.67	0.35	1.52
Tigwa	303.18	88.49	33.69	9.00	0.49	0.58	0.27	1.43
Malingun	70.46	56.59	14.71	4.79	0.28	0.64	0.33	1.90

Relief feature parameters

Relief ratio (R_h)

Relief ratio is the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). It is the measure of the overall steepness of a river basin and an indicator of the intensity of erosion process operating on the slope of the basin (Schumm, 1956; Withanage *et al.*, 2014). Gottschalk (1964) states that R_h normally increases with decreasing drainage area and size of watersheds of a given drainage basin. Low values of relief ratio suggest lesser soil erodibility which is primarily due to resistant basement rocks of the watershed and the low degree of slope (Meshram *et al.*, 2017). In this study, Upper Pulangi watershed was found to have the lowest relief ratio values while Nabalintungan and Malingun watersheds found to have the highest value suggesting the proneness to erosion of the latter watersheds over the former.

Relative Relief Ratio (R_{hp})

R_{hp} is defined as the ratio between the total relief and the perimeter of the watershed and is considered as an important morphometric variable used for the overall assessment of morphological characteristics of terrain (Withanage *et al.*, 2014). In this study, relative relief ratio was found to have the highest value in Nabalintungan watershed (R_{hp} = 2.92), while the lowest value was Upper Pulangi watershed with (R_{hp} = 0.82). Steeper slope with high relief ratio poses high chances of landslides while areas with low relief are more susceptible to flooding during intense rainfall events (Ali *et al.*, 2018).

Table 5. Morphometric values for relief parameters.

Watersheds	Z (m)	z (m)	H (m)	Rh	Rhp	Nr
Taganibong	1318	273	1045	0.080	2.09	2.40
Sawaga	2893	305	2588	0.059	1.53	2.58
Upper Pulangi	2115	347	1768	0.027	0.82	1.21
Manupali	2920	307	2613	0.058	1.55	3.47
Nabalintungan	2300	271	2029	0.090	2.92	3.63
Maapag	1648	290	1358	0.057	1.94	2.58
Panlibatuhan	1098	287	811	0.078	2.41	2.38
Tigwa	1637	353	1284	0.038	1.45	1.69
Malingun	1694	299	1395	0.095	2.46	2.70

Ruggedness Number (N_r)

N_r is the product of the maximum basin relief (H) and drainage density (D_d), where both parameters are in the same unit (Waikar & Nilawar, 2014). It is used to measure the flash flood potential of the streams (Patton & Baker, 1976). Lower values of this parameter suggest a watershed that is basically resistant to erosional process with essential structural complexity associated with relief and drainage density (Ali *et al.*, 2018). As shown in table 5, N_r value was lowest in Upper Pulangi watershed (N_r = 1.21) while highest in Nabalintungan watershed (N_r = 3.63) inferring higher tendency to degradation of the latter watershed over the former.

Prioritization of sub watersheds

Based on morphometric parameters

Sub-watersheds of Upper Pulangi were initially prioritized based on the assigned rank considering the morphometric parameters with direct effect to erosion rates.

Table 6 shows that Taganibong watershed has gained the priority area for conservation having the least compound value attributed by its inherent morphological characteristics while Upper Pulangi was observed to be the last priority for conservation.

Table 7 shows the morphometric parameters having an inverse effect to soil erosion wherein Upper Pulangi watershed was observed to have a higher probability of soil erosion and is therefore the first priority for resource conservation.

Averaging all the parameters revealed that Nabalintungan watershed obtained the priority while Upper Pulangi watershed being the last in rank, hence, the last option for mitigation intervention.

Table 6. Sub-watershed ranks based on morphometric parameters with direct effect to erosion.

Watershed	R_b	D_d	F_s	T	R_h	R_{hp}	N_r	L_{of}	Compound Rank	Priority
Taganibong	1	2	2	5	3	4	6	2	3.13	1
Panlibatuhan	9	1	1	1	4	3	7	1	3.38	2
Nabalintungan	5	5	5	4	2	1	1	5	3.50	3
Malingun	8	3	4	6	1	2	3	3	3.75	4
Maapag	2	4	3	2	7	5	4	4	3.88	5
Manupali	4	6	7	7	6	6	2	6	5.50	6
Sawaga	7	8	8	8	5	7	5	8	7.00	8
Upper Pulangi	6	9	9	9	9	9	9	9	8.63	9

Table 7. Sub watershed ranks based on morphometric parameters with inverse effect to erosion.

Watershed	R_f	R_c	R_e	C_c	Compound Rank	Priority
Upper Pulangi	1	3	1	7	3.00	1
Manupali	2	2	2	8	3.50	2
Sawaga	3	1	3	9	4.00	3
Tigwa	4	9	4	1	4.50	4
Maapag	5	7	5	3	5.00	5
Nabalintungan	6	6	6	4	5.50	6
Malingun	7	4	7	6	6.00	7
Panlibatuhan	9	5	9	2	6.25	8
Taganibong	8	8	8	5	7.25	9

Principal Component Analysis

For obtaining the inter-correlation ship among the morphometric parameters, a correlation matrix is obtained using SPSS 18.0 Software. The principal component analysis method was used to obtain the first factor-loading matrix, and thereafter, the rotated loading matrix using orthogonal transformation. The results are shown in the succeeding sections.

