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Assessment of the Influence of Watershed Characteristics on Discharge of Two River Basins in the Philippines

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Abstract

Watershed characteristics primarily determine the hydrologic response of catchments and river basins. While the general relationship between catchment characteristics and observed hydrologic response has been widely examined, the use of an array of morph metric parameters and multiple hydrologic response values have been limited especially in the Philippines. This paper aimed to assess the effect of geology, land cover, slope, and other morph metric parameters on the discharge of Philippine river basins through remote sensing and geospatial analysis coupled with historical datasets and field validation. The Baroro River Basin in La Union and Gumain River Basin in Pampanga were selected for the study due to their similar drainage area, climate type, and rainfall. Analysis of climate and stream flow data reveal distinct trends of peak discharge and lag time in the two basins, which could be attributed to the difference in litho logy. Overall, the basins were found to have almost similar morph metric parameters that are inconclusive of their effect on discharge. However, the findings also indicate that the slope and geology are the most significant factor among the basin characteristics; hence, further investigation is recommended.

Introduction

The hydrologic response of a watershed is dictated by the interplay of surface and sub-surface processes and natural catchment characteristics. These processes include climatic inputs (precipitation and evapotranspiration), rain interception, snow accumulation and melting, and water storage [1]. Consequently, natural watershed characteristics influence these processes. Major landscape descriptors include soil type, which control infiltration capacity, soil depth, and porosity; geomorphology in terms of relief, slope, channel length, drainage area and density; and geology, particularly lithology and geological structures [2]. Other factors, such as land cover and land use change (e.g., percent forest, agricultural, and urban cover), will significantly affect hydrologic processes as well [3].

The relationship between landscape descriptors and observed hydrologic response variables has been widely studied; however, most of these cited studies used only one or a few landscape variables and only one hydrologic response variable at a time, usually base flow index or peak flow rate [2,4,5]. The same can be said for studies in the Philippines, where hydrologic analysis are usually focused on drought assessment and flood modeling [6-8].

In this study, the roles of watershed characteristics on discharge have been evaluated. The study has been carried out in two basins, Baroro River Basin in La Union and Gumain River Basin in Pampanga. The basins were chosen based on their similar drainage area and both have the same climate type and similar monthly rainfall. The objective of the study is to compare in terms of the role of geology, land cover, morphometric parameters and slope on their discharge. The approach of the study is the integrated use of remote sensing, Geographic Information System (GIS), historical observations and field observation. The present effort differs from existing studies mainly by examining an array of geomorphometric parameters and landscape descriptors, which include soil, geology, topography, land use data. Also, in contrast to other studies that focused on either low flow or high flow conditions, this study will look into multiple hydrologic response values that will represent a wide range of hydrologic conditions. Specifically, this study aims to compare hydrologic responses and identify the dominant factors that control the hydrologic responses of selected Philippine watersheds. Ultimately, the goal of the study is to provide a toolbox or framework which can assist the understanding of how river basins in the country behave (Figure 1).

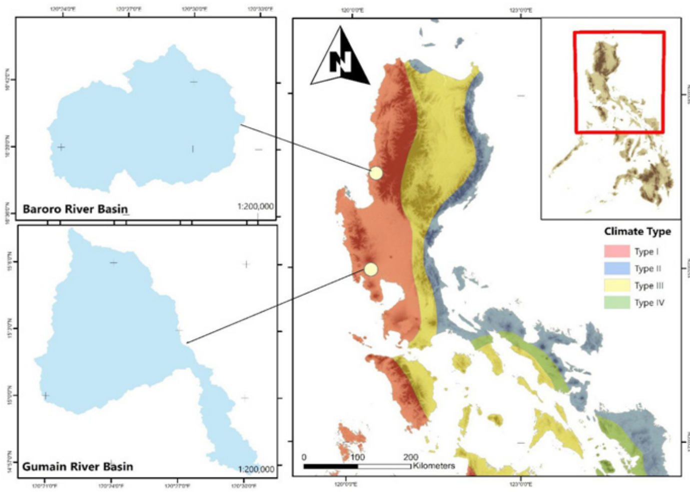

Figure 1: Location of Baroro (upper left) and Gumain (lower left) river basins. Both basins fall on the same climate type, Type I.

Geologic Setting (Regional)

This section discusses the different stratigraphic units included in the study area. The Baroro Basin lies in the Ilocos-Central Luzon Basin while the Gumain Basin lies in the Zambales Range.

Ilocos-Central Luzon Basin: The Ilocos-Central Luzon Basin, as shown in (Figure 2).

