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Watershed conservation prioritization using geomorphometric and land use-land cover parameters

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ABSTRACT

Geomorphometric features and land use/land cover are essential in the context of watershed prioritization for resources conservation and protection. Watersheds in tropical regions like the Philippines are under threat of degradation due to the combined effects of uncontrolled agricultural activities in the uplands and frequently increasing erosive precipitations brought about by climate change. Watershed managers are challenged with these pressing issues and concerns because most watersheds have no sufficient data as a basis for decision making. This paper presents the method of analyzing the different geomorphometric features and the existing land use or land cover to assess the propensity of the watershed against erosion so that areas needing immediate treatment can be prioritized. Arbitrarily, fourteen subwatersheds coded as SW_1 to SW_{14} were delineated using a digital elevation model and geographic information system tool. Geomorphometric features categorized as areal aspect, relief features, and channel morphology parameters were generated and analyzed. Parameters having direct and inverse effect to erosion risk were used as the criteria in the ranking process. Land use/land cover was added to geomorphometric parameters to come up with compound values for final prioritization. Results showed that SW_{13}, SW_{14}, and SW_4 were classified under very high priority implying focus for appropriate management actions while SW_{10}, SW6, and SW_7 were classified under very low priority suggesting favorable environmental condition in these areas. The study provides significant information helpful to watershed managers and planners especially in crafting a plan for integrated watershed management wherein programs and projects implementation have to be prioritized.

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INTRODUCTION

A number of watersheds in the country are classified under critical condition. Critical watersheds are at risk to denudation while providing irrigation for agricultural crop production, water supply for hydroelectric power generation, and other important domestic uses (DENR MC Series, 2008). Thus, in the pursuit of sustainable development, watersheds need protection and conservation as well as rehabilitation of degrading areas (Francisco and Rola, 2004; Javier, 1999). The Philippine Government through the Department of Environment and Natural Resources (DENR) Office has issued a memorandum circular mandating the agency to prepare doable and integrated watershed management plan for all critical watersheds in the country (DENR MC Series, 2008). Integrated watershed management planning involves a comprehensive characterization of the drainage area including geomorphometric and hydrologic characteristics. However, most watersheds in the region are ungagged with no sufficient data available for analysis. In this context, geomorphometric quantification studies are seen as a helpful and straightforward alternative course of action. The geomorphometric analysis is widely applied in the fields of earth science and engineering as an indirect assessment tool for soil erosion assessment, landslide susceptibility mapping, movement of groundwater and topography analysis (Sujatha, 2013), including the prevailing climate, structure and land cover of the watershed. Several works discuss that landform is fundamental in understanding the definitions of geomorphology (Evans, 2012). These definitions include "geomorphology as the science concerned with the form of the land surface and the processes which create it" (Summerfield, 1991) and "geomorphology as the science that investigates the landforms of the earth" (Ahnert, 1998). Geomorphometry is a term that has evolved from geomorphology, as a technique applied to the mathematical analysis of landforms. Thus, geomorphometry is a science of quantitative land surface analysis comprising an interdisciplinary field that has developed from mathematics, the earth sciences, and recently computer science (Pike, 1995). Generally, geomorphometry remains the most widely accepted technique applied in illustrating plains and scoured surfaces and to some extent in mapping regional landforms (Evans, 2012). Linking of geomorphometric parameters with the hydrological characteristics of the watershed allows the understanding of hydrological behavior of different watersheds. Several land surface quantification studies some are at a watershed and subwatershed scales have been reported to recognize drainage characteristics in relation to the hydrologic process like runoff, soil erosion, inundation, sediment transport, changing river flows, among others (Abdel-Fattah *et al.,* 2017; Chandrashekar *et al.,* 2015; Zhang *et al.,* 2015; Withanage *et al.,* 2014; Waikar and Nilawar, 2014; Kinthada *at al.,* 2013; Thomas *et al.,* 2011; Beven, 1987). Geomorphometric analysis of watershed is important in any hydrological processes relative to the management and conservation of soil and water resources in the watershed. Sufficient data on watershed hydrologic behavior is needed because of the compelling necessity of watershed management to prioritize programs and projects for conservation, development, and sustainability of all natural resources (Meshram and Sharma, 2015). Watershed Prioritization using morphometric parameters has gained attention to group of planners and researchers over several decades particularly in watershed management and conservation perspective (Kadam *et al.,* 2016; Ali and Ikbal, 2015; Malik and Bhat, 2015; Meshram and Sharma, 2015; Chandniha and Kansal, 2014; Iqbal and Sajjad, 2014; Khare *et al.,* 2014; Javed *at al.,* 2011; Javed *at al.,* 2009). Prioritization also allows the use of land use or land cover (LULC) as an additional factor that can be compounded to the geomorphometric parameters that have direct and inverse effects to erosion risk potential (Meshram and Sharma, 2015; Javed *at al.,* 2011). Prioritization of subwatershed is a method of ranking of subwatershed units based on the extent of denudation due to accelerated soil erosion and criticality condition of drainage areas (Pandy *et al.,* 2007). The criterion for ranking can be the average of annual soil loss, geomorphometric factors, land use or land cover, socioeconomic and other relevant factors. Subwatershed ranking involves the process of delineating the main watershed under study into subwatershed units and prioritize them according to the order by which they have to be considered for treatment (Ali and Ikbal, 2015). Delineation and quantification of geomorphometric features allow a detailed analysis of watershed topography using digital elevation model (DEM) within a GIS environment. Remote sensing and GIS are vital in the characterization and priority listing of watershed

