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Exploring Homogeneity among Catchments for Efficient Province-wide Watershed Management in Negros Occidental, Philippines

ABSTRACT

Catchment classification is one approach in natural resource management that is widely adopted in taking efficient steps towards implementing suitable soil and water conservation measures across a basin or region. Catchments have unique characteristics emerging from the heterogeneity and complexity of the systems and classifying them paves way to achieve order and simplicity. However, some constraints related to data availability could be a problem in a region where only few rivers are gauged and with only one type of climate data available. This study presents a way to decrease complexity by grouping these catchments based on their biophysical characteristics extracted from readily available datasets and using simple statistical approaches. Principal component analysis was first conducted to twenty-four biophysical variables which were reduced to eight factor components. A hierarchical clustering method was then performed to define the number of clusters and K-means clustering procedure was followed for the final grouping. Nine watershed clusters were formed with watershed size having the greatest contribution. Grouping catchments into clusters with similar biophysical characteristics does not only promote simplicity but also facilitates understanding of the nature of not only one watershed but also its relationship with other watersheds in a bigger landscape. The study also confirmed that spatially close watersheds exhibit similar characteristics.

Keywords: *catchment classification, cluster analysis, biophysical characteristics, physical similarity, watershed management*

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INTRODUCTION

One of the existing challenges in the field of hydrology is coming up with a generally agreed catchment classification system (*Wagener et al. 2007; Ali et al. 2012; Salami and Bueher 2020*) and framework (*Sawicz et al. 2011; Sivakumar et al. 2014*). Catchments are generally complex and dynamic environmental systems, with diverse components interacting with each other, where fluxes of energy, water and nutrients flow in and out of the landscape. *Beven* (*2000*) put forward the idea of "uniqueness of place", which recognizes the distinct characteristics of a catchment with respect to difference in hydro-climatic condition, soil, topography, geology, vegetation, and human modification through various temporal and spatial scales. However, despite the overwhelming complexities and differences among catchments, *Wagener et al.* (*2007*) believed that patterns and connections might be discernable, which could shed light to a way to put forth order among various watersheds. They further pointed out that a proposed catchment classification should be a rigorous scientific inquiry into the causes of similarities and relationships among catchments.

The uniqueness of a watershed is brought about by the interaction of its various internal and external components in time and space. These characteristics define the uniqueness of the watershed (*Beven 2000*) and affect its hydrological processes and in turn affect the socio-ecological system embedded within the watershed (*Chess and Gibson 2001; O'Neill 2005; Carillo et al. 2011; Mayer et al. 2014*). A systematic classification of the catchments based on patterns of their physical structures is one easier way to find order and to better understand these processes amidst of heterogeneity and complexity in a region.

At present, catchments are classified using different descriptive terms including those based on land cover (forested, agricultural, urban, etc.), storage (groundwater dominated, surface water dominated), catchment response (fast, slow), and catchment size (basin, watershed, subwatershed, mini-watershed, micro-watershed). These classification schemes however are considered limited and not well-defined (*Wagener et al. 2007*). The way forward is to come up with metrics that define the similarity or dissimilarity among catchments. These metrics are based on understanding the relationship between the structural features of the catchments (geomorphology, pedology, geology, vegetation) and climate variability to define hydrological response characteristics (streamflow, groundwater, soil moisture) of the catchments (*Carillo et al. 2011; Vasquez et al. 2019*). *Sivakumar et al.* (*2014*) proposed a catchment classification framework, which also includes other components such as catchment processes, hydroclimatic processes, other natural and anthropogenic factors, and the interaction of surface water, soil moisture and groundwater components.

There were several documented attempts of catchment grouping in other parts of the world using different bases. Small basins in Switzerland were classified using 37 parameters of catchment characteristics relevant to discharge and consequently their similar hydrological behavior with the use of a two- way indicator species analysis (*Breinlinger et al. 1996*). In Iran, *Choubin et al.* (*2017*) used remote sensing indices to identify homogenous hydrological watersheds among 38 catchments. *Bayrd* (*2006*) also grouped 17 catchments found in the United States through Principal Component Analysis (PCA) based on their lithologic and morphologic characteristics. *Mazvimavi* (*2003*) classified 52 catchments in Zimbabwe using catchment characteristics and flow characteristics through Ward's clustering technique. *Raux et al.* (*2011*) also classified 24 large drainage basins in the world using geomorphologic and climatic variables utilizing multivariate statistical analyses such as Cluster Analysis and PCA. Affinity Propagation clustering technique was performed on 18 sub-catchments in the Kingdom of Saudi Arabia (*Hidayatulloh et al. 2021*) and on 36 Scottish sites (*Ali et al. 2012*). In Chile, *Vasquez et al.* (*2019*) utilized a Bayesian clustering algorithm to classify 82 basins using physical, climatic, and hydrologic parameters. K-means algorithm was also used to classify catchments in upper Huai River Basin, China (*Yi et al. 2018*). These are just few of the many successfully conducted catchment classifications based on different sets of catchment characteristics and other external factors, covering different temporal and spatial scales, using different models and analysis tools, and for varying purposes. While there are many ways to classify catchments, most of the developed models have many parameters and require too much data (*Sivakumar et al. 2014*). Data availability is the main constraint in many areas in the Philippine archipelago and most catchment studies are catchment-specific.

There are thousands of watersheds of various sizes in the Philippines – most of which are found within the 421 principal river basins. The reviewed records showed that more than 270 studies were conducted in 160 Philippine rivers from 1975 until 2014. Most of these studies focused on watershed management and planning (19%) and followed by topics related to hydrology (11.3%), climate change (10.6%), biodiversity (10.4%), and soil resources (8.8%). More than 50% of the watershed studies, clumped under the main topic of hydrology, were related to the use of hydrologic modeling in prediction of the effect of climate, land cover change, and management approach to run-off and sediment load. Other studies also focused on the relationship of soil properties, climate, and land cover with the hydrologic processes and with some hydrological assessments, stream flow and water yield quantification.