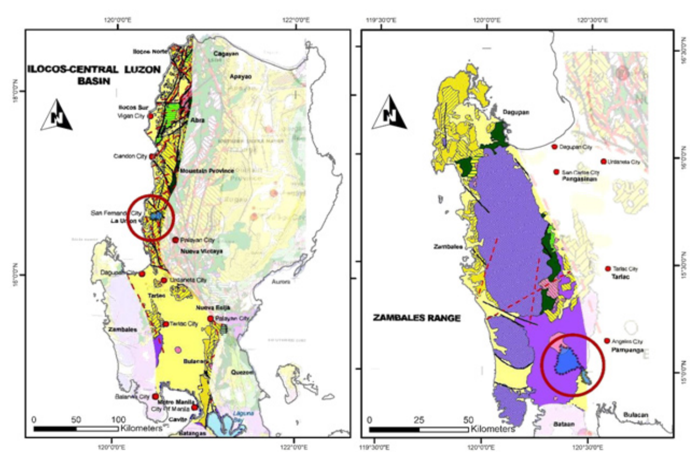

Figure 2: Stratigraphic basin maps of Ilocos-Central Luzon Basin (left) and the Zambales Range (right). Encircled are the basin locations.

Margins the northwestern side of the Philippines along a general north-south axis [9]. The northern part of the basin is filled with marine detrital sediments derived from the Luzon Central Cordillera Range located to the east. These Upper Oligocene-Middle Miocene sediments are mostly conglomerates, and sandstones conformably overlain by an Upper Miocene-Pliocene sedimentary sequence of sandstones, shales, and conglomerates with shallow water carbonates and tuffaceous components [9,10]. The eastern flank on the southern part is characterized by sediments with high amount from volcanic sandstones, shales and tuffs and by a shallow marine carbonate while the western flank has the Eocene ophiolites of Zambales overlain directly by the Neogene sediments dominated by turbidites [9].

Zambales Range - Bataan Volcanic Complex: The Luzon Volcanic Arc, which is associated to the east-dipping subduction of the South China Sea Oceanic Basin beneath the Luzon terrain, is divided into five segments: Taiwan, Babuyan, Northern Luzon, Bataan, and Mindoro [11]. The Bataan segment, also called the Bataan Volcanic Complex, comprises the Central Luzon area. To the north, it is separated from the Northern Luzon segment by the NW-trending Umingan Lingayen branch of the Philippine Fault, while the NE-trending Macolod Corridor separates it from the Mindoro segment to the south [12]. Two subparallel volcanic lineaments exist within the volcanic complex: The Western Bataan Lineament that developed on the Zambales ophiolite, and the Eastern Bataan Lineament that developed on the predominantly clastic sediments of the Central Valley basin [11]. Both of these volcanic belts have mostly basaltic-dacitic rocks with occurrences of pyroclastic flows and tuff [12], but represent different igneous suites – the western belt have rocks that are intermediate in chemistry between tholeiitic and normal calc-alkaline, while the eastern belt has a distinct shoshonitic, i.e., high-K calc-alkaline type [13].

Materials and Methods

To achieve the research objectives, the approaches used were the use of digital elevation model, geospatial tools to delineate the basins, generate the data needed to compute for morphometric parameters and actual field observations of geology and discharge.

Data Sets

The topographic data used in the study is the Interferometric Synthetic Aperture Radar (IFSAR) from the National Mapping and Resource Information Authority (NAMRIA) of the Department of Environment and Natural Resources (DENR) acquired in 2013 with the following resolutions: horizontal - 5 meters ± 2 meters, vertical: 2 meters ± 1 meter. The land cover map used is also from NAMRIA while the geologic map is from Mines and Geosciences Bureau, also of DENR. The soil map is a product of the concluded project of the Bureau of Soils and Water Management (BSWM) of the Department of Agriculture (DA) and Japan International Cooperation Agency (JICA). The historical discharge data was acquired from the Bureau of Research Standards (BRS) of the Department of Public Works and Highways (DPWH). Lastly, the climate data used is from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA).

Basin Information

The conditions for selecting catchment for comparison are the following:

(a) both catchments should have the same drainage area

(b) share the same climate type

(c) have similar monthly and annual rainfall amounts. These parameters will serve as independent variables to allow more effective examination of the major landscape characteristics that affect watershed response.

Considering the criteria and the available climate and stream flow data, the basins were chosen for this study as shown in (Table 1).

Basins	Baroro	Gumain
Locality	San Juan, La Union	Floridablanca, Pampanga
Climate type	Type I	Type I
Mean annual rainfall (mm)	2,340	2,078
Data range	1992-2001	1992-2001

Table 1: Information of selected catchments for comparison.

Morphometry

Morphometric parameters were derived using drainage generated from the IFSAR DEM. The drainage delineation was performed using the Arc Hydro algorithm [14] (Figure 3).