areas base on erosion extent and degree of soil and water resource depletion (Dabral *et al.,* 2008). The technique involves the derivation of various components such as stream networks and segments, watershed boundary, watershed area, relief values, slope and area profile of the watershed (Gumma *et al.,* 2016; Ali and Ikbal, 2015; Chandniha and Kansal, 2014; Iqbal and Saijad, 2014). The widely available DEM becomes the most common spatial data used in the geomorphometric analysis of a watershed (Evans, 2012). "DEM offers an efficient way to represent ground surface and allow automated direct extraction of hydrological features, thus bringing advantages in terms of processing efficiency, cost effectiveness, and accuracy assessment, compared with traditional methods based on topographic maps, field surveys, or photographic interpretations" (Vaze *et al.,* 2010). Extraction of geomorphologic features from DEMs using the GIS application tool is faster and has a lesser error than the traditional manual technique applied to topographic maps (Tribe, 1992). Such analysis is crucial to understanding the hydrologic process and hence is a prerequisite for hydrologic characterization of surface water of the basin (Sujatha, 2013). Geomorphometric parameters mainly derived from lithology and geological structures, thus, quantitative description of geomorphology, hydrology, geology and stream network patterns is highly informative for a reliable study of the watershed (Chandniha and Kansal, 2014). Some geomorphometric parameters such as bifurcation ratio, drainage density, stream length, compactness coefficient, stream frequency, texture ratio, length of overland flow, form factor, circularity ratio, and elongation ratio are termed as erosion risk assessment factor and have been used for prioritizing subwatersheds (Meshram and Sharma, 2017). A number of works on subwatershed ranking using the compound effect of geomorphometric and land use or land cover parameters had been conducted as an initial step in the prioritization process (Javed *et al*., 2011). A number of approaches in different platforms had been reported to identify the status of soil erosion in a watershed as basis for treatment prioritization (Naqvi *et al.,* 2015; Malik and Bhat, 2014; Vemu and Pinnamaneni, 2012; Jain and Das, 2010; Dabral *et al.,* 2008; Pandey *et al.,* 2007). Watershed prioritization and formulation of integrated watershed management programs for natural resource conservation require sufficient data on erosion and the eventual sedimentation rates (Pandy *et al.,* 2007). Another important factor that has of particular consideration in subwatershed prioritization is the land use or land cover status of the watershed (Javed *et al.,* 2009; Mishra *et al.,* 2007). Changes of land use or land cover in the watershed have been recognized as the main driver of environmental change resulting in accelerated soil erosion and are predominantly anthropogenic in nature (Malik and Bhat, 2014). Soil erosion may accelerate further under the worsening climate change all over the world which would also arise in Muleta Watershed. However, the implementation of a management program in most watersheds is constrained with the unavailability of resources. In addition, assessment of onsite soil erosion is also a time-consuming endeavor and needs a considerable amount of resources. Hence, the use of geomorphometric parameters in ranking critically prone to erosion area is vital in prioritizing watersheds for soil and water conservation (Kottagoda and Abeysingha, 2017). This study mainly aims to quantify geomorphometric and land use or land cover parameters relative to the propensity of the watershed to erosion threat in order to provide a baseline information to be used as the basis for decision making in prioritizing areas for conservation programs and projects implementation under meager budget within the subwatersheds. This study has been carried out in in the watershed of Muleta located within the provinces of Bukidnon and North Cotabato, Mindanao, Philippines in 2018.

MATERIALS AND METHODS

Watershed study

The Muleta watershed is a major tributary of Mindanao river basin located in Mindanao, Southern Philippines. It lies within the geographic coordinates of $7^0$17'05" to $7^0$58'48" N latitudes and $124^0$44'02" to $125^0$03'39" E longitudes with an area of 1,022.02 km^2 (Fig. 1). The river provides a water supply for domestic and commercial uses. It irrigates rice fields and other agricultural crops and livestock downstream. An integrated watershed management plan for the Muleta Watershed is currently on its finalization phase. Farming is the dominant land use of the watershed with isolated forest plantation and shrub vegetation. Cultivation along hillslope are evident for small-and large-scale agricultural crop production.

The remaining natural forest stand at the upper portion of the watershed is under the jurisdiction of the Protected Area Management Board (PAMB) for the Mount Kalatungan Range Natural Park (MKaRNP) of DENR. Majority of the Muleta subwatershed areas are at risk to denudation due to accelerated soil erosion at the hillslopes. Hence, a reforestation project through the National Greening Program (NGP) of the government is currently implemented in the selected sites of the watershed (Executive Order No. 193, 2015).

Records from the Philippine Atmospheric Geophysical and Astronomical Services Administration 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 1,703 mm for the period 1981-2011 (INREMP, 2018). The site is usually hottest in the month of May having the highest average temperature recorded. The soils of Muleta Watershed are classified into Alfisols, Ultisols, Inceptisols and mountain undifferentiated soils. The terrain is primarily rolling with sedimentary hills having good drainage with low to medium natural fertility. Some are characteristics of soils on the plateau, well-drained although with undulating to rolling landscapes with reddish brown to yellowish red clay loam (Dejarme-Calalang and Colinet, 2014).

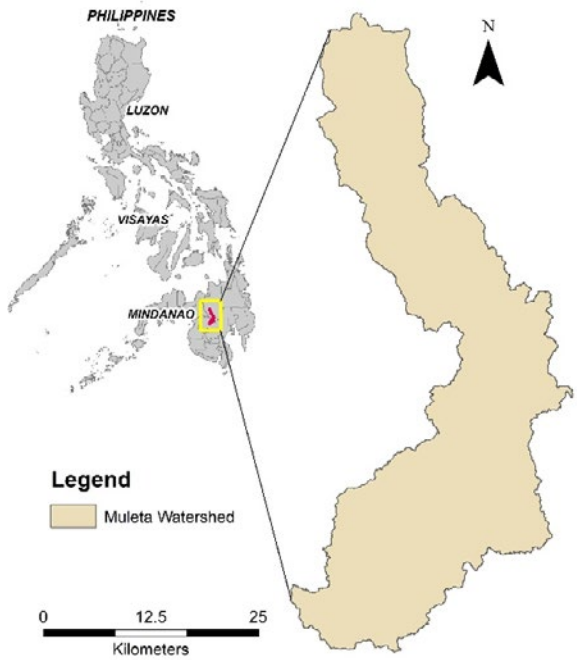


Fig. 1. Geographic location of the study area in Muleta watershed, Bukidnon and North Cotabato, Mindanao, Philippines

Watershed Delineation and Geomorphometric 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 National Research & Development Project for Watershed Management in the Philippines (NRDPWMP) was used to outline watershed boundary and stream network using Arc Hydro Tool of ArcGIS version 10.2. A threshold of 250 hectares (ha) was arbitrarily chosen in delineating perimeter and channels of the watershed that is representative to the actual configuration on the ground. An open source MapWindow GIS software was used to automatically demarcate stream orders following the technique commonly applied in previous works (Kadam *et al.*, 2016). The geomorphometric analysis as the common approach used for watershed characterization is defined as the quantitative assessment of hydrological unit (Chandniha and Kansal, 2014). The areal aspects, relief features and channel morphology of the 14 subwatersheds were used as input to determine different geomorphometric parameters following the equations from previous studies (Table 1).