Most of these catchment hydrology studies in the Philippines focused more on a specific river basin or watershed with limited application to other watersheds especially for ungauged rivers or in data-poor context regions. Studies on comparison, regionalization, classification, or prioritization of more than two watersheds based on similar characteristics are limited in local literature. More so, in the Island of Negros where only very few watersheds had been studied and gauged. The adage, "what gets measured gets managed", provides a good reason for the need to study, quantify and act on catchment patterns, processes and functions using the watershed as a unit of landscape study and for management. Hence, a regionalization study covering 33 watersheds found in the Island of Negros was conducted from 2016 to 2017.

Catchment classifications were generally based on the concept of relating climate and catchment characteristics to hydrologic behavior (*McDonnell and Woods 2004; Carillo et al. 2011; Vasquez et al. 2019*). These could be simplified into three types of similarities, the physiographic, climatic and hydrologic similarities. Based on reviewed studies, various climate, catchment and hydrologic characteristics and their combinations have been used in catchment classifications. There are those, which focused only on hydrologic components (*Sawicz et al. 2011; Brown et al. 2014; Salami and Buehler 2020*) or catchment physical structures (*Bayrd 2006*), those, which combined the physiographic and hydrological components (*Breinlinger et al. 1996; Mazvimavi 2003; Carillo et al. 2011; Ali et al. 2012; Rasavi and Coulibaly 2013; Yi et al. 2018; van Hoek 2019; Hidayatullo et al. 2021*) or physiographic and climate variable (*Raux et al. 2011*), and those, which combined the catchment physical structures with climate and hydrological data (*Sawicz et al. 2011; Sawicz 2013; Vasquez et al. 2019*). As there is no globally-agreed, broad-scale catchment classification system, the choice of parameters used in catchment classification in many cases is assessed based on the purpose of the classification and the available data. Considering the limitation on available hydrologic data, where only 6 out 33 rivers are gauged, and there is only one meteorological station in the province, this study only considered the catchment biophysical parameters, which are readily available from government offices. Geomorphometric, land cover, lithologic, and soil variables representing the catchment physical structures were measured, analyzed, and utilized for catchment characterization and classification. The primary purpose of this catchment classification is to reduce the complexity of 33 catchments by grouping them into similar categories based on catchment structures for locations with minimal available data.

Moreover, classification of watersheds into clusters based on homogenous catchment characteristics would allow for a more area-specific approach to soil and water conservation. Catchment characterization and classification involve valuable information that could be utilized for island-wide planning and management of water and soil resources using watershed as a management unit. These are also preliminary steps toward flood and soil erosion susceptibility analysis, flood vulnerability analysis of population in flood prone areas of the watershed, catchment condition analysis, and catchment prioritization.

Figure 1. Location of major watersheds in the Province of Negros Occidental, Philippines.

MATERIALS AND METHODS

Study Area

The Island of Negros is the fourth largest island in the Philippine archipelago comprising of two provinces (Negros Occidental and Negros Oriental), one highly urbanized city (Bacolod City), 18 component cities, 38 municipalities, and a total of 1,219 barangays (**Figure 1**). It is a volcanic island that is predominantly an agricultural region. More than 57% of its total land area is cultivated with sugarcane as its main crop, making it the country's main producer of sugar (*Guadalquier and Nicavera 2019*).

Most of the cities and towns of Negros Occidental are found in coastal areas where 109 rivers empty into the bigger bodies of water. The study covered 33 major watersheds with river systems having stream orders of more than three. These watersheds have catchment areas ranging from 30 to 2,100 km^2 with outlets found in 25 coastal cities and municipalities of the province.

Datasets

The readily available datasets utilized for the characterization and quantitative analysis of the catchment were accessed from different government offices such as National Mapping Authority and Resources Authority (NAMRIA), Mines and Geosciences Bureau (MGB), Bureau of Soils and Water Management (BSWM) (**Table 1**). Thematic maps were digitized, geo-referenced and projected following the coordinate system, WGS 1984 UTM Zone 51N, using ArcGIS software. Some processed shapefiles and raster data were also accessed from the Department of Agriculture-Bureau of Agricultural Research (DA-BAR) and from the PhilGIS website.

Watershed Biophysical Characterization

Geomorphology. Quantitative analyses of the land surface of watersheds were carried out using vector

Table 1. Map types, scales and sources used for geomorphology, geology, soil, and land cover parameters..

Parameter	Type	Scale	Source
Geomorphology	Digital Elevation Model	30-m/90-m	ASTER/SRTM
	Topographic map	1:50,000	NAMRIA
Geology	Geologic Map with accompanying report	1:250,000	MGB
Soil	Soil Map with accompanying report (1951, 1960)	1:200,000	BSWM
Land Cover	Land cover (2010)	(Shapefile)	DA-BAR

data extracted from stream networks and topographic lines. Basic morphometric parameters were determined using measuring tools in GIS while more advanced morphometric parameters were determined following standard derived formulas (**Table 2**). Relief parameters were determined using values extracted from the digital elevation model (DEM). Fifteen geomorphometric parameters were chosen based on the Department of Environment and Natural Resources (*DENR 2008*) recommendation for watershed characterization and those commonly found in reviewed literature. Five parameters were used to describe watershed size and shape (basin area, mean bifurcation ratio, elongation ratio, circularity ratio, and form ratio) and six parameters to describe watershed relief (relief ratio, basin mean elevation, hypsometric index, ruggedness number, and slope). Drainage characteristics of the watershed were described by drainage density, stream frequency, stream length ratio, length of overland flow, and stream order.