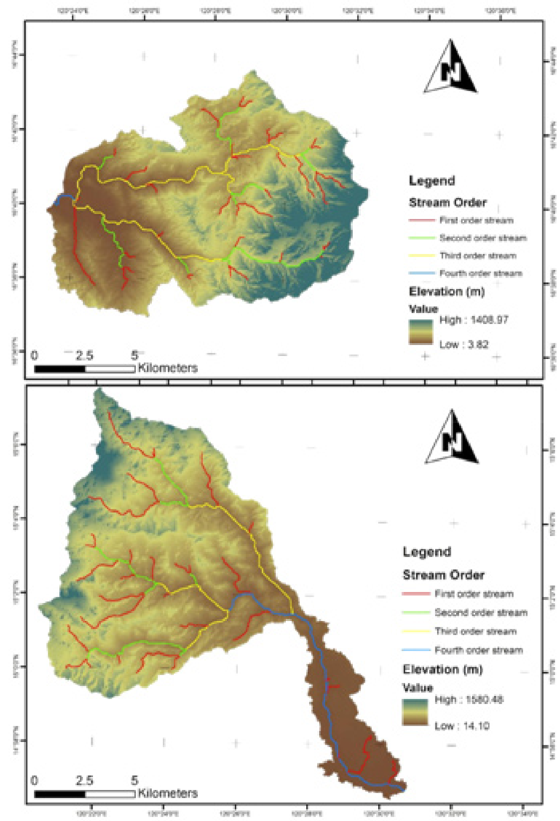

Figure 3: Elevation and stream order maps of Baroro (top) and Gumain (bottom) basins. Based on Strahler's stream ordering scheme, both are fourth order basins.

The formula used to compute the morphometric parameters are shown in (Table 2) and the basin characteristics are shown in (Table 3).

Parameters	Formula	Reference
Stream order (U)	Hierarchical rank (Strahler scheme)	[15]
Stream length (Lu)	Length of the stream	[16]
Bifurcation ratio (Rb)	Rb = Nu/Nu-1; where Rb = bifurcation ratio; Nu = total no.of stream segments of order "u"; Nu + 1 = number of segments of the next higher order	[17]
Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all orders	[18]
Drainage density (D)	D = Lu/A; where D = drainage density; Lu = total stream length of all orders; A = area of the watershed (km2)	[19]
Stream frequency (Fs)	Fs = Nu/A; where Fs = stream frequency; Nu = total no. of streams of all orders; A = area of the watershed (km^2)	[19]
Drainage texture (Rt)	Rt = Nu/P; where Rt = drainage texture; Nu = total no. of streams of all orders; P = perimeter (km)	[15]
Elongation ratio (Re)	Re = 2/Lb sqrt (A/p); where Re = elongation ratio A = area of the watershed (km^2); p = "Pi" value, i.e., 3.14; Lb = watershed length	[17]
Length of overland flow (Lg)	Lg = 1/D 9 2; where Lg = length of overland flow; D = drainage density	[15]
Form factor (Rf)	Rf = A/Lb 2 ; where, Rf = form factor A = area of the basin (km^2) Lb 2 = square of the basin length	[15]
Constant channel maintenance ©	C = 1/D; where D = drainage density	[17]
Shape index (Sw)	Sw = Lb2/A; where Lb = Watershed length; A = Area of watershed	[15]
Compactness coefficient (Cc)	Cc = P c/P u; where Pc = perimeter of watershed; Pu = perimeter of circle of watershed area	[20]
Elevation-relief ratio (E)	E ≈ Hsi = Elevmean - Elevmin Elevmax - Elevmin	Pike and Wilson -1971

Table 2: Formula used in the calculation of morphometric parameters.

Parameters	Baroro	Gumain
Basin perimeter P (km)	76.46	110.12
Basin area A (km^2)	127.17	138.07
Basin length Lb (km)	22.85	31.14
Maximum stream order U	4	4
Total number of streams Nu	54	45
Total stream length Lu (km)	85.83	105.16

Table 3: Basic basin characteristics used for the calculation of morphometric parameters.

Land-Cover Classification

The land cover data was analyzed and processed by the Land Resource Data Analysis Division under NAMRIA in collaboration with the Forest Management Bureau. The data source was LandSat ETM in 2003. The 21 land cover categories are adapted from the Food and Agriculture Organization of the United Nations (Figure 4).

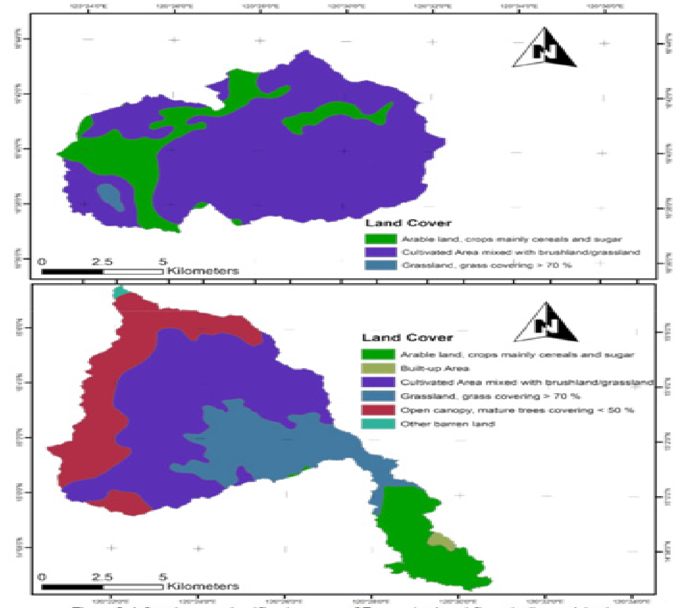

Figure 4: Land cover classification maps of Baroro (top) and Gumain (bottom) basins.