Land Use or Land Cover Data

Secondary data obtained from previous work was used in the analysis of land use or land cover (LU/LC) of sub-watersheds (Puno *et al.*, 2018). The classification was done using 2016 Sentinel-2 satellite image applied with object-based support vector machine algorithm. LU/LC was further processed to generalize land use of specific and similar category. For example, agricultural areas of all categories were lumped into one attribute labeled as cultivated. There were three LU/LC considered in the ranking process corresponding to cultivated, forest and shrub.

Prioritization of subwatersheds

Priority ranking was done according to the computed value of the selected geomorphometric parameter with direct effect to soil erodibility such as bifurcation ratio, drainage density, stream frequency, drainage texture, length of overland flow, total stream length, and the average slope of the subwatershed. Factors having the inverse effect to erodibility such as form factor, circularity

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

Parameters symbols and units	Formulas/Methods	Sources
Watershed width (W_w), *km*	$W_w = \frac{A}{L_w}$	Horton, (1932)
Circularity ratio (R_c)	$R_c = \frac{4\pi A}{P^2}$	Kadam *et al.,* (2016)
Elongation ratio (R_e)	$R_e = \frac{2\sqrt{A/\pi}}{L_w}$	Chandniha and Kansal, (2014)
Form factor (F_f)	$F_f = \frac{A}{L_w^2}$	Horton, (1945)
Compactness coefficient (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)	$R_h = \frac{H}{L_w}$	Rama, (2014)
Relative relief ratio (R_{hp})	$R_{hp} = H\frac{100}{P}$	Melton, (1957)
Ruggedness number, N_r	$N_r = D_d\left(\frac{H}{1000}\right)$	Adhikary and Dash, (2018)
Number of stream (N_u)	$N_u = N_1 + N_2 \ldots + N_n$	Horton, (1945)
Total stream length (L_u), *km*	$L_u = L_1 + L_2 \ldots + L_n$	Horton, (1945)
Drainage density (D_d)	$D_d = \frac{L_u}{A}$	Horton, (1932)
Stream frequency (F_s)	$F_s = \frac{N_u}{A}$	Horton, (1932)
Length of overland flow (L_g), *km*	$L_g = \frac{A}{2L_u}$	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)
Drainage texture (T_d)	$T_d = \frac{N_u}{P}$	Horton, (1945)
Bifurcation ratio (R_b)	$R_b = \frac{N_u}{N_u + 1}$	Horton, (1945)

Where A is watershed area; L_w is watershed length; Z and z are the highest and lowest elevations, respectively

ratio, elongation ratio and compactness coefficient were likewise considered in the ranking process. The details of the entire ranking process of subwatershed based on geomorphometric parameters was carried out following the methods employed from former studies (Meshram and Sharma, 2017; Chandniha and Kansal, 2014; Khare *et al.*, 2014; Javed *et al.,* 2011; Javed *et al.,* 2009). The ranking technique based on LU/LC was applied following from previous works (Javed *et al.,* 2011). The technique was carried out by assigning highest rank to the parameter with the highest area percentage for the cultivated and shrub and lowest rank with the highest area percentage for forest land. The rankings of parameters for each sub-watershed were averaged to come up with a compound value. Prioritization was finalized by averaging the two compound values of the respective geomorphometric and land use or land cover parameters for each subwatershed.

Priority index visualization

Thematic map layer containing the final rank values were generated in a vector file format and converted into raster file dataset using the Conversion Tools in ArcGIS version 10.2.2 software of Esri Incorporated under concurrent license number 4068044. The resulting raster dataset was further processed converting into a file of binary floating-point values that can be used for reclassification. Five priority index classification were chosen to correspond with the very low, low, moderate, high, and very high indexes (Gumma *et al.,* 2016). Subwatershed with the lowest compound value was assigned with very

high priority and recommended for the urgent need of treatment to control erosion while subwatershed with highest compound value was classified under very low priority suggesting a sound environmental condition within those areas.

RESULTS AND DISCUSSION

Cross tabulation of geomorphologic values

The watershed geomorphometric parameters are broadly classified into three categories corresponding to channel morphology, areal aspect and relief features of the watershed. Channel morphometric parameters such as 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_g), infiltration number (I_f), drainage texture (T_d), and constant of channel maintenance (C) are presented in Table 2. Similarly, areal aspect values for the main and fourteen subwatersheds such as watershed area (A) perimeter (P) watershed length (L_w) watershed width (W_w), circularity ratio (R_e), elongation ratio (R_e) form factor (F_f) and compactness coefficient are presented in Table 3, while the relief features values such as highest elevation (Z), lowest elevation (z), total watershed relief (H), relief ratio (R_h), relative relief (R_{hp}) ruggedness number (N_r), and average slope (S_m) are presented in Table 4 which are discussed in the subsequent sections.