Table 2. Methodology adopted for the computation of morphometric parameters.

Parameter	Description	Symbol/Formula	Reference
1. Basin Area	The area of bounded watershed that contributes to surface run-off	A	*Al-Rawas & Valeo 2010*
2. Mean Bifurcation Ratio	The average of bifurcation ratio of all orders. Bifurcation ratio is the ratio between the number of stream segments of one order and those of the next-higher order.		*Schumm1956*
3. Elongation Ratio	Ratio of diameter of a circle of the same area as the basin to the maximum basin length	$Re = \frac{D}{L} = 1.128\frac{\sqrt{A}}{Lb}$	*Schumm 1956*
4. Circularity Ratio	Ratio of basin area to the area of circle having the same perimeter as the basin	$Rc = \frac{4\pi A}{P^2}$	*Miller 1953*
5. Form Factor Ratio	Ratio of basin area to the square of basin length	$Rf = \frac{A}{Lb^2}$	*Horton 1932*
6. Relief Ratio	Difference in elevation between the river's source and the river's mouth divided by the river's total length	$Rr=Br/B_l$	*Schumm 1956*
7. Basin Mean Elevation	The mean watershed altitude	B_E	*Strahler 1952*
8. Hypsometric Integral	Generally summarizes the basin's relief; a general index of erosional development	$Hi = \frac{E_{mean} - E_{min}}{E_{max} - E_{min}}$	*Strahler 1952*
9. Ruggedness Number	Expresses the geometric characteristics of a drainage system; derived from the product of maximum basin relief and drainage density	$Rn=Bh(Dd)$	*Strahler 1968*
10. Slope	Percentage of area with slope of more than 18%	S	*Chorley 1979*
11. Drainage Density	Ratio of the total channel segment lengths cumulated for all orders within a basin to the basin area	$Dd = \frac{Sl}{A}$	*Horton 1945; Strahler 1952; Melton 1958*
12. Stream Frequency	Number of stream segments per unit area	$Fs=N_u/A$	*Horton 1932*
13. Stream Length Ratio	Ratio of the mean of segments of a given order to the (cumulative) mean length of the next lower order stream in the same basin		*Horton 1945*
14. Length of Overland Flow	Length of the run of the rainwater on the surface before it is localized into definite channels; roughly equals to half the reciprocal of drainage density	$Lof=1/Ddx2$	*Horton 1945*
15. Stream Order	Based on Strahler's method following the hierarchical rank	U	*Strahler 1964*

Hypsometric index was also determined to provide additional information on the watershed relief characteristics following *Brocklehurst and Whipple* (*2004*) method. The study utilized the hypsometry extension software of ArcGIS (*Davis 2010*) to automatically generate the hypsometry curve. From a projected DEM clipped to the boundary of the watershed, float values were converted to integer format and were reclassified into 100 elevation bins using spatial analyst tools. The values were used in the calculation of the hypsometric integral (HI) which provides a general index of erosional development within the watershed.

Geology. A clipped shapefile for each watershed was prepared to determine the covered lithologic units and their corresponding extent in percentage. The description of lithologic units was based on the report, Geology and Mineral Resources of the Philippines (*MGB 1981*). The lithologic types which greatly affect the flow characteristics focused on the permeability of the lithologic units were chosen as geologic indicators. Seventeen lithologic units found in thirty-three watersheds were reduced into three major classes, namely: igneous, sedimentary, and quaternary alluvium (**Figure 2.A**).

Soils. Proportions of soil types found within each watershed were identified based on the government map. Thirty-four soil types were combined according to their soil textural class based on the percentage of sand, silt, and clay. Three groups of soils were formed: heavy, medium, and light soils.

Land Cover. Built-up, cultivated, and forest land cover types were chosen as they are the land cover types which have significant impact on the hydrologic behavior of the landscape. The area covered was expressed in percentage.

Watershed Classification

Classification was based on similarities of their biophysical characteristics geomorphometric (15), geologic (3), soil (3), and land cover (3) variables. Factor analysis, particularly PCA, was conducted on the standardized computed values of the selected variables for each watershed to avoid multicollinearity among variables and for data reduction. The PCA also helped in finding a linear combination of variables that accounts for as much variation in the original variables as possible. Using Eigenvalue of 1.0 and based on rotated component matrices, the number of factors for cluster analysis was reduced to resolve duplication of correlated variables.

The 24 variables reduced to eight components were determined to be significant by comparison of the variance explained by each component. These were further used in watershed classification. Cluster analysis was used to determine groups of watersheds that are relatively homogeneous within themselves and heterogeneous among each other, based on their watershed biophysical characteristics.

Ward's method, a hierarchical clustering method, was first performed to define the number of clusters based on the agglomeration schedule and the dendrogram Ward's method, a hierarchical clustering method, was firstperformed to define the number of clusters based on the agglomeration schedule and the dendrogram produced. K-means clustering procedure was done for actual grouping of the watersheds. All statistical analyses were done using the SPSS statistical program, which also provided statistical tables showing additional information to better understand the nuances of clustering.

RESULTS AND DISCUSSIONS

Cluster Formation

Factor analysis with varimax rotation reduced the twenty-four biophysical variables into eight components which explain 85.14% of the total variations of the dataset. The first component, describing the drainage characteristics of the watershed, explained the highest variation (24.76%). The second component, explained 17.99% variance, consists of variables describing the shape of the watershed. The third component (11.58%) has variables related to the relief characteristics of the watershed. The fourth component (8.38%) consists of area and stream order, which both provided an idea of the extent of the watershed size. The lithologic units, igneous and sedimentary, together with cultivated area make up the fifth component, which explained 7.71% of the variance. The sixth component (5.57%) combined the variables explaining the stream network of the watershed and the extent of the alluvial deposits in the catchment. The seventh component (4.81%) is contributed by soil texture, particularly the clayey and loamy soils. The last component (4.34%) represents land cover characteristics of the catchment with a contribution of the lighter-textured soils (**Table 3**).