Slope analysis

The slope map was generated from the topographical digital elevation model derived from IFSAR. As this classification has scientifically established the relationship between runoff and slope of a given watershed area, it was adapted to categorize the area and % area of both watersheds (Figure 5).

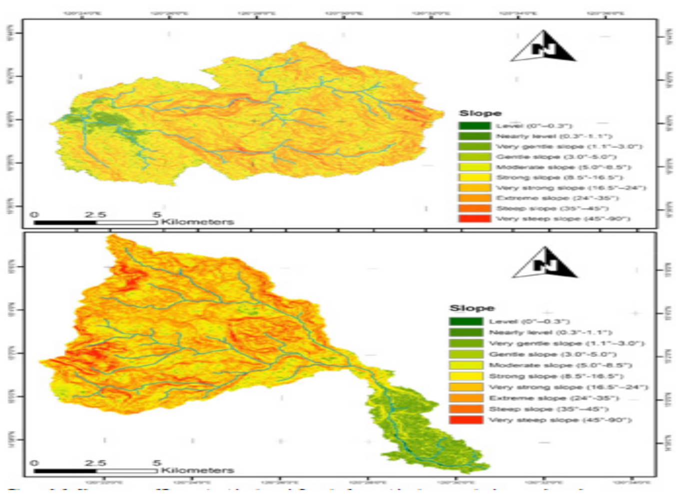

Figure 5: Slope maps of Baroro (top) basin and Gumain (bottom) basin categorized to ten slope classes.

The ten slope classes are: 1) level (0°-0.3°), 2) nearly level (0.3°-1.1°), 3) very gentle slope (1.1°-3.0°), 4) gentle slope (3.0°-5.0°), 5) moderate slope (5.0°-8.5°), 6) strong slope (8.5°-16.5°), 7) very strong slope (16.5°-24°), 8) extreme slope (24°- 35°), 9) steep slope (35°-45°), and 10) very steep slope (45°-90°) (Figure 5).

Results and Discussion

Climate and Discharge Analysis

The Dagupan and Clark Airbase Weather Stations of PAGASA were selected due to their proximity to Baroro and Gumain basins, respectively. In the case of Baroro, the Baguio weather station is located nearer than Dagupan, but the latter was chosen upon considering the geographical setting, topography, and projected rainfall in the basin. Shown as orange bars and lines in (Figure 6,7),

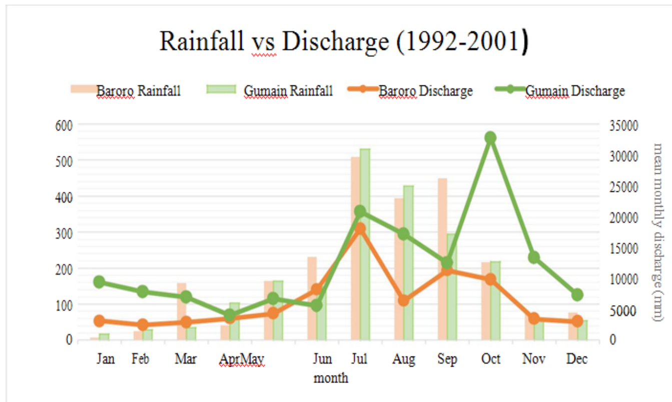

Figure 6: Mean monthly precipitation and stream flow data of Baroro and Gumain basins.

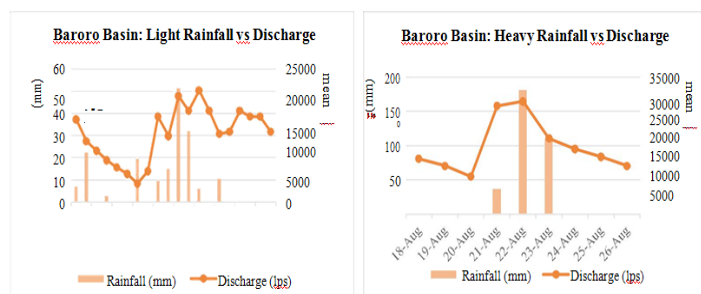

Figure 7: Baroro Basin: Light Rainfall vs Discharge (left), Heavy Rainfall vs Discharge (right).

it can be observed that the Baroro basin has a high peak discharge with very short to no lag time from the rainfall peak. It shows that the basin is very effective in discharging water right after a precipitation event. This is for both the monthly and daily rainfall vs discharge. The opposite can be observed in the Gumain basin as shown as green bars and line in (Figure 6,8), the basin has a longer lag time between the rainfall peak and the discharge peak.

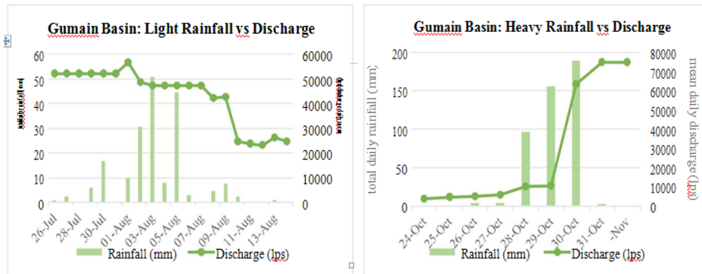

Figure 8: Gumain Basin: Light Rainfall vs Discharge (left), Heavy Rainfall vs Discharge (right).