Channel morphology parameters

A dendritic pattern of 4th order type (Fig. 2) was observed in the main watershed of Muleta which is also the common characteristic of the delineated subwatersheds. The pattern manifests watershed composed of fairly homogeneous rock without control by the underlying geologic structure. The

Table 2. Geomorphometric values for channel parameters

Watersheds	L_u	N_u	R_b	D_d (km/km^2)	F_s (Strm/km^2)	L_g (km)	I_f	T_d (Strm/km)	C
MW	601	139	4.92	0.59	0.14	0.29	0.23	0.37	1.70
SW_1	26.2	6	5.00	0.52	0.12	0.26	0.23	0.11	1.92
SW_2	37.1	8	2.25	0.76	0.16	0.38	0.22	0.15	1.31
SW_3	45.3	8	2.25	0.62	0.11	0.31	0.18	0.11	1.61
SW_4	13.5	3	2.00	0.54	0.12	0.27	0.22	0.07	1.85
SW_5	8.0	5	4.00	0.56	0.16	0.12	0.63	0.10	1.78
SW_6	29.7	7	2.25	0.54	0.13	0.27	0.24	0.12	1.84
SW_7	16.9	4	3.00	0.59	0.14	0.30	0.24	0.09	1.69
SW_8	59.5	12	2.83	0.66	0.13	0.33	0.20	0.14	1.51
SW_9	25.0	8	2.25	0.63	0.20	0.31	0.32	0.16	1.60
SW_{10}	20.1	4	3.00	0.52	0.10	0.26	0.20	0.08	1.94
SW_{11}	22.6	8	2.25	0.63	0.22	0.31	0.35	0.16	1.59
SW_{12}	27.6	12	3.25	0.52	0.23	0.26	0.43	0.25	1.91
SW_{13}	33.8	5	4.00	0.70	0.10	0.35	0.15	0.08	1.42
SW_{14}	25.6	4	3.00	0.61	0.09	0.30	0.16	0.06	1.65

Table 3. Geomorphometric values for areal parameters

Watersheds	A (km^2)	P (km)	L_w (km)	W_w (km)	R_e	R_c	F_f	C_c
MW	1022.02	372.04	82.75	12.35	0.44	0.09	0.15	3.28
SW_1	50.20	57.12	17.42	2.88	0.46	0.19	0.17	2.27
SW_2	48.55	55.08	18.12	2.68	0.43	0.20	0.15	2.23
SW_3	73.09	74.14	23.26	3.14	0.41	0.17	0.14	2.45
SW_4	25.01	44.14	12.95	1.93	0.44	0.16	0.15	2.49
SW_5	32.05	49.92	10.63	3.02	0.60	0.16	0.28	2.49
SW_6	54.64	60.48	9.95	5.49	0.84	0.19	0.55	2.31
SW_7	28.54	46.46	12.89	2.21	0.47	0.17	0.17	2.45
SW_8	89.75	82.88	21.89	4.10	0.49	0.16	0.19	2.47
SW_9	39.94	51.42	14.46	2.76	0.49	0.19	0.19	2.30
SW_{10}	38.96	51.18	14.84	2.63	0.47	0.19	0.18	2.31
SW_{11}	35.88	50.72	13.46	2.67	0.50	0.18	0.20	2.39
SW_{12}	52.79	48.22	10.95	4.82	0.75	0.29	0.44	1.87
SW_{13}	48.06	62.56	19.17	2.51	0.41	0.15	0.13	2.55
SW_{14}	42.27	63.14	19.61	2.16	0.37	0.13	0.11	2.74

dendritic pattern is more easily developed with longer time of formation of a drainage basin (Pareta, 2012). Another important channel morphologic parameter which determines the dominance of powerful geological control over the region/environment is the bifurcation ratio (R_b) (Javed *et al.*, 2011). The values may vary between first order and second order of the stream as influenced by lithological and geological development of the watershed (Kadam, *et al*, 2016). The lowest and highest bifurcation ratio values (Table 2) of the subwatersheds are depicted in SW_4 and SW_1, respectively suggesting less structural disturbance in the former while structural disturbance has controlled the drainage pattern over the latter subwatershed (Khare *et al*., 2014; Javed *et al*., 2011). Results show further that SW_1 possess higher erodibility potential as compared to SW_4 by a multiple of 2.5 suggesting former subwatershed to be subject under treatment for conservation. The drainage density (D_d) was recognized as a determining factor of water travel time across watershed (Langbein, 1947; Javed *et al*., 2011). The lowest and highest values for this parameter were observed in SW_5 and SW_2, respectively, suggesting that the latter is more prone to erosion as compared with the former by a factor of 3.04. The lower drainage density is attributed to very resistant or permeable subsoil material, low relief, and dense vegetation while the higher drainage density value is due to weak or impermeable subsurface material, mountainous relief and sparse vegetation (Choudhari *et al*., 2018; Khare *et al*., Vishal, *et al*., 2014; 2014; Bera and Bandyopadhyay, 2013). However, existence of imbalances and local variations were observed across the subwatershed particularly on the extent of vegetation density. For example, SW_5 was recorded to have the highest drainage density when it has spares vegetation as compared to SW_2 in the actual. This discrepancy maybe attributed to changes of land cover over the years brought about by cultivation in

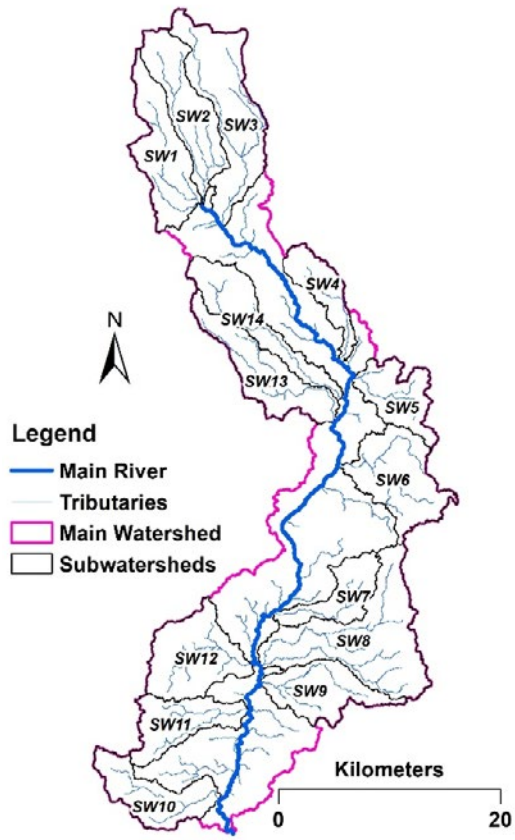


Fig. 2. Stream network of Muleta watershed

Table 4. Geomorphometric values for relief parameters

Watersheds	Z (m)	z (m)	H (m)	R_h	R_{hp}	N_r	S_m (%)
MW	2842	25	2817	0.03	0.76	1.66	16
SW_1	2617	592	2025	0.12	3.55	1.06	18
SW_2	2842	596	2246	0.12	4.08	1.72	28
SW_3	2723	513	2210	0.10	2.98	1.37	25
SW_4	572	257	315	0.02	0.71	0.17	8
SW_5	382	231	151	0.01	0.30	0.04	5
SW_6	439	200	239	0.02	0.40	0.13	6
SW_7	546	68	478	0.04	1.03	0.28	15
SW_8	513	41	472	0.02	0.57	0.31	20
SW_9	239	40	199	0.01	0.39	0.12	20
SW_{10}	275	28	247	0.02	0.48	0.13	15
SW_{11}	442	35	407	0.03	0.80	0.26	20
SW_{12}	545	43	502	0.05	1.04	0.26	18
SW_{13}	736	205	531	0.03	0.85	0.37	10
SW_{14}	1068	213	855	0.04	1.35	0.52	14