The resulting component scores applied in the hierarchical cluster analysis using Ward's method produced a dendrogram which presents the distance at which clusters were joined and at what level any two clusters were joined (**Figure 3**). A cluster distance of not more than ten was set and nine clusters were

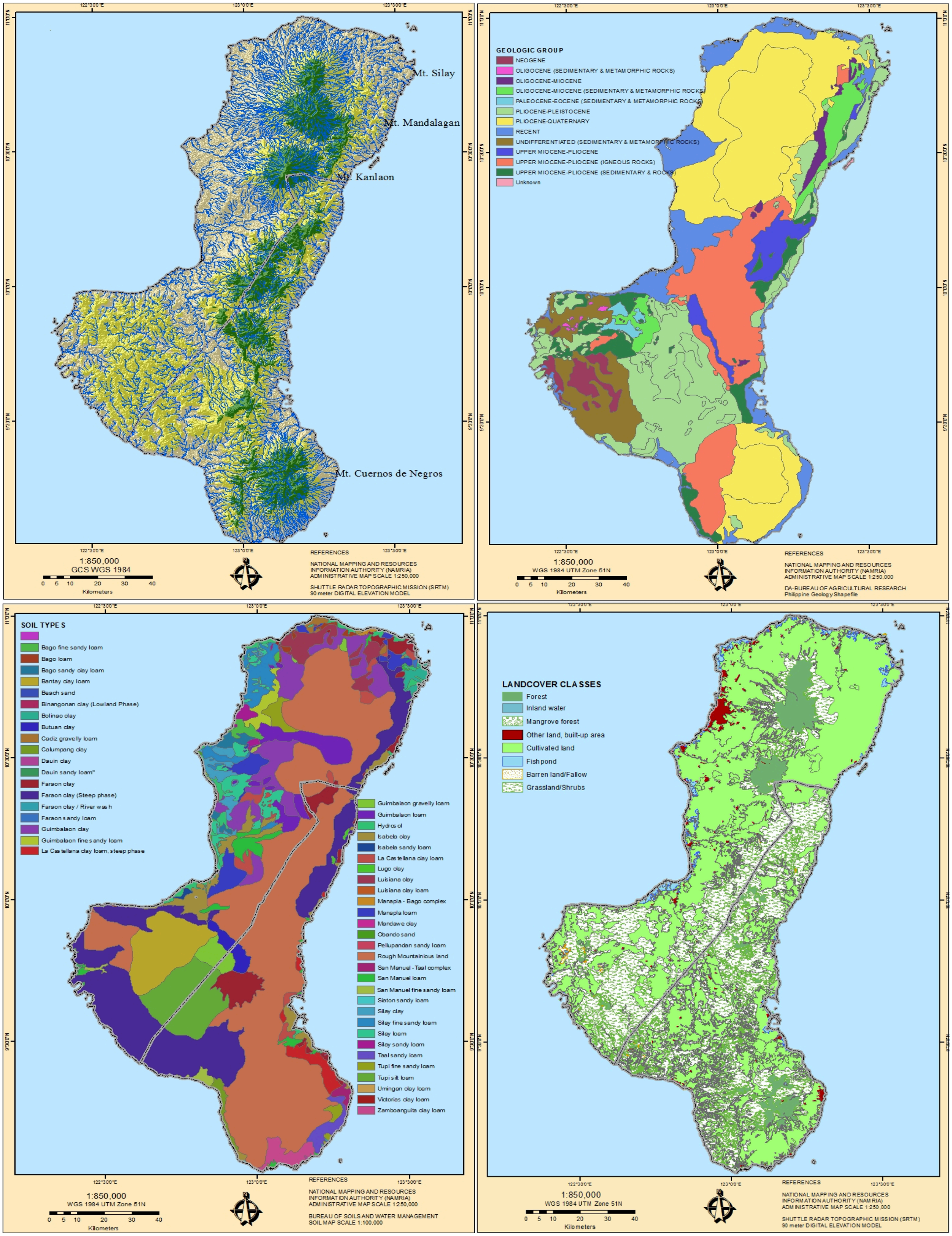


Figure 2. Drainage system (A), Geologic map (B), Soil map (C), and Land cover man (D) of the Negros Island.

Table 3. Component variables and variance explained by each component.

Component	Variables	Percent Variance	General Characteristics
1	Length of overland flow, Drainage density, Stream frequency, Hypsometric integral	24.76	Watershed drainage
2	Elongation ratio, Form factor ratio, Circularity ratio	17.99	Watershed shape
3	Relief ratio, Slope, Basin mean elevation, Ruggedness number	11.58	Watershed relief
4	Area, Stream order	8.38	Watershed size
5	Igneous, Cultivated, Sedimentary	7.71	Geology
6	Mean bifurcation ratio, Stream length ratio, Alluvium	5.57	Stream characteristics
7	Medium soil, Heavy soil	4.81	Soil
8	Forested area, Built-up area, Light soil	4.34	Land cover
Total	(a total of 24 variables)	85.14	