Morphometric Analysis

A drainage basin's morph metric characteristics affect its hydrology [21] (Table 4).

Parameters	Baroro Basin	Gumain Basin
Morphometry (values)		
Drainage density	0.68	0.76
Stream frequency	0.42	0.33
Mean bifurcation ratio	3.39	3.26
Drainage texture	0.71	0.33
Length of overland flow	0.74	0.66
Elongation ratio	0.56	0.43
Form factor	0.24	0.14
Constant channel maintenance	1.48	1.31
Compactness coefficient	1.91	3.32
Hypsometic integral	0.5	0.5

Table 4: Summary of morphometric parameters of both basins.

The drainage pattern is shaped by the basin's infiltration and runoff characteristics [22,23]. Morphometric parameters such as mean bifurcation ratio, drainage density, stream frequency, drainage texture and elongation ratio have been observed to have a direct relationship with the runoff potential while other parameters such as length of overland flow, constant channel maintenance, form factor and compactness coefficient have an inverse relationship with runoff potential [24].

Stream Order: As suggested by Strahler (1964) [16], determining the stream order is the first step in geomorphological analysis. The Baroro and Gumain river basins are both fourth-order basins.

Basin Relief and Hypsometry: Basin relief (H) is defined to be the difference between the highest and lowest elevation. Hypsometric integral is also estimated based on the elevation-relief ratio (E) which is the the ratio of area under the hypsometric curve to the area of the entire square. The Hsi of both basins is 0.5, based on the stages of development of the basins under study The watersheds are considered to attain the equilibrium stage if Hsi ranges between 0.35 and 0.60. The other categories are that a) the watersheds will be in equilibrium (youthful) stage if Hsi $\geq$ 0.60, and the watersheds are in monadnock phase if Hsi $\leq$ 0.35 [25].

Mean bifurcation ratio (Rbm): The Bifurcation ratio (Rb) may be defined as the ratio between the numbers of stream segments of any given order to the number the next higher order [26]. Basin characteristics such as lithology and geometry contribute to the unequal bifurcation ration from one order to another [27]. Rb is also considered as an index of relief and dissection [15] but if without significant geologic control will vary minimally for different regions in different environments [18]. The Rbm of Baroro is 3.38 while Gumain basin has a very close Rbm value of 3.26. While higher Rbm may specify early hydrograph peak during storm events [28], the small difference in Rbm values of the basins may be inconclusive of this interpretation. For Rbm which ranges between 3.0 and 5.0, the influence of geological structure on the drainage network is negligible [29].

Drainage Density (Dd): Drainage density (Dd) defined by Horton (1932) [19] is the length of drainage per unit area. This parameter is a measure of all the streams across all orders per unit area [25]. The drainage densities of both basins are relatively low with Baroro basin has 0.67 km/km^2 which is slightly lower than that of Gumain basin with 0.76 km/km^2. High Dd implies that a basin may have impermeable subsurface material, low vegetative cover with high relief areas which results to rapid hydrological response to rainfall events [30].

Stream Frequency (Fs): As defined by Horton (1932) [19], stream frequency (Fs) is the total number of stream segments of all orders in the drainage basin divided by the total drainage area. The stream frequency relates to permeability, infiltration capability and relief of watershed [31,32]. Fs of Baroro basin (0.42) is higher compared to Gumain basin (0.32) but both values are still considered low values. High Fs specifies low infiltration capacity thus increase in stream population is observed.

Length of overland flow (Lg): The length of overland flow (Lg) is the length of water over the land surface before it gets concentrated into stream channels (Biswas, 2016) [33] which will then be runoff. Compared to related studies and as the Lg values of Baroro basin (0.74) and Gumain basin (0.65) suggest, the overland flow is dominant in smaller watershed than of larger watersheds [25]. Higher Lg value of Baroro basin suggests gentler slopes and longer flow paths as opposed to the higher slopes of Gumain basin that could result to less time for water to reach the outlet.

Elongation ratio (Re): The elongation ratio (Re) is one representation of the shape of the basin which is the ratio of the diameter of the circle of the same area as the basin to the maximum basin length [17]. The ratio is a meaningful index for classifying drainage basins into varying shapes: a) circular (above 0.9), b) oval (0.8-0.9), c) less elongated (0.7-0.8) and d) elongated (below 0.7) [33]. The Re of Baroro is 0.56 and of Gumain is 0.43 which both fall under elongated category. A circular basin is more efficient in the discharge of runoff than an elongated basin [25] which in this case, Baroro basin is more circular than Gumain basin.

Form Factor (Rf): The form factor (Rf) is the ratio of the basin area to the square of the basin length [15]. The value of the form factor varies from 0 (highly elongated shape) to 1 (perfect circular shape). The Rf values of Baroro and Gumain basins, 0.24 and 0.14 respectively, are consistent with their Re, suggesting that both are elongated in form but with Gumain basin being more elongated.