the latter subwatershed. The stream frequency (F_s) is one of the channel morphologic parameters that has a direct effect to erosion. F_c is accounted for as the total number of streams of all orders per unit area of the watershed (Khare *et al*., 2014). Low stream frequency values indicate the occurrence of subsurface permeability of the material and low relief (Javed *et al*., 2011). In this study, SW_{12} has the highest while SW_{14} has the lowest stream frequency value (Table 2) implying variability in terms of permeable subsurface material across the landscape. Anotther factor having a direct effect to erosion is the length of overland flow (L_g) described as the length of water on the land surface before entering into a definite stream channel (Rama, 2014). This parameter is a measure of soil erodibility which independently affects the formation of the hydrologic and physiographic characteristics of the watershed (Rama, 2014). Previous studies disclosed that the shorter the length of overland flow, the faster the surface runoff from the streams. The length of overland flows value lesser than 0.2 denotes very low water potential for water flow and infiltration (Ali and Ikbal, 2015). For this study, SW_2 was observed to have the highest propensity to erosion while SW_5 has the least due to the inherent highest length of overland flow value in the former subwatershed. The length of overland flow value of 0.38 in SW_5 implies more water potential for overland flow and moderate infiltration over the area. Muleta watershed is generally classified under coarse drainage texture (T_d) as described based on the similarity to previous studies. This watershed characteristics feature is more prominent in impermeable material which depends primarily on natural factors corresponding to rainfall, vegetation, lithology, soil type, infiltration capacity, relief and stage of formation (Ali and Ikbal, 2015; Ahmed and Rao, 2014). Presence of easily weathered rocks and absence of vegetation in the watershed may result to fine drainage texture while massive and hard rocks may have formed into a coarser drainage texture. However, scanty vegetation of arid climate causes finer textures than those formed on similar parent materials within humid regions (Ali and Ikbal, 2015). As reported, drainage texture is classified into five namely very coarse, coarse, moderate, fine and very fine with values ranging from less than 2, between 2 and 4, between 4 and 6, between 6 and 8, and greater than 8, respectively (Smith, 1954). The climatic condition and vegetation cover of Muleta watershed plus the occurrence of relatively hard rocks favor the formation of a very coarse drainage texture as generally depicted by a value of lesser than 2 across subwatersheds (Table 2). The inverse of drainage density is the constant channel maintenance (C) of the watershed. The value of constant channel maintenance is affected by lithology, permeability and infiltration capacity of surface material, climatic condition and extent of vegetation as well as rock type, and duration of erosion (Ali and Ikbal, 2015; Aravinda and Balakrishna, 2013). The previous study showed that the lower value of constant channel maintenance (0.30) indicates that the watershed is influenced by the presence of structural disturbances having high runoff and low permeability. For Muleta subwatersheds, the constant channel maintenance values range from 1.31 to 1.94. The lowest and the highest values were observed in SW_2 and SW_{10}, respectively, suggesting high probability to land degradation in the former watershed over the latter.

Areal morphology parameters

Areal aspect parameters corresponding to the watershed area (A), perimeter (P), length (L), elongation ratio (R_e), circularity ratio (R_c), form factor (F_f) and compactness coefficient (C_c) are presented in Table 3. In the absence of actual data from the field, these parameters are helpful to initially assess the hydrologic processes as they have an inverse effect on the dependent erosion variable (Meshram and Sharma, 2017). The area of Muleta watershed requires further delineation of its subwatersheds so that areas needing immediate erosion control measure can be prioritized considering limited resources. The watershed is relatively large enough to capture rainfall. However, it has a smaller form factor and circularity ratios indicating that the watershed has low susceptibility to flooding due to its high permeability. Subwatersheds, particularly at the northern section of the main watershed, are mostly elongated. A more elongated shape facilitates the runoff of rainwater which has a greater tendency to favor erosion process (Da Cunha and Bacani, 2016). The elongated shape of Muleta Watershed (Fig. 1) depicts the amount of water that can be generated by precipitation (Da Cunha and Bacani, 2016). Previous studies disclosed that an elongated watershed with low form factor indicates a flatter peak flow for a longer duration (Nageswara *et al*., 2010). Flood flows of such elongated watersheds