First factor-loading matrix

From the correlation matrix of 12 morphometric parameters, the first unrotated factor-loading matrix was obtained. There were three components whose eigen values are greater than 1 (Table 8), together account for about 90.27% of the total variance in the Upper Pulangi River. First three components having eigenvalues above 1 means that the component explains at least as much of the variation as the original variables. But the correlation between the first three components and original variables (Table 9) are not in range since we need to concentrate on loadings that are above 0.4 or below -0.4. Thus, at this stage, it is difficult to identify a physically significant component. It is necessary to rotate the first factor-loading matrix to get a better correlation.

Rotation of the first factor-loading Matrix

The rotated factor-loading matrix is obtained by post-multiplying the transformation matrix with the selected component of the first factor-loading matrix. It can be observed from Table 10 that the first component is correlated well with D_d, F_s, and L_{of} which may be termed as stream-drainage component.

Table 8. Principal Components, Eigenvalues, and Proportion of Variance before rotation.

Principal Components/correlation				
Rotation: (unrotated = principal)				
Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	7.33987	4.99631	0.6117	0.6117
Comp2	2.34356	1.19509	0.1953	0.8070
Comp3	1.14847	.323243	0.0957	0.9027
Comp4	.824928	.545551	0.0687	0.9714
Comp5	.279378	.240021	0.0233	0.9947
Comp6	.0393567	.0195095	0.0033	0.9980
Comp7	.0198472	.0152646	0.0017	0.9996
Comp8	.00458263	.00458263	0.0004	1.0000
Comp9	0	0	0.000	1.0000
Comp10	0	0	0.000	1.0000
Comp11	0	0	0.000	1.0000
Comp12	0	.	0.000	1.0000

The second component is strongly correlated with R_f and good with R_e, also it can be termed as elongation-form component. The third component is correlated.

With R_h and R_{hp} and may be term as relief component for Upper Pulangi River. As seen (Table 10), the most correlated parameter in each component are stream frequency (F_s), form factor (R_f) and relative relief ratio (R_{hp}) so finally these parameters have been taken for the prioritization.

Comparison of two morphometric approaches for prioritization of sub-watersheds

By taking all the morphometric parameters, the compound parameter values of nine sub watersheds of Upper Pulangi River were calculated and the prioritization rating is shown in Table 11.

Table 9. Unrotated Matrix.

Variable	Comp1	Comp2	Comp3
R_b	-0.0073	-0.0137	-0.0001
D_d	0.5062	0.1205	-0.0771
F_s	0.6864	-0.1670	0.0772
L_{of}	0.5102	0.1144	-0.0706
T	0.0075	0.0021	-0.0082
R_c	0.0117	0.0245	0.0006
R_e	0.0879	0.4801	0.1299
R_f	-0.0557	0.8238	-0.0476
C_c	0.0228	0.0109	-0.0298
R_h	0.0032	0.1477	0.6230
R_{hp}	0.0146	-0.1111	0.7580
N_r	-0.0210	-0.0171	0.0168

Table 10. Rotated Matrix.

Variable	Comp1	Comp2	Comp3
R_b	0.0443	-0.1110	0.7112
D_d	0.3592	0.0395	0.1321
F_s	0.3441	-0.0592	0.1164
L_{of}	0.3590	0.0369	0.1339
T	0.3051	-0.3013	-0.1589
R_c	0.2102	-0.4742	-0.2927
R_e	0.3550	0.0627	0.1910
R_f	0.3488	0.0728	0.1951
C_c	-0.2319	0.04479	0.2613
R_h	0.2770	0.4115	-0.0574
R_{hp}	0.3062	0.2584	-0.2506
N_r	0.1122	0.4687	-0.3540

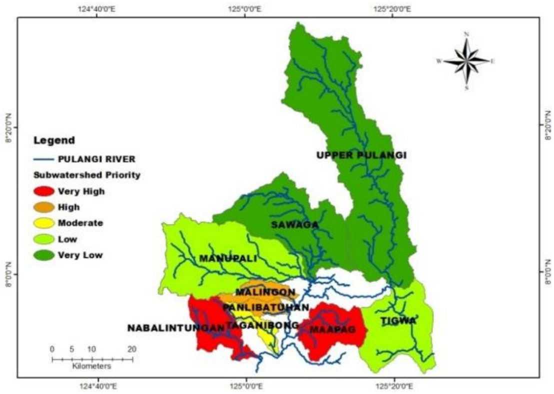

Fig. 2. Priority index map of sub watersheds.