Compactness coefficient (Cc): The compactness coefficient (Cc) is the relationship of a basin with that of a circular basin with the same area [20]. The Cc of Baroro is 1.91, closer to 1 than that of Gumain which is 3.31. Both basins have CC > 1, which indicates they have a more deviation from the circular nature. Here, Gumain basin is expected to have more concentration time before attaining peak flow compared to Baroro basin.

Drainage texture (Rt): The drainage texture (Rt) or texture ratio is the ratio between the number of streams and the basin perimeter [15]. Rt has been classified into five classes such as: a) very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) [34]. Based on this classification, both basins fall in the very coarse class with Rt values of 0.70 and 0.32 for Baroro and Gumain, respectively. Coarse basins have large basin lag time as opposed to small lag time of finer textures. Comparing the basins, Baroro has faster basin response time than Gumain.

Constant channel maintenance (C): The constant channel maintenance (C) is the reciprocal of drainage density (Dd) and expresses how much drainage area is required to maintain a unit length of stream [17]. The C of Baroro is 1.48 while that of Gumain is 1.31. Low C is characteristic of low resistant soils, sparse vegetation and mountainous terrain while high C is more associated with resistant soils, good vegetation and relatively plain terrain. These are consistent with the characteristics of the study basins relative to each other.

Land Cover

The land cover classification by NAMRIA was further classified into four classes: 1) agriculture (includes all croplands), 2) impervious surface (built-up areas), 3) forest (includes canopy) and 4) grasslands. Land cover affects hydrologic processes in drainage basins [27]. As shown in Figure 4 and presented in (Table 5).

Land cover (% area)	Baroro Basin		Gumain	
	sq km	%	sq km	%
Agriculture	127.83	99.09	77.78	55.96
Impervious surface	0	0	0.81	0.59
Forest	0	0	31.56	22.71
Grassland	1.18	0.91	28.82	20.74

Table 5: Land covers classification of the two basins.

Baroro and Gumain basins have a high percentage of agriculture lands. The flat topography of agriculture lands and the crops facilitation of infiltration may result to a reduced runoff potential. Same as how the forests and the grasslands cover retard. A small percentage of built-up area is seen downstream of Gumain basin, this impervious surface promotes runoff.

Slope Analysis

Watershed hydrology is greatly affected by hillslope processes [21]. Both Baroro and Gumain basin are classified into 10 slope classes. In the Baroro watershed, the maximum area of 41.34 km^2 (32.05%) falls in the strong slope category range while the minimum area of 0.099 km^2 (0.08%) falls in the level slope category. In the Gumain wbasin, the maximum area of 34.43 km^2 (24%) falls in the very strong slope category while the minimum area of 0.552 km^2 (0.40%) falls in the level slope category. Runoff increases as slope also increases [35] especially during extreme rainfall events, it is then expected that the steep slopes zones in Gumain Basin have contributed to the translation to high discharges. The longitudinal profiles of the main rivers in the basins were also extracted from the DEM shown in (Figure 9).

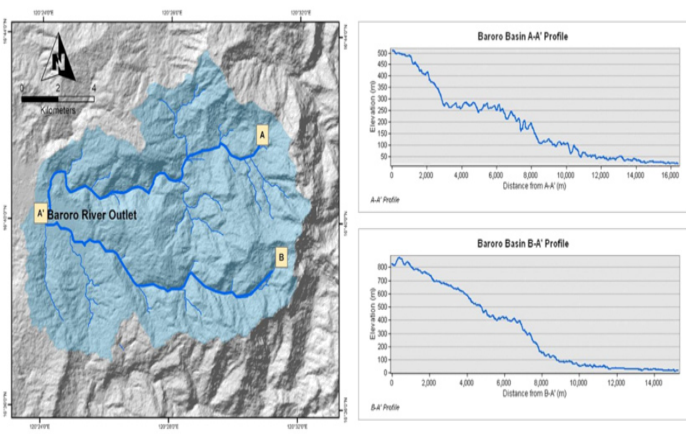

Figure 9: Longitudinal profiles of the two main rivers in Baroro basin.

For Baroro basin and (Figure 10) for Gumain basin. The figures show that rivers in Gumain basin have steeper slopes promoting increase in runoff.

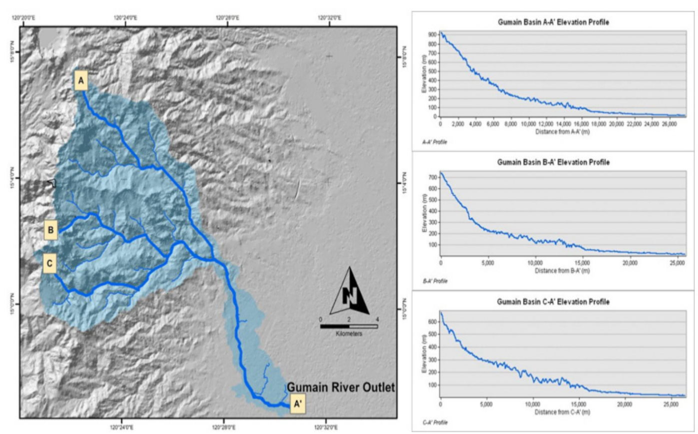

Figure 10: Longitudinal profiles of the three main rivers in Gumain basin.