such as in Muleta are manageable to control than those of the circular watersheds. Further, the lower drainage density value indicates slower storm response giving lower runoff yield. Elongation ratio (R_e) expresses the relationship between the diameter of a circle of the same area as the watershed and its maximum length. 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). Analysis of elongation ratio indicates that SW_6 is more stable against erodibility as depicted by its greater value (Table 3) than SW_{14} having the least elongation ratio value. Except for SW_6 and SW_{12}, being circular and less elongated, respectively, the rest of the subwatersheds 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). The elongated shape of most subwatersheds in Muleta is attributed to high relief and steep slope suggesting susceptibility to headward erosion and sedimentation load (Chandrashekar *et al.*, 2015; Mahadevaiah and Narendra, 2014). Circularity ratio (R_c) is an important morphometric which describes the roundness of a watershed. It is expressed as the ratio between the area of the watershed and the area of the circle having the same circumference as the perimeter of the watershed under study (Kadam et al., 2016). Influenced by stream density, steam frequency, geological structures, relief, slope, climate, and land use/cover of the watershed (Dikpal *et al.*, 2017; Gajbhiye *et al.*, 2014; Mahadevaiah and Narendra, 2014), circularity ratio becomes very useful in flood vulnerability assessment in terms of predicting peak time at the outlet of the watershed (Ali *et al.*, 2018). For Muleta subwatersheds, R_c ranges from 0.13 to 0.29 corresponding to SW_{14} and SW_{12}, respectively, indicating elongated shape in all subwatersheds (Thomas *et al.*, 2011). Form factor (F_f) is defined as the ratio of watershed area to the square of the basin length (Javed *et al*, 2011). A watershed of perfectly circular shape has a form factor of 0.7854 (Londhe et al., 2010). The form factor of the main watershed of Muleta was calculated to be 0.15 indicating elongated shape (Fig. 3). Form factor values of the subwatersheds are presented in Table 3 with SW_{14} and SW_6 having the lowest and the highest values, respectively, suggesting higher likelihood of the former to erosion over the latter subwatershed although flood flows of such elongated subwatershed are manageable to control than the rounded ones (Ali *et al.*, 2018; Mohammed *et al.*, 2018). Other geomorphometric parameters with inverse effect to erosion, also known as Gravelius index (GI), is the compactness coefficient (C_c) expressed in terms of the relationship between hydrologic processes to that of a circular watershed having the same area as the hydrologic watershed (Rama, 2014). Compactness coefficient of the main watershed was calculated to be 3.28, while the C_c of the subwatershed ranges from 1.87 to 2.74 (Table 3). C_c is indirectly related with elongation ratio of the watershed thus, lower values indicate more elongated shape and less erosion (Rama, 2014).

Relief feature parameters

Watershed relief features (Table 4) have been analyzed as potential parameters in understanding the geomorphologic processes and landform characteristics (Ali *et al.*, 2018). Expressed in terms

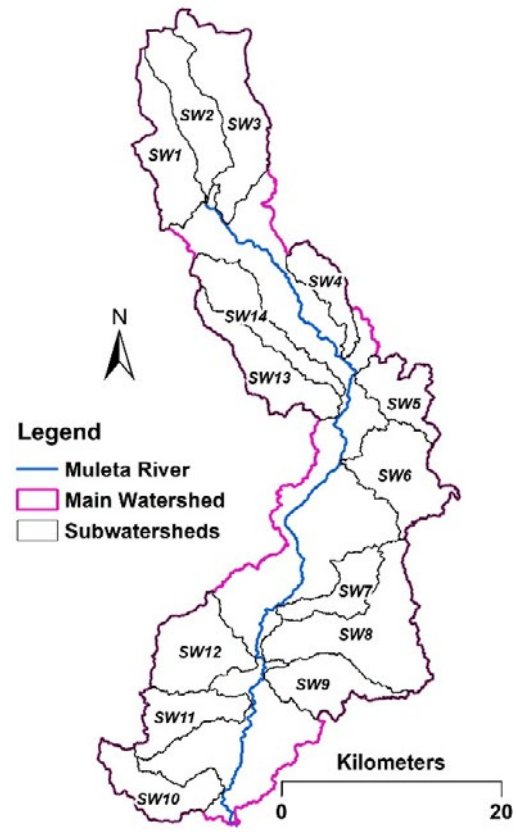


Fig. 3. Subwatersheds of Muleta

of localized topographic relief, these factors have direct influence to erosion occurring in the watershed expressed in terms of sediment yield with a strong positive correlation (Zhang, *et al*., 2015). Relief ratio (R_h) calculated as the ratio between the total relief (H) and the watershed length (L_w), measures the overall steepness of the watershed and is an indicator of the intensity of erosion operating on the hillslopes of the landscape (Soni, 2017; Javed *et al.,* 2009). 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 and Sharma, 2017). In this study, SW_9 and SW_2 were found to have the lowest and the highest relief ratio values, respectively, suggesting the proneness of the latter subwatershed over the former. The relative relief (R_{hp}), defined as the ratio between the total relief and the perimeter of the watershed, was calculated to be the highest and lowest at the SW_2 and SW_5, respectively. This morphometric parameter is potential for the overall assessment of terrain characteristics (Ali *et al*., 2018). 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). Ruggedness number (N_r) is defined as the product of the maximum watershed relief and drainage density and is extensively the characteristics of high regions (Rama, 2014). Generally, 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). Ruggedness ratio for the study area was lowest in SW_5 while highest in SW_2 implying higher tendency of the latter subwatershed to degradation over the former. With respect to local relief, previous studies reported a positive correlation between erosion rate and mean slope at certain critical degree and type of land cover (Zhang *et al*., 2015; Montgomery and Brandon, 2002). Under different land use/cover scenarios, increasing slope gradient had irregularly augmented soil erosion rates which was found to be maximum at a certain critical degree of slope (Zhang *et al*., 2015; Duley, 1932). Non-linear relationship between slope and erosion was established although other report presented an indirect influence of this variable on soil rates. It was disclosed that soil erosion was best correlated with runoff velocity, a factor that is strongly dependent to slope gradient (Fox and Bryan, 1999). The percent minimum and maximum mean slope (S_m) values were observed in SW_5 and SW_2, respectively, denoting higher runoff velocity in the latter during intense rainfall resulting to faster sediment yield accumulation at the watershed outlet point due to accelerated onsite erosion of soil particles.