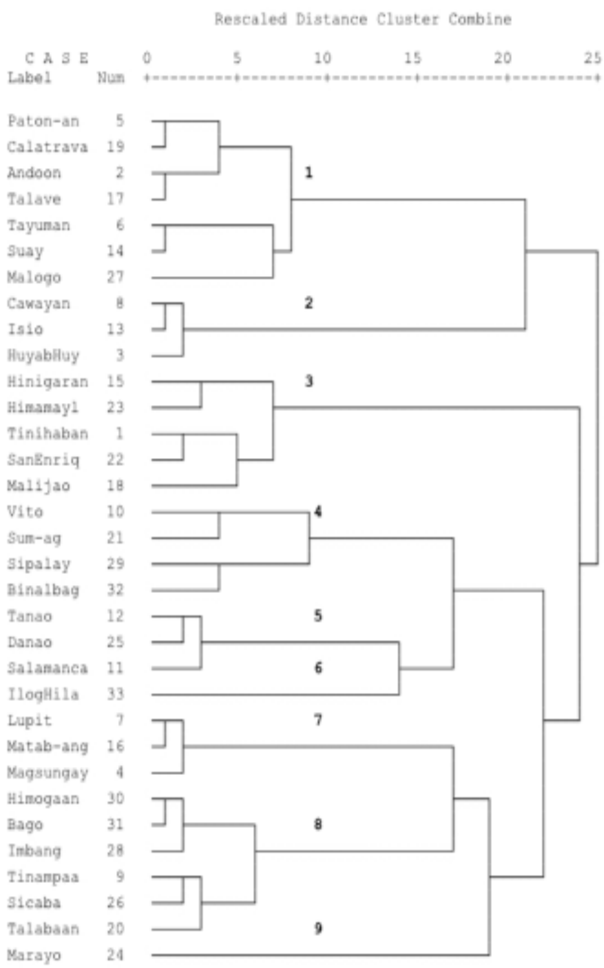


Figure 3. Classification tree of watersheds produced from hierarchical cluster analysis.

initially identified. This was used as input cluster number in K-means cluster analysis.

The *F* ratio values described the differences for each factor among clusters (**Table 5**). Watershed size showed a higher contribution (F = 11.61) in the formation of clusters. This is followed by land cover variables (F = 9.02), variables describing the drainage characteristics (F = 8.58), watershed shape variables (F = 7.68), catchment geology (F = 6.97), and soil variables (5.08). Watershed relief and variables describing the stream characteristics indicate least contribution to the separation of clusters.

Cluster analysis also provided additional information about the general characteristics of the clusters formed from the final cluster centers table provided by SPSS. The regression factor scores provided an idea on how well each component predicted the score for each of the analyses (**Table 6**). Cluster 1 has high scores from variables pertaining to watershed size and drainage characteristics. Cluster 2 is defined by medium and heavy soils. Watersheds in Cluster 3 are strongly influenced by their stream characteristics and proportion of alluvium. Cluster 4 watersheds are distinct by their land cover characteristics and light-textured soil. Cluster 5 and Cluster 9 are grouped based on their relief characteristics with a bit of influence on drainage characteristics for Cluster 5 and watershed shape for Cluster 9. Cluster 6 watersheds are identified by their watershed size and a bit from their shape and stream characteristics. Cluster 7 is strongly influenced by their lithological characteristics and Cluster 8 has higher scores in watershed drainage and shape factors.

Watershed Clusters

Narrative descriptions of the inherent characteristics of each watershed cluster type are discussed below together with their spatial location in the region and their predicted level of susceptibility to flood and erosion (**Figure 4**).

Cluster 1 – Watersheds with a large catchment area and few, long stream networks. The large drainage area of Ilog-Hilabangan river basin of around 2,109 km^2 makes it look like a veritable giant compared to more than half of the major watersheds with less than 100 km^2

Table 5. Analysis of variance showing contribution of each component factor.

Factor	Cluster		Error		F	P-Value
	Mean Square	Df	Mean Square	Df		
Drainage	2.963	8	0.346	24	8.577	0.000
Shape	2.876	8	0.375	24	7.675	0.000
Relief	1.033	8	0.989	24	1.044	0.432
Size	3.179	8	0.274	24	11.608	0.000
Geology	2.796	8	0.401	24	6.968	0.000
Stream	1.783	8	0.739	24	2.412	0.046
Soils	2.514	8	0.495	24	5.078	0.001
Land cover	3.002	8	0.333	24	9.021	0.000

Table 6. Final cluster centers highlighting the factors with higher contribution in each cluster.

Factor	Regression Factor Score for Each Cluster								
	1	2	3	4	5	6	7	8	9
Drainage	**1.824**	0.156	-0.468	-0.477	0.314	-0.395	0.389	**1.158**	-1.634
Shape	-0.110	0.089	-0.003	-1.586	-1.346	0.815	-0.597	**1.111**	0.340
Relief	-1.087	-0.008	-1.482	-0.102	**0.562**	0.439	-0.178	0.169	**0.560**
Size	**3.693**	-0.682	-0.911	-0.035	0.085	**1.147**	0.017	-0.527	0.228
Geology	0.430	0.502	0.389	-0.831	-1.850	-0.454	**1.381**	-0.840	-0.109
Stream	0.061	-0.668	**2.247**	0.062	-0.769	0.269	-0.108	0.093	-0.090
Soils	0.058	**1.029**	0.370	-0.077	0.092	0.842	-0.850	-1.008	-0.467
Land cover	0.577	0.087	-0.196	**1.322**	-3.850	-0.155	-0.449	0.298	-0.214