Geology vs Discharge

Baroro basin is covered by the Amlang Formation of Late Miocene to Early Pliocene which is characterized by turbiditic sandstones and shales with minor conglomerates. In the field, it was observed that the river bed and banks have thick beds/layers of highly indurated medium-grained interlaminated lithic sandstones. At the top of the Tangadan falls shown in (Figure 11-13).

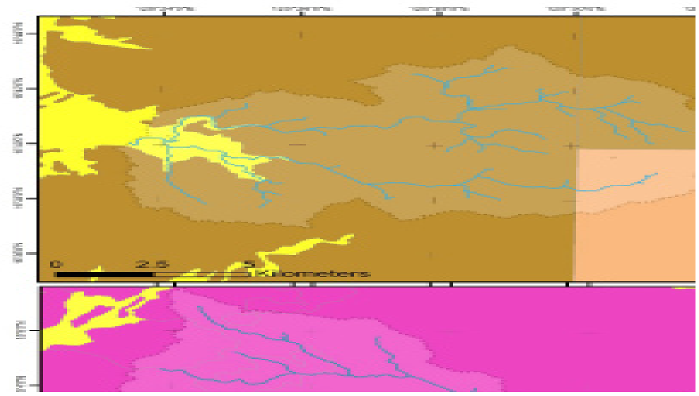

Figure 11: Geologic maps of the river basins. Highlighted in both maps are the basin boundaries.

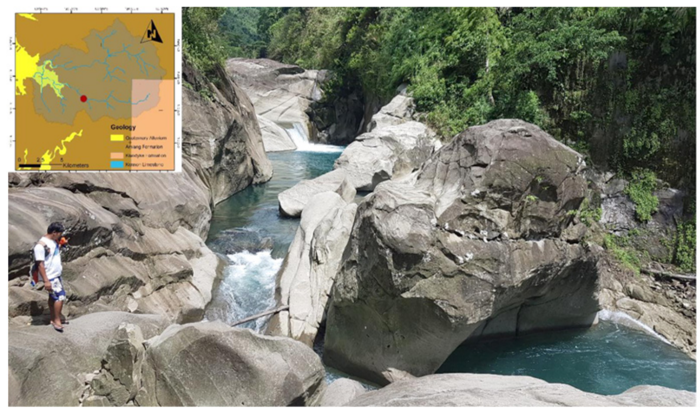

Figure 12: Upstream of Tangadan Falls. Inset map shows the location of the falls upstream of the gaging station.

Figure 13: Very thick light gray massive outcrop of conglomeratic lithic sandstone located upstream of Tangadan Falls

observed is a very thick light gray massive, with no distinct sedimentary structure, outcrop of conglomeratic lithic sandstone. The clasts consist of pebble size igneous (probably andesites) rocks surrounded by medium grained sand size (igneous) lithic clasts. The outcrop covers the bed and the walls of the surrounding outcrop around the falls. The lower member shown in (Figure 14).

Figure 14: Above: Downstream of the Tangadan Falls. Below: Alternating beds of interlaminated lithic mudstones and highly indurated thicker beds of laminated fine to medium grained lithic sandstone.

downstream of the falls, is composed of alternating beds of interlaminated lithic mudstones and highly indurated thicker beds of laminated fine to medium grained lithic sandstone. These non-porous and impermeable rocks do not promote infiltration forcing the water to travel via overland flow. This significantly reduces the lag time and increases peak discharges. This is observed in the comparison of monthly and daily rainfall vs discharge shown in (Figure 6,7). Gumain basin is in the Bataan Volcanic Arc Complex of Late Miocene to Recent. The lithology of the outcrop shown in (Figure 15).

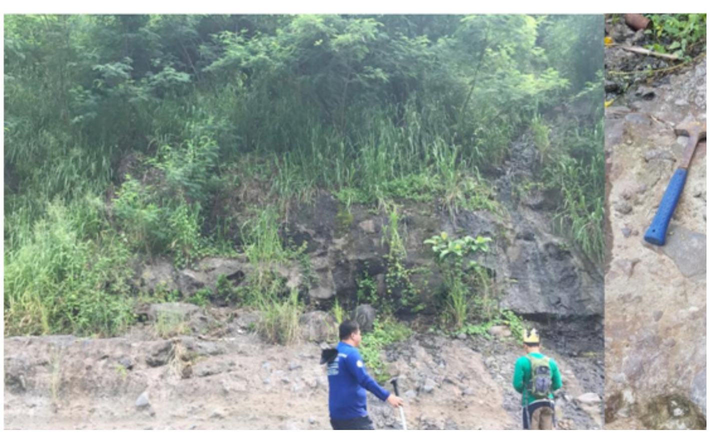

Figure 15: Massive outcrop of polymictic conglemerate at the right bank of the Gumain River.

is polymictic conglomerate. It is composed of different rocks and it is matrix-supported. The clasts are dominantly sub-rounded to sub-angular pebble to mostly cobble-sized dark gray porphyritic (with visible plagioclase crystals) and esites and lighter gray dacites. While the matrix is brownish gray in color, fine to medium-grained tuffaceous with some visible amphibole crystals; appears reddish in color. It is indurated and massive, no structures were observed. Lastly, it is covered on top by very thick recent lahar deposits same as what is shown in (Figure 16). which was seen a few meters away.