Prioritization of subwatersheds Based on morphometric parameters

Subwatersheds were initially prioritized based on the assigned rank taking into account the morphometric parameters with direct effect to erosion rates. Rankings (Table 5) show that SW_2 has gained the first priority area for conservation having least compound value attributed by its inherent geomorphological characteristics while SW_4 was observed to be the last priority. On the basis of morphometric parameters having an inverse effect to soil erosion (Table 6), SW_{14} was observed to have a higher probability of soil erosion and is consequently

Table 5. Subwatershed ranks based on geomorphometric parameters with direct effect to erosion

Watersheds	R_b	D_d	F_s	T_d	L_g	L_u	Slope	Compound rank	Priority
SW_1	1	13	10	8	12	7	6	8.14	11
SW_2	9	1	4	4	1	3	1	3.29	1
SW_3	9	6	11	7	6	2	1	6.00	7
SW_4	14	11	9	13	10	10	9	10.86	14
SW_5	2	9	5	9	14	10	10	8.43	12
SW_6	9	10	8	6	9	3	9	7.71	10
SW_7	5	8	6	10	8	8	5	7.14	9
SW_8	8	3	7	5	3	1	1	4.00	3
SW_9	9	5	3	3	5	4	1	4.29	4
SW_{10}	5	14	13	12	13	5	3	9.14	13
SW_{11}	9	4	2	2	4	4	1	3.71	2
SW_{12}	4	12	1	1	11	2	1	4.57	5
SW_{13}	2	2	12	11	2	1	2	4.57	5
SW_{14}	5	7	14	14	7	1	1	7.00	8

be the first priority for resource conservation. Averaging the two parameters revealed that SW_2 obtained the first priority while SW_5 being the last in rank, hence, the last option for mitigation intervention.

Land use/land cover (LU/LC) parameters

Prioritization was carried out based on the classified satellite image of LU/LC of the subwatersheds. For convenience, LU/LC was generalized into three main types corresponding to forest, shrub and cultivated. Other land uses/land cover were isolated with relatively small areas, hence, assumed not affect the entire process of prioritization. LU/LC was expressed in percentage to account the proportional effect by area in the prioritization process. Proportioning is assumed to be appropriate because other subwatershed have larger forest area although it is comparatively smaller when expressed in percentage. The ranking was done by assigning highest rank to the parameter with the highest percentage for the cultivated and shrub and lowest rank with the highest percentage for forest cover (Balasubramanian *et al.*, 2017). Ranks of individual LU/LC parameters were then averaged to arrive the compound values for final ranking (Table 7). Results show that SW_4 was the top priority for conservation while SW_{10} as the last priority owing to a lesser percentage of cultivated and shrub areas and the prevalent forest vegetation which is assumed to protect the soil from degradation.

Based on compound morphometric and land use/land cover parameters

The mean compound values were computed from the morphometric and LU/LC parameters for final prioritization of subwatersheds (Table 8). Results show that SW_{13} receives the highest priority with 4.66 mean compound value suggesting high susceptibility to

Table 6. Subwatershed ranks based on geomorphometric parameters with inverse effect to erosion

Subwatersheds	F_f	R_c	R_e	C_c	Compound rank	Priority
SW_1	6	12	6	3	6.75	6
SW_2	4	13	4	2	5.75	4
SW_3	3	7	3	8	5.25	3
SW_4	5	3	5	12	6.25	5
SW_5	12	4	12	11	9.75	12
SW_6	14	10	14	5	10.75	14
SW_7	7	6	7	9	7.25	7
SW_8	9	5	9	10	8.25	9
SW_9	10	11	10	4	8.75	10
SW_{10}	8	9	8	6	7.75	8
SW_{11}	11	8	11	7	9.25	11
SW_{12}	13	14	13	1	10.25	13
SW_{13}	2	2	2	13	4.75	2
SW_{14}	1	1	1	14	4.25	1

Table 7. Subwatershed priorities and ranks based on land use/land cover

Watersheds	Forest		Shrub		Cultivated		Compound Rank	Priority
	Area (%)	Rank	Area (%)	Rank	Area (%)	Rank		
SW_1	26.0	10	7.0	7	65.3	9	8.67	10
SW_2	41.0	13	14.4	2	41.6	14	9.67	11
SW_3	43.2	14	11.9	4	43.3	13	10.33	13
SW_4	2.1	1	16.0	1	80.0	5	2.33	1
SW_5	10.9	5	1.9	10	79.7	6	7.00	5
SW_6	17.2	7	1.8	11	76.0	7	8.33	9
SW_7	38.3	12	7.4	6	50.2	12	10.00	12
SW_8	22.7	9	13.7	3	62.3	11	7.67	7
SW_9	17.9	8	8.7	5	72.4	8	7.00	5
SW_{10}	33.2	11	1.1	12	64.0	10	11.00	14
SW_{11}	16.8	6	0.2	14	80.6	4	8.00	8
SW_{12}	8.4	4	0.7	13	89.1	2	6.33	4
SW_{13}	7.2	3	4.0	8	87.4	3	4.67	3
SW_{14}	4.9	2	2.4	9	90.9	1	4.00	2

degradation owing to its inherent fragile biophysical characteristics attributed by the combined effect of critical morphometric and LU/LC variables. Highest priority would mean a greater degree of erosion, hence, suitable conservation measure is highly recommended for soil and water resources sustainability (Meshram and Sharma, 2015). On the other hand, SW_{10} was observed to have favorable environmental status taking into consideration of its geomorphologic features and existing vegetation cover. Priority index map (Fig. 5) was generated based on the final priority values using the GIS application tool. Final priority values were classified into five corresponding to very low, low, moderate, high, and very high (Gumma *et al*., 2016).