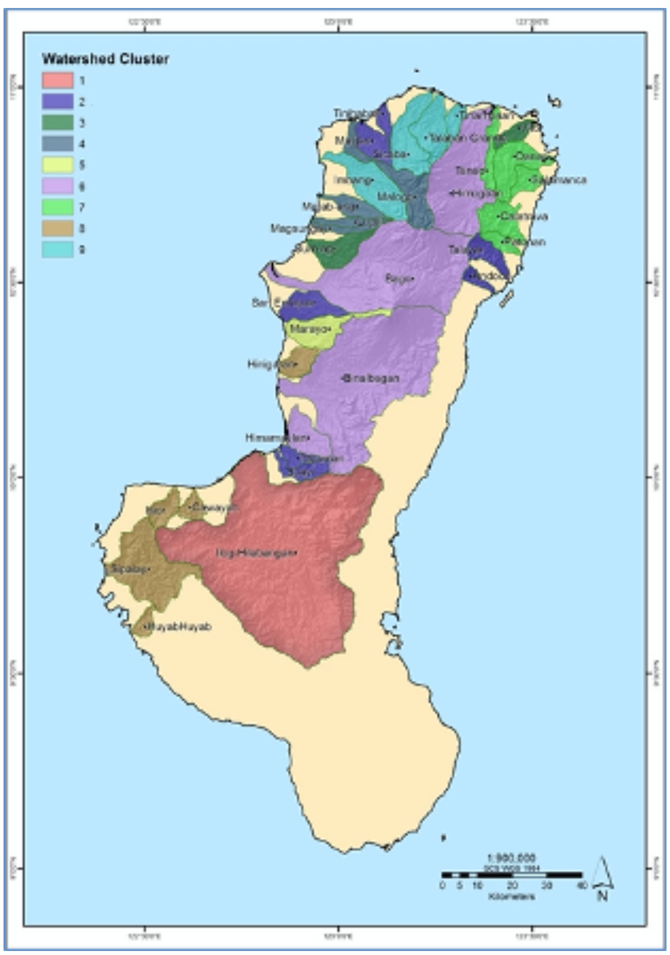


Figure 4. The spatial distribution of the nine watershed clusters.

catchment area. Its immense size and high stream order set it apart from other watersheds. Drainage variables such as length of overland flow, stream frequency, drainage density, as well as hypsometric integral are all related to area. Hence, these also contribute to the uniqueness of this catchment. Ilog-Hilabangan is one of the watersheds with low values in drainage density and stream frequency and high length of overland flow and stream order number. Its fewer number and longer length of streams result in relatively longer travel distance of runoff before it gets concentrated at its main channel.

Cluster 2 – Small watersheds with moderate to heavy soils. San Enrique, Suay, Tayuman, Malijao, Tinihaban, Talave, and Andoon are the watersheds belonging to this cluster. What makes this cluster distinct is their very high proportion of moderate and heavy-textured soils, which is almost 100% of their total catchment area. Clay, hydrosol, clay loam, loam, and rough mountainous land are their dominant soil textures. In terms of soil hydrologic group, they have Group B and D soils which have low to high runoff potential. The different combinations of the proportion of their clayey and loamy soils render these watersheds to very low to very high erodibility.

These are small watersheds with less than 100 km^2 catchment area. Though these are quite scattered around the island, these are found to go by pairs, beside each other; Tayuman and Suay located at the south-western side, San Enrique at the west-central side, Malijao and Tinihaban at the north-western side, and Talave and Andoon at the eastern side.

Cluster 3- Watersheds with many but shorter lower order streams. Watersheds of this cluster have the highest recorded mean bifurcation ratio and stream length ratio values. Sum-ag and Vito watersheds have third order stream network with shorter but many lower order streams. This stream network characteristic is favorable to flood but because these have low relief (30-70 mASL), this is cancelled out. High runoff may occur in the upstream areas where the first order streams meet the second order streams but because the topography is not steep at the downstream section and the receiving higher order stream is longer, a higher infiltration rate is expected. Despite being low relief catchments, Sum-ag watershed has less than 1%, while Vito watershed has no alluvium deposits.

Cluster 4- Highly-urbanized watersheds. This cluster of watersheds is distinct for it is greatly influenced by its location in highly-urbanized areas. Lupit, Magsungay, and a portion of Matab-ang watersheds drain the city proper of Bacolod City, the capital of the province. These have a relatively high percentage of built-up area and zero forest cover. Their high percentage of impervious land surface increases their runoff potential and the risk of flooding. Moreover, this cluster is also characterized with high percentage of light-textured soils. More than 80% of their soil cover has sandy-loam texture. This soil texture assures good drainage. In terms of soil factor, the watersheds have low flood susceptibility but their lightness in terms of structure makes them more susceptible to erosion.

These watersheds are small-sized watersheds with almost similar catchment shape, drain from the same recharge area, and are spatially adjacent to each other. But just a watershed away, Malogo watershed, a medium-sized catchment with a unique catchment shape, is located. It was included in this cluster despite its contrast with the other three watersheds, making it a group outlier. It could have been counted in this cluster because it showed unique characteristics in its land cover. Among the thirty-three watersheds, it is one of the eleven watersheds with remaining forest cover and the only watershed with more than 20% of its drainage area covered with forest. Its forest cover is around 55% of its drainage area, while its urban area is just around 3.45%.

Cluster 5- Watershed with high maximum elevation. Marayo watershed is another stand-alone watershed belonging to a cluster where watershed relief characteristics are distinctive. Marayo is a medium-sized watershed which recorded the highest ruggedness number and relief ratio. These two relief parameters are strongly influenced by the watershed's maximum elevation. Its watershed shape is also distinctive which is likened to a tadpole. Its tail, indicating its upstream area, is long, narrow and steep. Its remotest end has an elevation of about 2,350 mASL located at Mt. Kanlaon and it slides down between two large watersheds, Bago and Binalbagan River basins. Despite its very high ruggedness number and relief ratio values or very steep upstream area, the watershed has low susceptibility to flood due to its very low hypsometric integral, indicating that more than 90% of its watershed area is located at low elevation.