Table 11. Priorities of sub-watersheds and their ranks

Watersheds	R_b	D_d	F_s	L_{of}	T	R_c	R_e	R_f	C_c	R_h	R_{hp}	N_r	Compound Value	Final Priority
Nabalintungan	5	5	5	5	4	6	6	6	4	2	1	1	4.17	1
Maapag	2	4	3	4	2	7	5	5	3	7	5	4	4.25	2
Panlibatuhan	9	1	1	1	1	5	9	9	2	4	3	7	4.33	3
Malingun	8	3	4	3	6	4	7	7	6	1	2	3	4.50	4
Taganibong	1	2	2	2	5	8	8	8	5	3	4	6	4.50	5
Manupali	4	6	7	6	7	2	2	2	8	6	6	2	4.83	6
Tigwa	3	7	6	7	3	9	4	4	1	8	8	8	5.67	7
Sawaga	7	8	8	8	8	1	3	3	9	5	7	5	6.00	8
Upper Pulangi	6	9	9	9	9	3	1	1	7	9	9	9	6.75	9

Table 12. Priorities of sub-watersheds and their ranks using PCA.

Watersheds	F_s	R_f	R_{hp}	Compound Value	Final Priority
Nabalintungan	5	6	1	4.00	1
Maapag	3	5	5	4.33	2
Panlibatuhan	1	9	3	4.33	3
Malingun	4	7	2	4.33	4
Taganibong	2	8	4	4.67	5
Manupali	7	2	6	5.00	6
Tigwa	6	4	8	6.00	7
Sawaga	8	3	7	6.00	8
Upper Pulangi	9	1	9	6.33	9

Nabalintungan watershed with a compound parameter value of 4.17 receives the highest priority (one) followed by the Maapag watershed with a compound value of 4.25. Highest priority indicates the greater degree of erosion in the sub watersheds and it becomes possible area for soil conservation measures. Table 12 also showed the prioritization rating of the sub watersheds using PCA approach. Both the prioritization schemes gave the same result. However, in the prioritization of sub watersheds made by the first approach (Table 11), 12 morphometric parameters were taken, whereas in the PCA-based scheme, parameters were reduced from 12 to 3 which saves time. These results will assist fluvial geomorphologist and hydrologist to select parameters and to save time.

Conclusion

The quantitative morphometric analysis was carried out in nine sub watersheds of Upper Pulangi River using GIS technique for determining the linear/channel morphology, areal aspect, and relief features of the watershed. Channel morphometric parameters such as bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), length of overland flow (L_{of}), and drainage texture (T) have a direct relationship with erodibility; higher the value, more is the erodibility and is rated as first in rank. Areal aspect such as circularity ratio (R_c), elongation ratio (R_e), form factor (F_f) and compactness constant (C_c) have an inverse relationship with erodibility; lower the value the more is the chance of erosion and is therefore rated as first in the rank for soil conservation measures. The prioritization based on different morphometric parameters is time consuming. However, PCA-based approach allows for more effective parameters for prioritizing watersheds. The morphometric analysis of different sub watersheds shows their relative characteristics with respect to hydrologic response of the watershed. Results of morphometric analysis show that Nabalintungan and Maapag watersheds (Fig. 2) are possibly having high vulnerability to degradation due to its faint biophysical characteristics attributed by the effects of its critical morphometric variables. Hence, suitable soil erosion control measures are required in these watersheds to preserve the land from further erosion. The present study demonstrates the utility of RS, GIS and PCA techniques in prioritizing sub watersheds based on morphometric analysis. This study also provides significant information that are helpful to watershed managers and planners in coming up with an informed decision and actions in relation to planning for watershed management, for soil and water conservation programs and project implementation under limited resources.

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Conflict of interest

The author declares that there is no conflict of interests regarding the publication of this manuscript.

Abbreviations

A	Area
C	Constance of channel maintenance
C_c	Compactness coefficient
D_d	Drainage density
C_p	Compound value
Comp1	Component 1
Comp2	Component 2
Comp3	Component 3
DEM	Digital elevation model
DENR	Department of Environment and Natural Resources
E	East
Esri	Environmental Systems Research Institute
F_s	Stream frequency
Geo-SAFER	Geo-informatics for the Systematic Assessment of Flood Effects and Risk for Resilient
GIS	Geographic Information System
H	Total relief
Ha	Hectare
I_f	Infiltration number
INREMP	Integrated Natural Resources and Environmental Management Project
Km	Kilometer
km2	Kilometer squared
L_b	Basin Length
L_o	Length of overland flow
L_{sm}	Mean stream length
Lu	Total stream length

Lw Watershed length
mm millimeter
N North
NAMRIA National Mapping and Resource Information Authority
NGP National Greening Program
Nr Ruggedness number
Nu Number of streams
P Perimeter
PAGASA Philippine Atmospheric Geophysical and Astronomical Services Administration
PCA Principal Component Analysis
R_{bm} mean bifurcation ratio
Rb Bifurcation ratio
Rc Circularity ratio
Re Elongation ratio
Rf Form factor
Rh Relief ratio
Rhp Relative relief ratio
RS Remote Sensing
SAR Synthetic aperture radar
Strm Stream
T Drainage texture
Ww Watershed width
Z Highest elevation
Z Lowest elevation

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