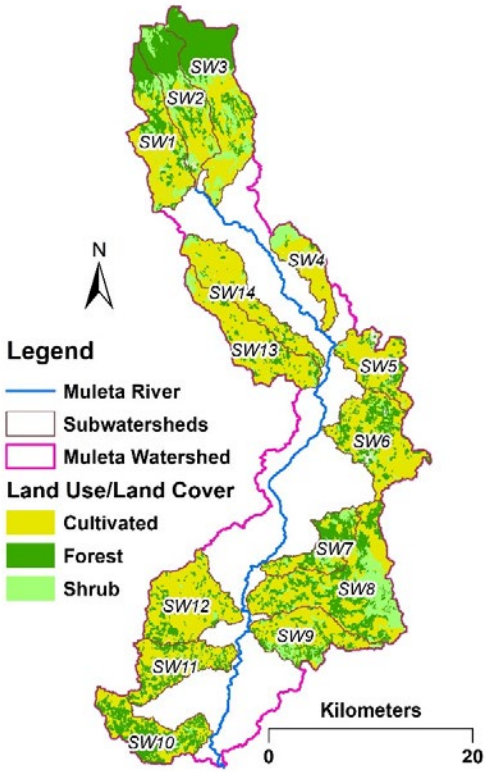


Fig. 4. Land use/land cover map of subwatersheds

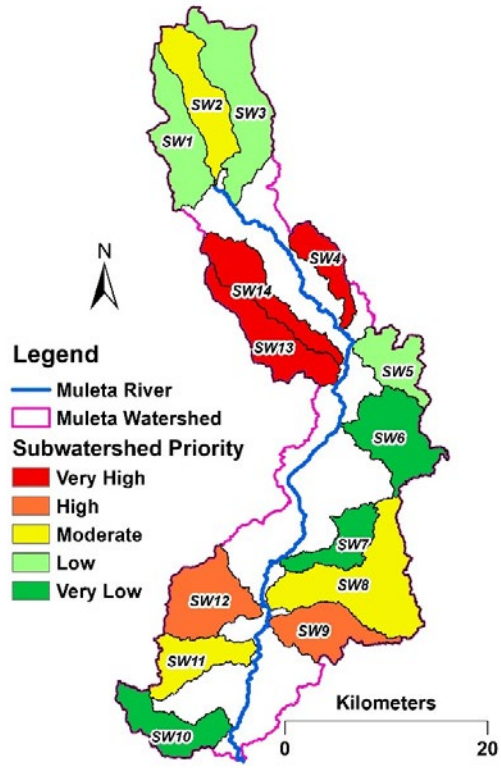


Fig. 5. Priority index map of subwatersheds

Table 8. Final priority values of subwatersheds

Subwatersheds	Compound for Geomorphometry	Compound for LU/LC	Mean Compound	Final Priority
SW_1	7.45	8.67	8.06	11
SW_2	4.52	9.67	7.09	7
SW_3	5.63	10.33	7.98	9
SW_4	8.55	2.33	5.44	3
SW_5	9.09	7.00	8.04	10
SW_6	9.23	8.33	8.78	13
SW_7	7.20	10.00	8.60	12
SW_8	6.13	7.67	6.90	6
SW_9	6.52	7.00	6.76	4
SW_{10}	8.52	11.00	9.76	14
SW_{11}	6.48	8.00	7.24	8
SW_{12}	7.41	6.33	6.87	5
SW_{13}	4.66	4.67	4.66	1
SW_{14}	5.63	4.00	4.81	2

Subwatersheds with very high priority (SW_{13}, SW_{14}, and SW_4) are more elongated situated at the midsection of the main watershed with high cultivation in the case of SW_{14} (Table 7) than the three least priority subwatersheds (SW_{10} SW_6 and SW_7). This may be due to surpassing a number of geomorphometric parameters considered in the analysis over the quantity of LU/LC during the prioritization process. Erosion triggering geomorphometric characteristics attributed by low circularity and elongation ratios with high linear morphometric values were observed along the top three priority subwatersheds. In addition, a higher percent of cultivation which is assumed to accelerate erosion rates was also depicted, thus, suitable erosion control is sought to prevent the land from further degradation (Zhang *et al*., 2015; Duley, 1932).

CONCLUSION

The study illustrated the procedure of delineating and quantifying geomorphometric and land use/land cover parameters in the subwatersheds of Muleta. Delineation was carried out using high resolution digital elevation model within the GIS environment. Setting the threshold to 250 hectares, Muleta is classified as 4th order watershed with a dendritic pattern of the channel network. Alongside with the aim of prioritizing subwatershed relative to soil and water resources conservation, the study had collected important technical pieces of information elaborating the intricate relationship between various geomorphometric and hydrologic variables. Out of 14 subwatersheds, SW_{13}, SW_{14}, and SW_4 were observed as the most susceptible to land degradation due to their inherent geomorphometric characteristics being prone to soil erosion, hence, needing immediate attention for soil and water conservation. Morphometric analysis is considered satisfactory as it allows understanding of the relationship of various aspect of the watershed under study. For example, the elongated shape with an unstable slope in the watershed depicts lower susceptibility to flooding but higher susceptibility to erosion. The application of GIS and remote sensing techniques made the methodology straightforward and fast which can be an alternative course of action especially when data from the field are unavailable. Generally, the study provides information useful to watershed managers in coming up with a more informed decision and actions in relation to watershed prioritization for soil and water conservation programs and project implementation under limited resources. The analysis has generated important data and information helpful in crafting integrated watershed management plans for the critical watersheds in the country in general and for Muleta watershed in particular.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

A	Area
C	Constance of channel maintenance
C_c	Compactness coefficient
D_d	Drainage density
DEM	Digital elevation model
DENR	Department of Environment and Natural Resources
E	East
Esri	Environmental Systems Research Institute
F_f	Form factor
F_s	Stream frequency
GI	Gravelius index
GIS	Geographic Information System
H	Ratio between the total relief
Hectare	ha

I_f	Infiltration number
km	Kilometer
km^2	Kilometer squared
L	Length
L_g	Length of overland flow
L_u	Total stream length
LU/LC	Land use or land cover
L_w	Watershed length
MKaRNP	Mount Kalatungan Range Natural Park
MW	Muleta watershed
N	North
NAMRIA	National Mapping and Resource Information Authority
NGP	National Greening Program
N_r	Ruggedness number
NRDPWMP	National Research & Development Project for Watershed Management in the Philippines
N_u	Number of stream
P	Perimeter
PAMB	Protected Area Management Board
PCAARRD-DOST	Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development-Department of Science and Technology
R_b	Bifurcation ratio
R_c	Circularity ratio
R_e	Elongation ratio
R_h	Relief ratio
R_{hp}	Relative relief ratio
SAR	Synthetic aperture radar
S_m	Mean slope
Strm	Stream
SW_1	Subwatershed 1
SW_2	Subwatershed 2
SW_3	Subwatershed 3
SW_4	Subwatershed 4
SW_5	Subwatershed 5
SW_6	Subwatershed 6
SW_7	Subwatershed 7
SW_8	Subwatershed 8
SW_9	Subwatershed 9
SW_{10}	Subwatershed 10
SW_{11}	Subwatershed 11
SW_{12}	Subwatershed 12
SW_{13}	Subwatershed 13
SW_{14}	Subwatershed 14
T_d	Drainage texture
W_w	Watershed width
Z	Highest elevation
z	Lowest elevation

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