Cluster 6- Large, elongated watersheds with medium to heavy soils. This cluster includes a river basin (Binalbagan), a large watershed (Bago), and two medium-sized watersheds (Himogaan and Himamaylan) with drainage areas occupying the northern to central spine of the island. The larger watersheds have a 5th order river system, while Himamaylan is a 4th order river system. Aside from their distinctive large size, these also have moderate to heavy textured soils, mainly clayey, loamy and rough mountainous lands. The three larger watersheds have relatively high percentage of hydrologic soil group D indicating higher runoff potential, while Himamaylan watershed has higher group B soils which makes it less susceptible to flood. In terms of soil erodibility, the watersheds have very low to moderate susceptibility. Their watershed shape parameters values also indicated that these are elongated catchments, except for Himamaylan watershed, which is less elongated in shape.

Cluster 7- Agricultural watersheds underlain with sedimentary rock. Five watersheds belong to this cluster, Danao, Calatrava, Tanao, Salamanca, and Paton-an. These watersheds have small to medium catchment areas (30-150 km^2) located very close to each other clumped together at the north-eastern side of the island. More than 90% of their catchment area is cultivated to crops, thus these are considered agricultural catchments. Except for the Tanao watershed, which could be considered as an outlier in the group, the four watersheds are predominantly underlain with limestone, shale and sandstone, which are common lithologic units found at the north-eastern and south-western sides of the island. Geologically, these watersheds have low susceptibility to flood and erosion.

Cluster 8- Elongated watersheds with coarse drainage network. This watershed cluster is distinct from other clusters due to its drainage characteristics and catchment shape. In terms of shape, Sipalay, Isio, Cawayan, Huyabhuyab, and Hinigaran watersheds have the highest elongation ratio values that range from 0.63 to 0.74. These values signify elongated to less elongated shape and a relatively higher susceptibility to flood and erosion. Their less elongated shape could be observed with their pear-shaped catchments. The influence of their catchment shape on susceptibility, however, is canceled out with their other geomorphological characteristics, such as their drainage characteristics. These recorded the lowest drainage density and stream frequency values, which signify fewer and shorter stream segments relative to their catchment area. With less number and farther apart channels, a coarse drainage pattern is produced. These also have the highest length of overland flow values which also signifies less contribution to runoff and erosion. Except for Hinigaran watershed, Huyabhuyab, Sipalay, Isio, and Cawayan watersheds are clustered together at the south-western side of the island.

Cluster 9- Medium-sized watersheds with high maximum elevation. Watersheds belonging to this cluster are defined by their catchment relief characteristics. These are medium-sized watersheds with high maximum elevations: Imbang (1,660 mASL), Sicaba (1,520 mASL), and Talabaan (1,330 mASL). Their high maximum elevation contributed to their high relief ratio values, very high ruggedness number values and moderate mean basin elevation values. Their upstream catchment begins at the mountain slopes of Mt. Silay and Mt. Mandalagan and their outlets drain at the northern coastline of the island. Considering the contribution of other geomorphologic factors, these catchments may be moderately susceptible to flood and erosion.

Tinampaan watershed is also a cluster member of this group despite its relatively lower maximum elevation (400 mASL). It is just a small-sized watershed with moderate relief ratio and ruggedness number values, and low mean basin elevation value. The closeness to other bigger watersheds that could be observed is only its spatial proximity to Talabaan and Sicaba watersheds.

Spatial Proximity and Physical Similarity

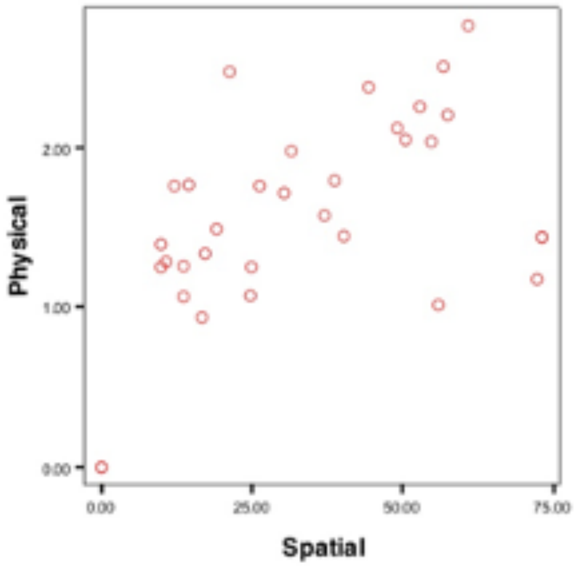
Spatial proximity and physical similarity are two separate approaches often used in regionalization studies in the selection of donor catchment for runoff predictions of ungauged catchments. Together with regionalization by regression as the third approach, these three approaches are compared as to which could closely predict the hydrologic behavior of the ungauged watersheds. *Oudin et al.* (*2008*) found that spatial proximity approach is better than physical similarity and that regression approach is least satisfactory. This result was confirmed in the studies of *Merz and Blöschl* (*2005*); *Zhang and Chiew* (*2009*); *Bao et al.* (*2012*); and *Drogue et al.* (*2016*). These also suggested that an integrated or combined spatial proximity and physical similarity could help improve the estimation.

This classification is mainly based on the physical similarity approach, where watersheds were grouped according to their most similar attributes. However, when shown on a spatial map, some of the watersheds of the same group seem to be closer to each other. Thus, it is interesting to know whether watersheds with similar attributes that are grouped together in a cluster are also spatially close to each other in the case of an island region. The distance of the watersheds from their cluster centers based on the cluster membership data (which represents physical similarity) was compared with the measured mean spatial distance of the watersheds relative to other cluster members, (which represents spatial proximity). Pearson's correlation analysis showed that at 0.01 level of significance, there is a moderate positive correlation between the two variables (Pearson's r= 0.509 at p= 0.002) indicating that most watersheds classified in clusters based on their strong physical similarity are also spatially close to each other.