Figure 16: Recent lahar deposits from the 1991 Mt. Pinatubo eruption.

This very thick recent lahar deposits are made up mostly of pumice fragments that range from sand to cobble size. They are very poorly sorted due to high variation in grain size, very loose and can easily be eroded due to low degree of compaction. It is observed to be bedded and inversely graded. This deposit composed the river beds and the banks. This type of lithology allows the water to infiltrate thus the low runoff potential. Water travels slower through soil via throughflow compared to the overland flow. This also increases the lag time of the river which is observed on both the monthly and daily rainfall vs discharge as shown in (Figure 6,8). The high extreme discharge observed in Gumain shown in (Table 6) and (Figure 17).

Baroro River			
Date	**Q (cms)**	**Rank**	**P**
Jul-01	30.6	1	1
Sep-99	25.6	5	5
Oct-00	13.5	9	10
Jun-00	7.7	18	20
May-99	5.7	28	30
May-97	5.1	37	40
Mar-97	4.6	46	50
Mar-00	3.4	55	60

Jan-99	2.8	64	70
Nov-01	2	74	80
Apr-93	0.9	83	90
May-93	0.9	87	95

Gumain River			
Date	**Q (cms)**	**Rank**	**P**
Oct-93	188.1	1	1
Oct-99	47.2	5	5
Mar-94	34.1	10	10
Jun-00	21.4	20	20
Aug-97	13.1	30	30
Jul-95	7.8	40	40
Nov-95	3.3	50	50
Sep-96	1	60	60
May-96	0.6	70	70
Mar-97	0.4	80	80
Mar-95	0.1	90.5	91
Aug-98	0.1	94	94

Table 6: Results of the flow duration analysis of Baroro River; b. flow duration values of Gumain River.

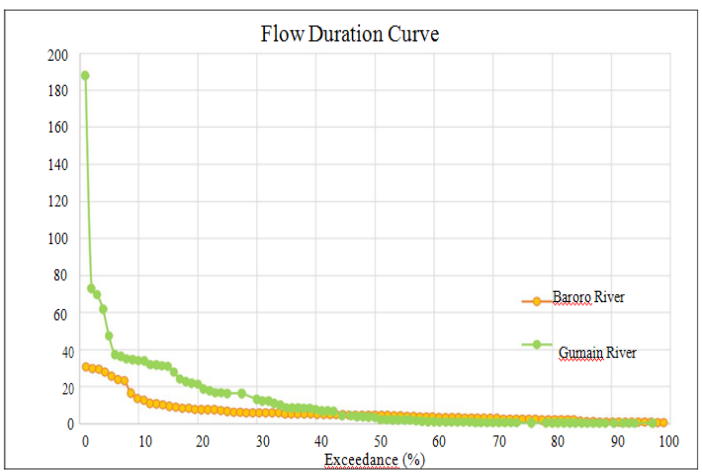

Figure 17: Flow duration curve of both basins showing that Gumain have extremely high and low discharges while Baroro has a relatively steady discharge

Is possibly due to the stored water that did not translate to runoff during light rains and the steady discharge observed in Baroro may also be attributed the geology of the river being effective in discharging water after rainfall so there is no additional volume of stored water discharged during extreme events.

Conclusions

This chapter assessed the impact of morphometric parameters, land cover, slope and geology of Baroro and Gumain river basins. Trends in the daily and monthly climate and streamflow data indicate a high peak discharge with very short to no lag time from the rainfall peak for the Baroro basin, while the opposite was observed in the Gumain basin with a longer lag time between the rainfall peak and the discharge peak. This may be mainly attributed to the difference in lithology

The former has thick sandstone beds and mudstones which are non-porous and highly impermeable (i.e., very effective in discharging water right after a precipitation event), whereas the latter has conglomerates and poorly sorted lahar deposits that promote infiltration. The water that is 'stored' in the infiltration could have contributed to the high discharges observed in Gumain during extreme events. This study also showed the limitation of morphometric parameters to capture the basin shape as with the case of Gumain River Basin. The constriction in the midstream portion of Gumain could also have effect on discharge.

All other things considered, the basins have almost similar morphometric parameters where the difference may be insignificant and inconclusive of their effect on discharge. However, among the basin characteristics, slope and geology affect discharge up to 54%. It is then highly recommended to have other studies on basins with geology and slope as the controlled factors to determine the influence of other basin characteristics such as land use to discharge. Through continued work on this field, we can potentially address the current constraints in river basin management in the country.

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