Watersheds considered as outliers can be identified and these had substantial effect on the fit of the curve. (**Figure 5**) The scatter plots show the dispersion of the points representing the relative distances of the watersheds from one another. Outliers were omitted and an improved correlation value at p = 0.0005 of Pearson's r = 0.841 appeared, indicating a strong correlation between the two compared factors.

Correlation analysis was also conducted for each cluster with more than two member watersheds (**Table 7**). Cluster 4, the highly urbanized watersheds with the forested Malogo watershed, got the highest correlation coefficient of r= 0.99. This is followed by Cluster 8 composed of elongated watersheds with coarse drainage pattern (r = 0.85), Cluster 6 of large, elongated watersheds with medium to heavy soils (r = 0.84), and Cluster 2 composed of small watersheds with moderate to heavy soils (r = 0.79). Cluster 9, medium-sized watersheds with high maximum elevation, and Cluster 7, agricultural watersheds, got the lowest coefficient of correlation values of r = 0.45 and r = 0.36, respectively.

Despite the strong correlation relationships discovered in most watershed clusters, only Cluster 4 has



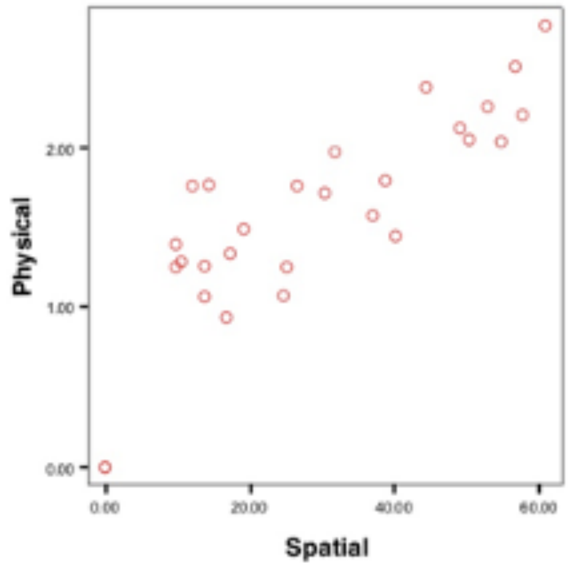


Figure 5. Scatterplots of clustered watersheds showing relationship between physical similarity and spatial proximity with (left) and without outliers (right).

Table 7. Correlation values computed for clusters with more than two watersheds.

Cluster	Pearson Coefficient	*p*-Value	N
2	0.702	0.120	6
4	0.990*	0.010	4
6	0.841	0.364	3
7	0.363	0.549	5
8	0.849	0.069	5
9	0.418	0.582	4

strong significant correlation with p value of 0.01. The high estimate of correlation coefficient values with high p-values means high correlation with low probability. This could be attributed to the small sample size (N) for each cluster.

Generally, the values show that most of the watersheds that were clustered not only share similar features but are also near each other. This could also mean that these watersheds share some similar physical features because these are located at the same region and were formed and are continually affected by the same processes of nature. This is in line with the hypothesis that regional catchments are relatively homogenous and have similar characteristics (*Bao et al. 2012*). Hence, the use of physical similarity approach that also take into consideration the closeness of watersheds based on their characteristics is a reasonable approach not only in regionalization approach (*Heřmanovskỳ and Pech 2008*) but also in watershed classification.

CONCLUSIONS AND RECOMMENDATIONS

Classifying watersheds into groups with similar catchment biophysical characteristics does not only promote simplicity but also facilitates and provides explanation and understanding of the nature of not only one watershed but also its relationship with other watersheds in a bigger landscape. Nine watershed clusters were established, described, and mapped out with watershed size having the greatest contribution to the grouping and followed by land cover, drainage characteristics, watershed shape, catchment geology, and soil variables.

Analysis showed a positive relationship between spatial proximity and physical similarity of watersheds in a given region. This confirmed the general observation that regional catchments are relatively homogenous and share similar characteristics and this holds true too in an island region.

The main contribution of this study for the province is the establishment of a comprehensive database for its major watersheds. The characterization has covered important information that could be utilized for island-wide planning and management of water and soil resources using watershed as a management unit. At present, only a few of these watersheds were characterized and for different purposes and contexts. But putting all these major watersheds in one picture together in spatial thematic maps, the government, community, and academe in the province would have something concrete to work with. It is hoped that with these information, the provincial government would: include watershed management in its priority list of programs covering both small and large watersheds at risk, making watershed as their unit for planning and decision-making; conduct watershed studies to further identify common issues and threats on water, soil, and people, and assess condition of clustered watersheds; establish co-management agreements among cities and municipalities drained by the same watershed and provide guidance and mechanisms in the management process; identify other available natural and social resources, socio-political and cultural structures, networks and dynamics, and existing social and environmental issues and threats in each watershed to improve the established database; and increase awareness and ownership of the community through information, education and communication campaign about the characteristics and ecological functions of their watershed in a form best understood and appreciated by the local community.

Results of catchment classification could be further improved if other parameters were considered to further understand how catchment structures and external factors could affect the catchment hydrologic functions. The limitation of the study presented here is the focus on the catchment biophysical characteristics only due to the limited availability of hydrologic and climate data and more recent datasets from government offices. However, the simple clustering methodology could serve as a guide to other islands or regions as a first step to decrease the complexity of the catchments given limited available data.

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